UNDERSTANDING THE LINKS BETWEEN THERMAL COMFORT AND OCCUPANT ADAPTIVE BEHAVIORS IN NATURALLY VENTILATED MULTI–PATIENT WARDS IN A POST–EPIDEMIC CONTEXT

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Keywords

Thermal comfort, adaptive behaviors, hospital ward, natural ventilation

Abstract

To date, we lack comprehensive evidence about the dynamic links between the environmental, spatial, and socio-cultural aspects of adaptive thermal comfort in clinical settings. This paper reports for the first time on the entangled interactions between the adaptive behaviors among one of the largest samples of hospital occupants (750) and environmental, spatial, seasonal, temporal, and operational conditions, and personal factors as they unfolded in occupied naturally ventilated multi-patient wards in one of the worst Ebola-affected countries. The analysis of a multidisciplinary dataset, which consisted of indoor and outdoor environmental measurements, window-opening behaviors, and adaptive thermal comfort perceptions, attitudes, and preferences, was conducted through the application of descriptive and inferential statistics and narrative analysis. Comparisons between modeled, reported, and observed thermal adaptability indicated that although occupant-controlled window operation was irresponsive to environmental changes, all occupant types were willing to adapt their metabolic rates, move to cooler places, and interact with building controls. At the same time, nursing practices integrated actions for the restoration of thermal comfort among patients. Established adaptive thermal comfort indexes with applicability in hot-humid clinical spaces overestimated the experienced discomfort. In contrast, reported thermal comfort was defined by lower tolerance levels to elevated temperatures during the warm season (28.20°C–29.38°C) and higher relative humidity levels during the rainy season (66.25%–67.50%). However, seasonal differences were not found in the occupants' preferences for higher indoor airflows with the acceptable levels standing at 0.90 m/s. These results will help healthcare professionals to prevent indoor overheating in naturally ventilated wards.

Introduction

Natural ventilation remains the primary environmental mechanism for cooling and airborne infection control in hospitals with limited resources across the globe (Kigali Cooling Efficiency Program, 2018). In these hospitals, unmet rising space cooling loads made necessary not only by climate change but also by higher expectations in medical care could result in severe indoor overheating (Escombe et al., 2019). Although evidence about occupant adaptive behaviors, especially among those who are most vulnerable to thermal discomfort, is required for the efficient mitigation of indoor overheating (Carmichael et al., 2013), to date there is a lack of empirical data as regards thermal performance and adaptability in naturally ventilated inpatient facilities with warm and humid conditions.

Published evidence about thermal comfort surveys that combined both environmental and subjective measurements in hospital spaces across the equatorial zone are limited to only five studies with three of them being realized in Malaysia (Yau & Chew, 2009 and 2014; Azizpour et al., 2013; Khalid et al., 2019) and the rest in Madagascar (Nematchoua et al., 2017) and Thailand (Sattayakorn et al., 2017). None of these studies was conducted in naturally ventilated facilities with hospitalized patients as participants. This paper reports on a case-study and mixed-methods investigation of the entangled interactions between thermal comfort perceptions; adaptive behaviors; and environmental, spatial, seasonal, temporal, and operational conditions; and personal factors as they unfolded in real-time in naturally ventilated hospital wards with hot-humid settings.

Methods

Multidisciplinary methods have been widely applied for the real-time collection of environmental and behavioral data in occupied buildings. A case-study and mixed-methods approach consisting of archival research, a building and site survey, indoor and outdoor environmental monitoring, photographic-recording of the window openings, movement-mapping, semi-structured interviews, and thermal comfort interviews were applied for the collection of environmental, spatial, personal, and behavioral data in eight naturally ventilated wards over fieldwork of nine weeks throughout the rainy (Sep.2016) and the dry (Mar.Apr.2017) seasons (Figure 1).

Rigorous piloting and participatory design with nurses and doctors contributed to the synergetic management between ethical regulations, scientifically approved recording procedures, nursing schedules, and infection control practices. The application of the codesigned protocol resulted in the compilation of one of the largest databases comprised from indoor and outdoor microclimatic parameters (7,933 hours); window-opening behaviors (1,914 hours); movement and activity patterns (17 hours); and physical, personal, and behavioral factors regarding thermal comfort (45,000 data and in-depth interviews with a three-hour duration). The case-study hospital (Figure 2) is one of the largest government-run tertiary hospitals located at one of the 2013–2016 Ebola outbreak's epicenters with equatorial-monsoonal climate (Koettek et al., 2006).

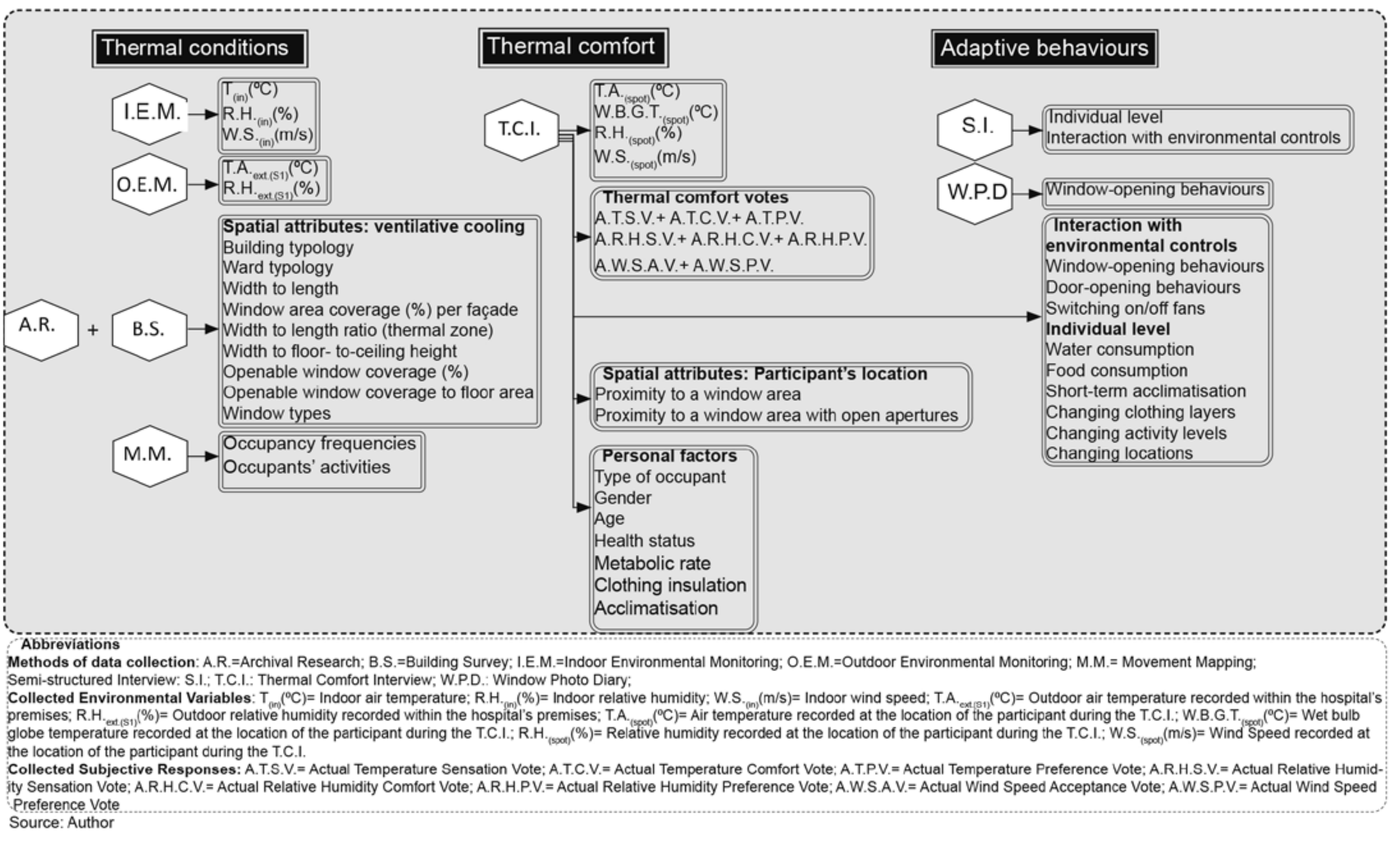


Figure 1: Methods of data collection and type of collected data. (Source: Author.)

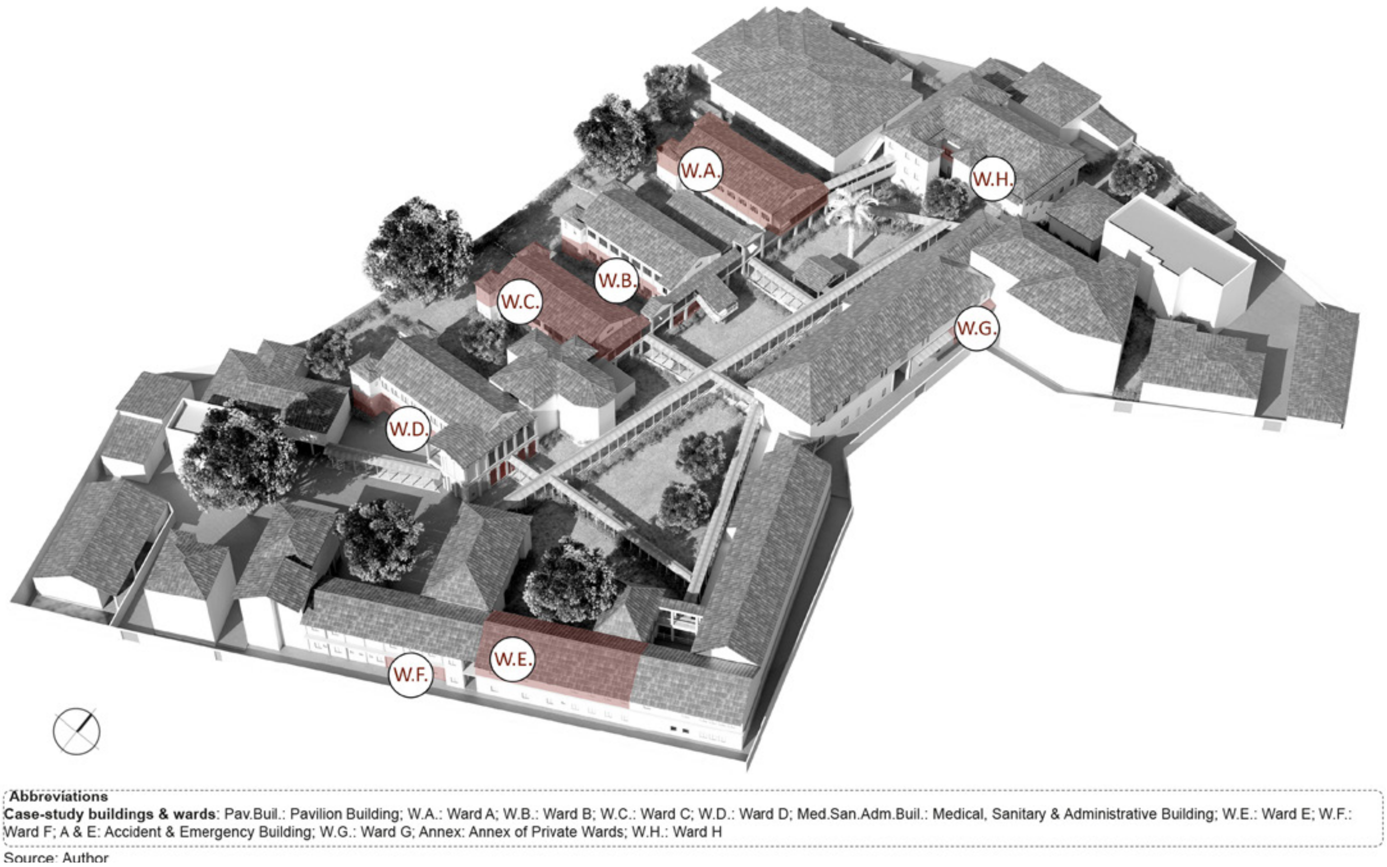


Figure 2: Aerial photo-realistic view of the hospital with the case-study buildings and wards. (Source: Author.)

Equipment	Physical Measurement	Measurement Range
TGU-1500	T.A. (°C)	-30–50°C
	R.H. (%)	0–100%
PCE-WB 20SD4	T.A. (°C)	-21.60–50°C
	R.H. (%)	5.00–95.00%
	T.G. (°C)	-25.30–48.9°C
TROTEC TA300	W.V. (m/s)	0.1–25 m/s

Table 1: Equipment for indoor and outdoor environmental monitoring and thermal comfort assessment. (Source: Author.)

Author	Equation
ASHRAE 55 (2013)	90% applicability low limit
	$T_o = 0.31 * T_{rm} + 15.30$
	$10°C < T_{rm} < 33.5°C$
Vellei et al. (2017)	For R.H. > 60.00%
	$T_{op} = 0.53 * T_{rm} + 12.85$
	For 40.00% <= R.H. > 60.00%
	$T_{op} = 0.53 * T_{rm} + 14.16$
	R.H. <= 40%
	$T_{op} = 0.52\ T_{rm} + 15.23$

Table 2: Applied adaptive thermal comfort standards. (Source: Author.)

Mean (n) (SD)		
Model	**Sep. 2016**	**Mar.Apr. 2017**
ASHRAE 55 (2013)	24.09	24.10
	(276)(0.03)	(360)(0.01)
Vellei et al. (2017)		
R.H. <= 40%	-	30.22
		(337)(0.14)
40.00% <= R.H. > 60.00%	-	29.44
		(337)(0.14)
R.H. > 60.00%	27.51	28.13
	(278)(0.47)	(337)(0.14)

Table 3: Summary statistics of comfortable temperatures estimated according to the low limit with 90% acceptability of the ASHRAE 55 Standard (2013) and models developed by Vellei et al. (2017). (Source: Author.)

Case-Study Building	Openable Window Façade Coverage (%)	Width to Floor-to-Ceiling Height Ratio
Pav. Buil.	59.48–76.61	2.69–2.84
Med. San. Adm. Buil.	25.96–27.69	2.00–2.12
A & E	9.77	2.13
Annex	58.05	3.85

Table 4: Characteristics of the natural ventilation design among the four buildings with the eight case-study wards. (Source: Author.)

According to the historical weather data, diurnal fluctuations remain below 3°C with temperatures exceeding 25°C from 9:00 to 19:00, relative humidity values peaking between 3:00 and 8:00 and wind speed plummeting from 5:00 to 8:00 (Meteonorm, 2016). The equipment used for indoor and outdoor environmental monitoring is illustrated in Table 1. Data analysis was conducted through the application of descriptive and inferential statistics (STATA 14.2) and content analysis (NVivo 11). For the overheating assessment, the adaptive thermal comfort models according to the low limit with 90% acceptability of the ASHRAE 55 Standard (2013) and those developed by Vellei et al. (2017) for different levels of indoor humidity (Tables 2–3).

Results and Discussions

All four buildings had advantageous orientations toward the prevailing wind directions (from W to SSW) (Figure 2) with the 'Pav.Buil.' containing the wards with the highest facade coverages of the openable window (59.48%-76.61%) (Table 4). The only functional fans were installed in 'Med. San.Adm.Buil.' and the 'A & E'; however, their operation was disrupted by the intermittent electricity supply. The width to floor-to-ceiling height ratio was unbeneficial for wind-driven ventilation only in the Annex (3.85) (Table 4) while the only most easily accessible and operable window (without railings or mosquito screens) were in the 'Med.San. Adm.Buil.' (Figure 3). Overall, the windows in all the selected wards lacked adequate shading devices, with double-glazed windows' internal window curtains trapping solar radiation and by convection inducing higher adjacent air temperatures. At the same time, heat gains by conduction through the heavyweight external walls and by convection through the uninsulated ceilings and floors reduced the potential of nocturnal cooling contributing to higher night-time overheating.

Most patients reported asking for help in Sep.2016 (54.55%) and fanning themselves in Mar. Apr.2017 (60%), while visitors preferred moving to cooler outdoor places both in Sep.2016 (44.44%) and in Mar. Apr.2017 (50.00%) (Figure 4). Visitors' tendency to move to cooler indoor and outdoor places was reflected in the changes in their locations over an hour before the T.C.I. both in Sep.2016 (33.33%) and in Mar. Apr.2017 (9.60%), while similar changes were uncommon among nurses and patients (Figure 5). Dominant among nurses and doctors was the belief that thermal discomfort among patients was a symptom that required medical examination and the provision of medication (Figure 6).

Both in Sep.2016 and Mar. Apr.2017, rehydration and self-fanning were the dominant heat-copying mechanism among nurses (33.33%) (Figure 4). Changes in the consumption of liquids over an hour before the T.C.I. were reported by all occupant types with patients expressing the highest percentages of change (56% in Sep.2016 and 30.66% in Mar. Apr.2017) (Figure 5). Giving water to patients was one of the prevalent responses of both nurses and doctors (Figure 6). Although only nurses in Sep.2016 (13.04%) reported changing their metabolic rates by taking a break, all occupant types had changed their activities over the last hour from the time of the T.C.I., both in Sep.2016 and in Mar. Apr.2017 (Figures 4–5).

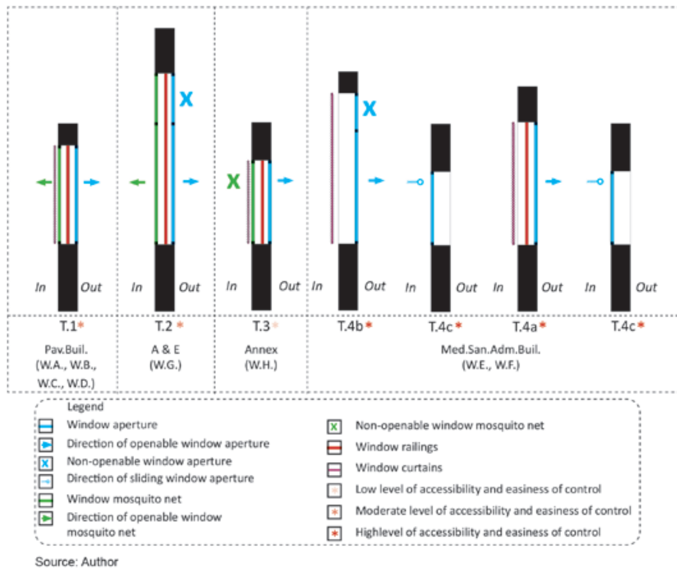


Figure 3: Characteristics of the design of the windows in the case-study wards. (Source: Author.)

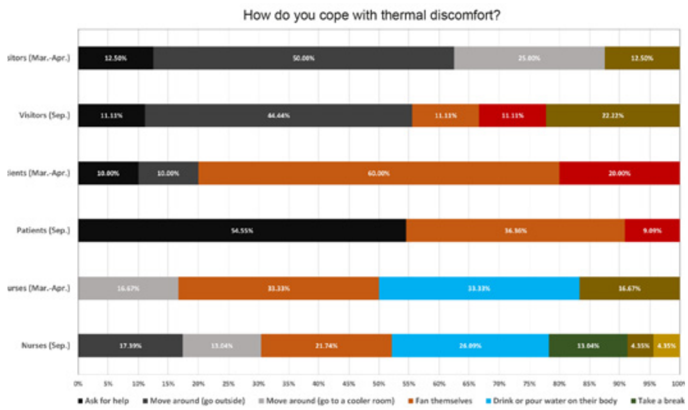


Figure 4: Stacked columns (100%) illustrating the prevalence (%) of different adaptive behaviors for the prevention of heat-related discomfort at individual level among nurses, patients, and visitors. (Source: Author.)

Changing clothes was a very unusual adaptive behavior among all occupant types both in Sep.2016 and in Mar. Apr.2017 (Figures 4–5). By contrast, changing bed coverings and patients' clothes, along with fanning them, accounted for the most common responses of both nurses and doctors (Figure 6). Whereas proximity to a window or a fan was a rare heat-copying behavior, high percentages of all occupant types stood during their T.C.I in a distance less than two meters from an open window both in Sep.2016 (44%–81.51%) and in Mar.Apr.2017 (32.85%–98.21%) (Figures 4–5).

However, the median changes in the total percentages of open apertures from the morning to the evening shift were low standing in the -3.25 to 14.29% range in Sep.2016 and from -3.00% to 7.87% in Mar.Apr.2017 (Figure 7). Furthermore, 66.39% (162/244) and 70.58% (343/486) of participants reported their willingness to open the windows in Sep.2016, and in Mar.Apr.2017, respectively, with the group of nurses prevailing both in Sep.2016 (88.27%) and in Mar.Apr.2017 (58.60%). Regarding the operation of fans, again nurses reported the highest percentages in Sep.2016 (79.75%) and in Mar.Apr.2017 (84.76%).

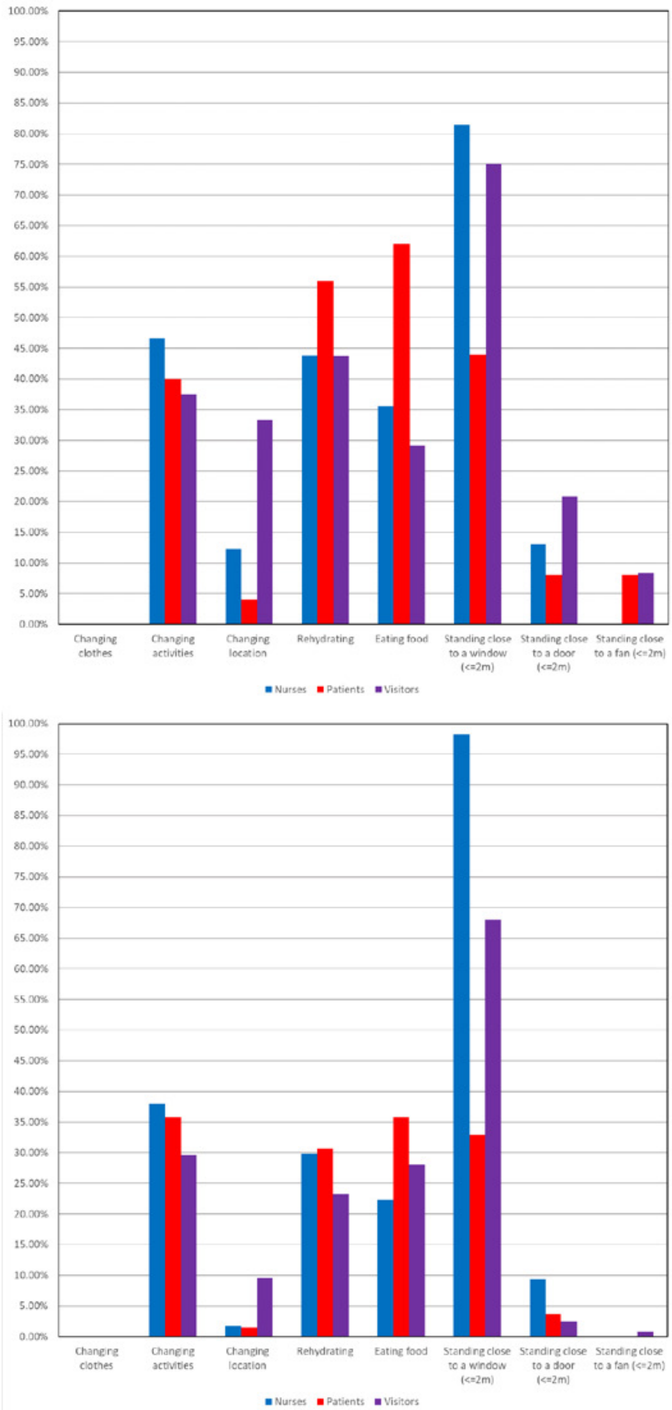


Figure 5: Reported changes in adaptive behaviors among nurses, patients, and visitors between 10 to 30 minutes and from 30 to 60 minutes before the time of the Thermal Comfort Interview (T.C.I) in a) Sep.2016 and in b) Mar.Apr.2017. (Source: Author.)

All case-study buildings had mean 24-hour T.A.(in) values in the 27.68°C–28.71°C range in Sep.2016 and between 28.92°C and 30.56°C in Mar.Apr.2017, while the R.H.(in) values stood between 75.82% and 82.32% in Sep.2016 and from 58.41% to 70.99% in Mar.Apr.2017 (Table 5). The range and variability of recorded thermal conditions were higher in the buildings exposed to higher airflow rates (Table 5). Both in Sep.2016 and in Mar.Apr.2017, indoor recorded temperatures exceeded the lower limit of 90% acceptability of the ASHRAE 55 adaptive thermal comfort standard (Table 3) over the whole duration of the monitoring periods, with maximum differences, which were higher during nighttime in Mar.Apr.2017, varying between 5.37K and 8.86K.

Applying the adaptive thermal comfort model developed by Vellei et al. (2017) for different indoor relative humidity levels in Mar.Apr.2017 (Table 3) estimated overheating was less severe with temperature differences exceeding the comfortable zone by 3K to 5 K occurring over less than 20% of monitoring period only in the 'Pav.Buil.' and the 'Med.San. Adm.Buil.' However, outdoor weather was a very weak modifier of indoor thermal conditions. In Mar.Apr.2017, the $T_{op.(spot)}$(°C) values corresponding to votes expressing neutrality, comfort, and acceptability stood in the 30°C–31°C region across all buildings (Figure 8).

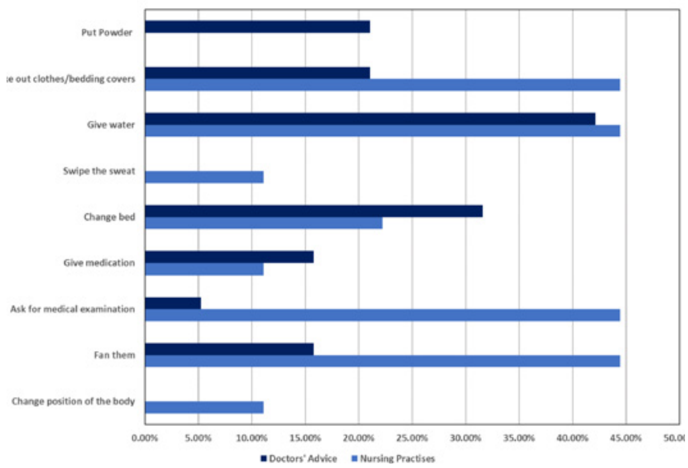
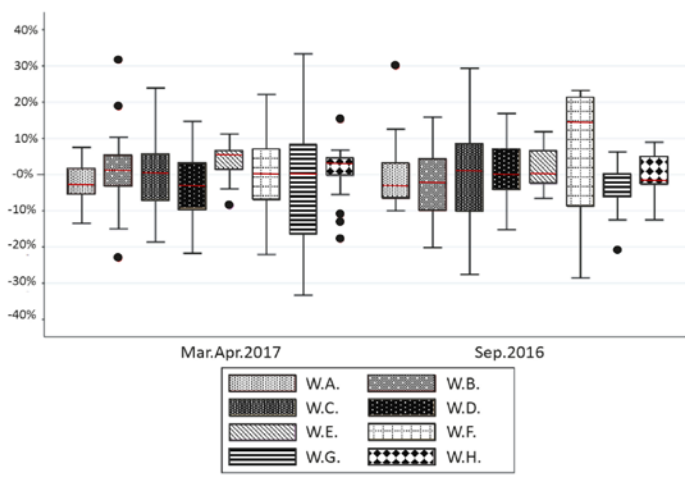


Figure 6: Columns illustrating the prevalence (%) of different actions realised by nurses and suggestions made by doctors for the restoration of patients' thermal comfort. (Source: Author.)



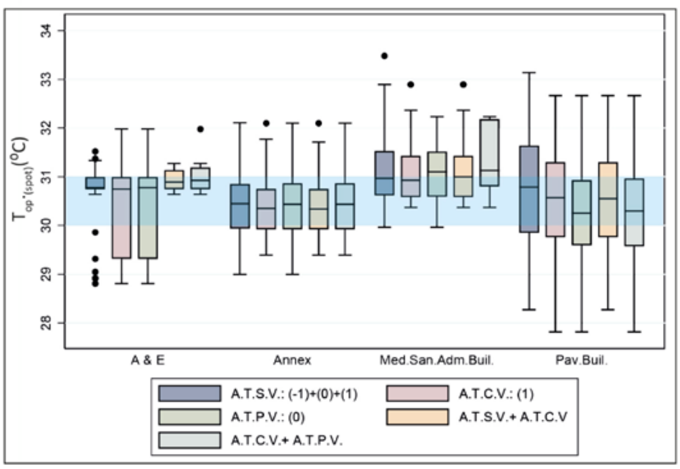
Source: Author

Figure 7: Boxplots comparing the differences in the percentages of open apertures (%) between the morning and the evening shifts in the selected wards. (Source: Author.)

	Mean (SD)	
Case-Study Building	T.A.$_{in}$(°C)	R.H.$_{(in)}$(%)
	(24-hour)	(24-hour)
Sep. 2016		
Pav. Buil.	27.68 (1.15)	82.32 (7.17)
Med. San. Adm. Buil.	28.68 (1.21)	79.80 (6.59)
A & E	28.00 (0.27)	75.82 (2.30)
Annex	28.71 (0.57)	78.48 (2.56)
Mar.Apr. 2017		
Pav. Buil.	28.92 (1.17)	70.99 (7.09)
Med. San. Adm. Buil.	30.56 (0.89)	65.75 (6.18)
A & E	30.38 (0.20)	58.41 (1.98)
Annex	29.48 (0.47)	68.81 (5.61)

Table 5: Summary statistics of indoor recorded environmental conditions. (Source: Author.)

In the separate total samples of nurses, patients, and visitors, acceptable temperatures estimated as the intersection points between the two probit curves of the preference votes for warmer or cooler revealed that acceptable range of T$_{op.(spot)}$ values were lower in Mar.Apr.2017 (28.20°C–29.38°C) than in Sep.2016 (29.12°C–30.38°C) while acceptable range of R.H.$_{(spot)}$ values were lower in Sep.2016 (66.25%–69.75%) than in Mar.Apr.2017 (71.25%–71.50%) with all of them representing cumulative proportions of participants that stood below 60% (Table 6). Occupants' preferences for higher indoor airflows did not display any seasonal standing at 0.90 m/s.



Source: Author

Figure 8: In Mar.Apr.2017, Top.(spot)(°C) values corresponding to temperature-related sensation votes (A.T.S.V.) classified as 'slightly cool' (-1), 'neutral' (0), and 'slightly warm' (1), comfort votes (A.T.C.V) classified as 'comfortable' (1), preference votes (A.T.P.V.) classified as 'without change' (0), and the combination between votes of neutrality and comfort (A.T.S.V. and A.T.C.V.) and between comfort and acceptability (A.T.C.V. and A.T.P.V.). (Source: Author.)

Occupant Types	T$_{op.(spot)}$(°C)	R.H.$_{(spot)}$(%)
Sep. 2016		
Nurses	30.38	66.25
Patients	29.12	69.75
Visitors	29.13	67.50
Mar.Apr. 2017		
Nurses	29.38	71.25
Patients	29.00	71.45
Visitors	28.20	71.50

Table 6: Acceptable thermal conditions estimated as the intersection points between the two probit curves of the preference votes for warmer or cooler and for less or more humid conditions. (Source: Author.)

By contrast to the characteristics of the ventilation design and construction in the case-study wards, several studies have shown that in hot-humid climates the limited cooling capacity of natural ventilation can be reinforced through the decrease in the thermal storage capacity of the building envelope and the internal heat gains along with improvements in the ventilation and surrounding microclimate (Halawa et al., 2017; Kumar et al., 2017). Conditions of inadequate ventilation resulting in overheating and bad air quality have been recorded in outpatient settings with limited resources across the Global South (Njogu et al., 2018; Nematchoua et al., 2019; Wright et al., 2017). Design of windows in hospital wards has been primarily driven by security, safety, and maintenance concerns that limit accessibility and easiness of control among occupants (Hosking, 1999) while the limited evidence about occupant-controlled window operation in hospitals shows that occupants during warm days open the windows but leave their position unchanged over the day (Shi et al., 2018; Short et al., 2012).

In the case-study hospital, despite the high percentages of window coverages and the reported willingness, especially among nurses, to change the position of the window openings, these intentions were not reflected in the observed window operation. At the same time, despite the widely accepted fact that capacity for thermal adaptability among hospital occupants is overall restricted due to safety and occupational requirements (Lomas and Ji, 2009), all type of occupants in the case-study wards reported a wide range of adaptive behaviors for the restoration of thermal comfort at an individual level.

However, it became evident that nurses were in control of the operation of the windows and fans. At the same time, nursing practices integrated actions for the restoration of thermal comfort among patients. Furthermore, extended thermal adaptability, as well as thermal acclimatization, contributed to the acceptability of thermal conditions above the thermal comfort zone according to established overheating standards and published field-surveys in air-conditioned general wards in Thailand (21°C–28°C) (Sattayakorn et al., 2017).

Conclusion

In hospital wards where the manipulation of the natural forces of wind, temperature, and humidity is the only mechanism for the provision of thermal comfort and infection control, nurses need to be trained to understand the fluctuations between the indoor and outdoor environmental conditions and act accordingly. Beyond the lack of awareness about the climate-responsive operation of building controls, crucial drivers related to socio-cultural norms and established hierarchies among nurses need to be addressed.

As the current COVID-19 pandemic evolves across the Global South, it is likely that naturally ventilated clinical spaces in inadequate buildings are being repurposed for the treatment of COVID-19 cases. In these strictly regulated clinical environments, hospital occupants being totally deprived of their capacity for thermal adaptability will be likely exposed more frequently, over prolonged periods, to extreme uncomfortable thermal conditions.

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