Thermal comfort and occupant adaptive behaviours in naturally ventilated hospital wards in a hot-humid post-epidemic context

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ABSTRACT

In free-running hospitals, which comprise a significant part of the healthcare infrastructures in countries with the weakest public health systems, unmet space-cooling demand can exacerbate indoor overheating. To date, we lack a comprehensive understanding of human thermal adaptability in naturally ventilated inpatients facilities. Building on a mixed-methods longitudinal thermal comfort survey in eight naturally ventilated multi-patient wards during the rainy and dry seasons at the main tertiary hospital in a post-epidemic context, the links between thermal comfort and occupant adaptive behaviours were explored through predictive correlations, probit regression and narrative analysis. The findings revealed that nurses directed the operation of the building controls while acceptable thermal conditions were defined by lower tolerance levels to elevated temperatures during the warm season and higher relative humidity levels during the rainy season. The mitigation of thermal distress among patients through the control of indoor humidity and airflow can function synergistically with airborne infection control.

INTRODUCTION

Hospitals with significantly low annual carbon emissions for cooling (Kigali Cooling Efficiency Program, 2018) across the equatorial zone compose the fragile healthcare infrastructures among the world's weakest public health systems. Heatwaves, which already affect hospital operations, are predicted to occur more frequently and with greater severity contributing to more extended periods of indoor overheating and operational disruptions in hospitals (WHO, 2020). Although evidence about indoor overheating and hospital occupant adaptive behaviours is instrumental for the alleviation of existing vulnerabilities (Carmichael, et al., 2013), to date, we lack thermal comfort indexes with applicability in naturally ventilated inpatient facilities with hot-humid conditions while thermal comfort field surveys that combine physical and subjective measurements and include patients as participants have not yet been performed in naturally ventilated wards across the equatorial zone (Koutroumpi, 2020). Building on the existing evidence that in the strictly regulated hospital environment, physiological and behavioural adaptive capacities significantly differ between diverse hospital occupants (Eijkelenboom & Bluyssen, 2019), this paper aims to explore how occupant behaviours and thermal adaptability can mitigate critical differentiations in thermal discomfort among hospital occupants while taking into account the impact of relative humidity, indoor airflows, personal factors and spatial conditions.

METHODS

Collected sample

A mixed-methods longitudinal field survey was conducted over nine weeks during the rainy (September 2016) and dry seasons (March-April 2017) in eight naturally ventilated wards at the main tertiary government-run hospital with equatorial-monsoonal climate (Am) (Koettek, et al., 2006) at one of the epicentres of the 2014-16 Ebola outbreak. The case-study hospital is in Africa's west coastal zone, at a central urban location (Figure 1). A multidisciplinary dataset, which consisted of environmental and behavioural data, was collected according to the instructions of the ASHRAE 55: 2013. Twenty-one semi-structured interviews with twelve doctors and nine head nurses, 750 Thermal Comfort Interviews (T.C.Is.) (45,000 data), indoor and outdoor environmental monitoring (7,933 hours), and window-opening behaviours (1,914 photos) comprised the collected dataset. In total, twenty participants were excluded from the analysis of the T.C.Is. due to their exposure to high airflows coming from personal fans. The final sample consisted of 50.68% (370) nurses, 25.62% (187) patients and 23.70% (173) visitors, who were interviewed across four surgical (43.70%), two medical (14.50%) and two mixed (42.60%) wards.

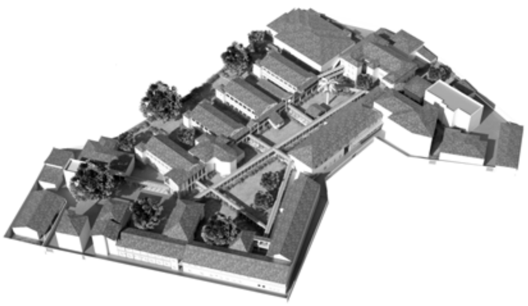
a)

Source: Google Earth (7.3)

b)

Source: Author

c)



Source: Author

Figure 1. Location and architectural characteristics of the case-study hospital: a) aerial view of the urban location; b) southeast view; c) aerial photorealistic view.

Methods of data collection and data analysis

Infection control practises were integrated with scientifically standardised protocols and nursing routines following one-week piloting and co-designing processes with doctors and nurses. Context-specific infrastructural challenges and safety concerns hindered the installation of a network of sensors and the monitoring of the existing ceiling fans' operation, which was intermittent due to regular electricity power cuts. The technical specifications of the equipment for the recording of the physical data are illustrated in Table 1. Although from the critical location of the nurse station monitoring of the indoor air temperature and relative humidity was continuous, recording of the indoor air velocities was repeated intermittently while at multiple locations over the morning or the evening shifts sporadic recordings of air and global temperature, relative humidity and wind speed were performed in the distance from thirty to fifty centimetres during five minutes around each participant throughout each T.C.I. (Figure 2).

Table 1. Technical specifications of the equipment for the recording of the physical data during continuous and sporadic environmental monitoring.

Instrument's Name	Measurement Range	Accuracy
Gemini Tinytag Ultra (TGU-1500)	-30 to +70°C 0% to 100%	+-0.2°C
TROTEC TA 300 Anemometer	0.1 to 25 m/s	+-0.05 m/s
Thermal Stress Meter PCE-WB 20SD	-21.60 to 50°C	+-0.5 °C

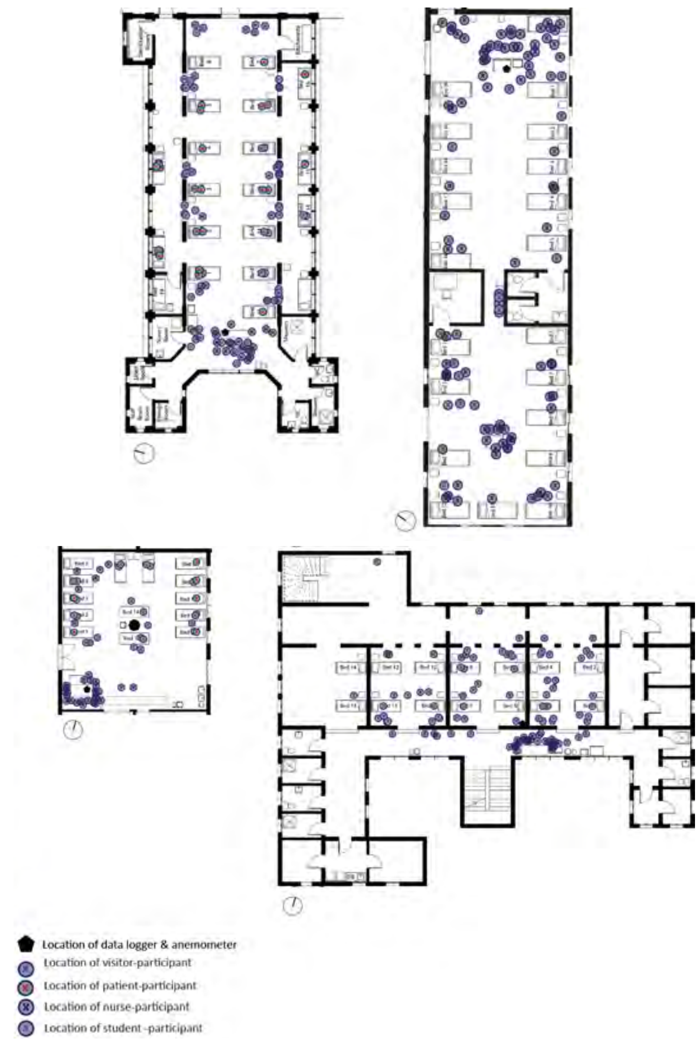


Figure 2. Spatial distribution of the physical measurements in plan views of the case studies' representative typologies. Source: Author.

Voluntary participation in the T.C.Is. was limited to nurses and adult patients and visitors with the ability to provide consent. The following measures were taken to reduce sampling error: a) initial estimation of the required sample size (384) according to Equitation (1) (Lehmann, 2006) for statistically significant results (95% confidence intervals); b) maximisation of the final sample by extending the presence of the research team in the case-study wards despite operational difficulties and unexpected events (patients' deaths etc); c) exclusion of occupants lacking continuous presence in the wards over the last fifteen minutes before the T.C.I.; d) piloting both the content of the questionnaire and the process for the collection of the physical and spatial data in a sub-sample of the case-study wards during normal operation.

$$SS = \frac{z^2 SD(1-SD)}{E^2} \quad (1)$$

where:

SS is sample size, *Z* is score (Z) equal to 1.96 (for 95% confidence intervals), *SD* is standard deviation equal to 0.5, *E* is margin of error equal to 0.05.

Four stages with a total duration of ten minutes comprised each T.C.I. Firstly, the research assistant explained in English or the local language the information letter. Following the participant's signature of the consent form, the interview began including standardised questions about thermal comfort, personal factors (gender, age, health status, metabolic rates, clothing layers, education), adaptive behaviours and satisfaction levels that the research assistant completed in printed questionnaires. At the last stage, the physical measurements were taken at three different heights (0.1m, 1.1m and 1.7m around standing participants and 0.1m, 0.6m and 1.1m around seated participants and patients reclining in their beds) and the spatial attributes (distance from existing environmental controls along with the state of the controls) at the participant's locations were recorded. Semi-structured interviews were performed only during the rainy season, either during the morning or the evening shifts at various locations within the hospital premises. Due to both doctors' and nurses' limited availability, the discussions were short (between three and eight minutes) while permission for digital recording was granted only from two participants. Questions about adaptive behaviours for the amelioration of thermal discomfort at an individual level and in relation to patient care and aspirations for better space-cooling were made similarly to all interviewees. Photos of the window-openings position in the case-study wards were taken from specific locations two times per day (10:00-11:00 during the morning shift and 17:00-18:00 during the evening shift) following a standardised route.

A statistical analysis of the quantitative data was performed with STATA (SE 16), while NVivo 11 was used for the thematic content analysis of the transcripts from the semi-structured interviews. Indoor overheating was modelled according to Equations (2-6) of the low and upper limits of ASHRAE 55: 2013 models for 90% acceptability to account for the high expectations of thermal comfort in hot-humid settings. Relative humidity levels above 37% have been associated with mild and severe adverse health effects (Sterling, et al. 1985). Due to the non-normal distribution of the collected data, data analysis was performed according to non-parametric inferential statistical methods along with predictive correlation and regression methods. Wilcoxon Rank Sum Test, a distribution-free tool (Wright & London, 2009), was used to explore the variation in exposure to indoor thermal conditions between different groups of occupant types. In statistically significant correlations between categorical variables, Cramer's V effect sizes were computed. Specific cut-off points were used to indicate the percentage of variance in the dependent variable that was explained by the predictor (McHugh, 2018). Probit regression, which was used for the investigation of cumulative proportions of the nominal variables of thermal comfort votes at specific cut-off points, is suitable for the analysis of small samples that are very common among thermal comfort field surveys in hospitals (Khalid, et. al, 2019). A simple linear regression model was applied to investigate the links between the reported thermal comfort votes and recorded environmental conditions.

$$Top=0.31*Trm+15.30 \quad (2)$$

$$Top=0.31*Trm+20.30\ldots\ldots \quad (3)$$

$$Trm=(1-a)*[te(d-1) + a*te(d-2) + a*te(d-3)+\ldots \quad (4)$$

where:

Top is the operative temperature, *Trm* is the running mean outdoor temperature.

$$Top(spot) = \left(TA(spot)x\sqrt{10xWS(spot)}\right)\left(\frac{Tmrt(spot)}{1.00+\sqrt{10xWS(spot)}}\right) \quad (5)$$

(CIBSE, 2006)

$$Tmrt(spot) = \left(\frac{(Tglobe(spot)+273)^4+\left(1.1x10^8xWS(spot)^{0.6}\right)}{\varepsilon xD^{0.4}}\right)x(Tglobe(spot - TA(spot))^{\frac{1}{4}} - 273 \quad (6)$$

(Hoyt, et al. 2017)

where:

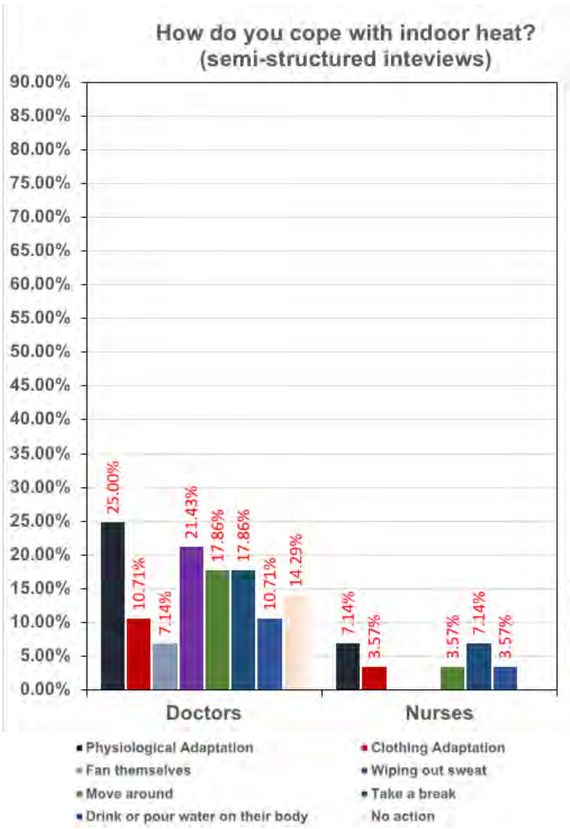
Top(spot) is the operative temperature around the occupant, *TA(spot)* is the air temperature around the occupant, *WS(spot)* is the wind speed around the occupant, *Tmrt(spot)* is the mean radiant temperature around the occupant, ε is emissivity equal to 0.95 for globe with diameter of 0.075m , *D* is the diameter of the globe.

RESULTS

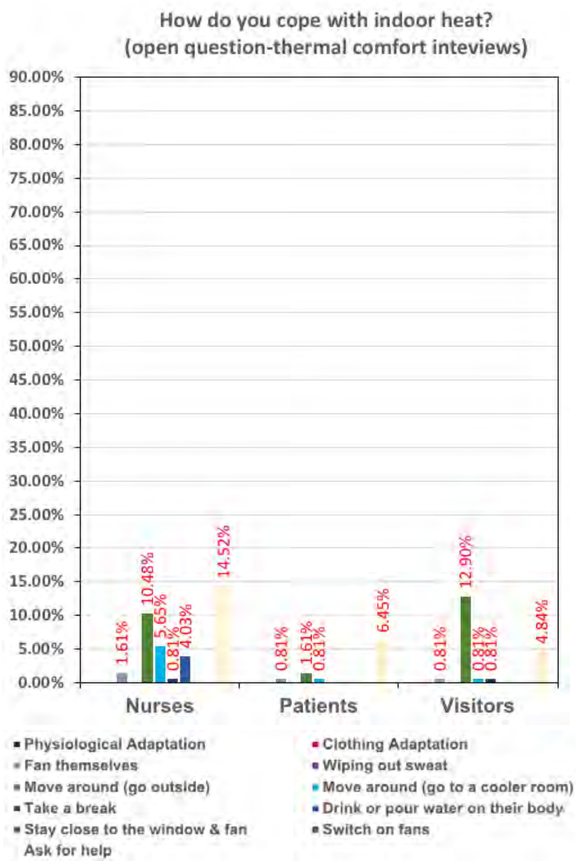
Reported and observed adaptive behaviours during the rainy season

Both doctors (25%) and head nurses (7.14%) considered their physiological capacity of thermal acclimatisation their most substantial aspect of thermal adaptability, followed by the adaptive behaviour of taking a break (17.86% for doctors, 7.14% for nurses) (Figure 3a). Although only 46.58% of nurses reported having changed their metabolic rates over the last hour before the T.C.I., an adaptation of metabolic rates through recent rehydration and food consumption were reported by nurses (43.84%, 35.62%), patients (56.00%, 62.00%) and visitors (43.75%, 29.17%) (Figures 3b-c). Moving to cooler places and asking for help accounted for the most prevalent adaptive behaviours among nurses (10.48%, 14.7%), patients (1.61%, 6.45%) and visitors (12.90%, 4.84%) (Figure 3b). However, a minority of nurses (12.33%) and patients (4.00%) admitted having changed their locations over the last hour before the T.C.I. (Figure 3c). Although clothing adaptation was mentioned during the semi-structured interviews with doctors (10.71%) and head nurses (3.57%), changing clothes was a very uncommon behaviour among all occupant types (Figures 3a-c).

a)



b)



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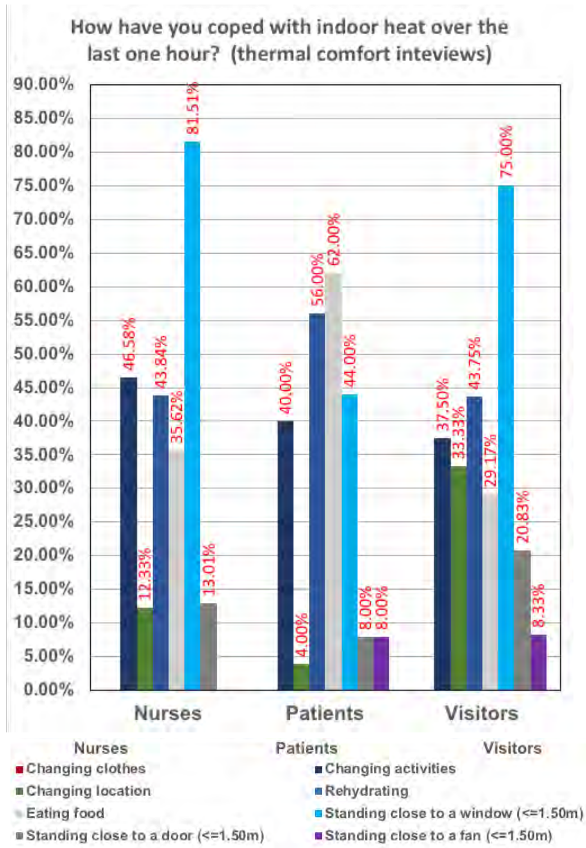
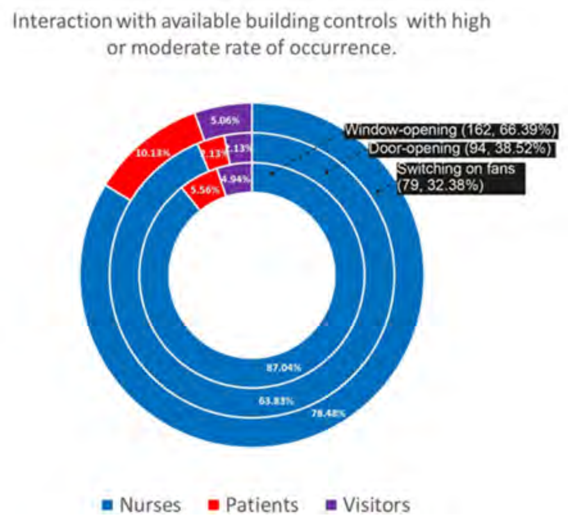


Figure 3. Clustered bar graphs with percentages of reported adaptive behaviours for the restoration of thermal comfort among diverse hospital occupant types during the rainy season: a) adaptive behaviours reported by head nurses and doctors during the semi-structured interviews (n=21); b) adaptive behaviours reported by nurses, patients, and visitors during the T.C.Is. (response rate 28.28%); c) adaptive behaviours over the last hour before the T.C.Is. reported by nurses, patients, and visitors (response rate 100%). Source: Author.

Whereas moving closer to a window was the prevailing behaviour among both nurses (81.51%) and visitors (75.00%) over the last hour before the T.C.I. and window-opening (66.39%) was the most popular frequent interaction with existing environmental controls (Figures 3b-c), median percentages of changes in the percentages of open apertures between the morning and the evening shifts stood between 0.00% (0.06<SD>0.11) and 4.5% (SD=0.12) in all case-study buildings (Figure 4b) Although nurses directed the operation of the existing environmental controls (window-opening 87.04%, door-opening 63.83% and fan-operation 78.48%) (Figure 4a), opportunities for interaction with existing controls in close distance occurred to all occupant types (Figure 4c). However, adaptive behaviours affected the variation across all types of thermal comfort votes in relation to indoor temperature, relative humidity, and airflow only among patients (Cramer's V effect sizes from 0.27-0.70, p-value<0.001), with window-opening accounting for 49% (Cramer's V effect size 0.70, p-value<0.001) of their preference votes about indoor relative humidity

(Figure 5). Overall, despite the observed discrepancies between preferred adaptive behaviours, existing adaptive capacity and performed adaptive actions, votes of satisfaction (69,67%) with existing environmental controls prevailed, with nurses expressing the highest levels of content (63.53%) (Figure 4d).

a)



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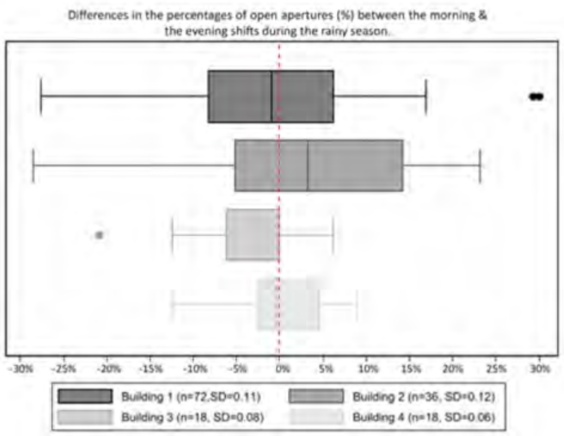

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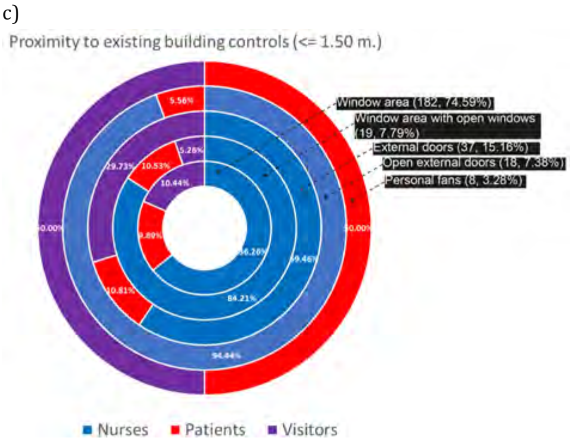


d)

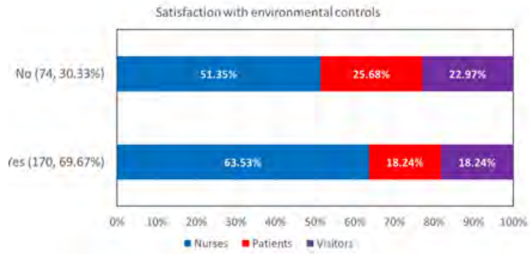


Figure 4. Descriptive graphs of the reported and observed interactions with existing environmental controls during the rainy season: a) pie chart with the distributions per occupant type of high and moderate frequency of interaction with windows, doors and fans; b) boxplots of differences in the percentages of open apertures (%) between the morning and the evening shifts during the rainy season; c) pie charts of the distributions per occupant type of the proximity in a distance equal or less than 1.50m from existing environmental controls at the time of the T.C.I.; d) Stacked bar (100%) graphs of the distribution of different occupant types for different satisfaction levels. Source: Author.

Recorded thermal conditions, modelled overheating and reported thermal comfort during the rainy and the dry seasons

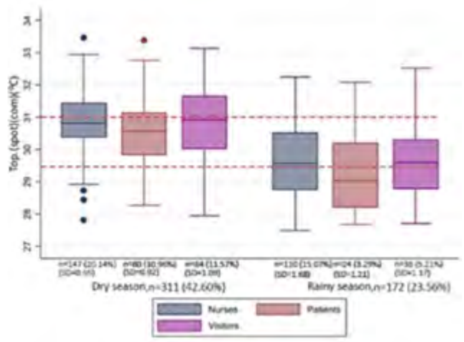
At the hospital site during both seasons, whereas outdoor environmental conditions slightly differed from historical levels, significant deviations were monitored by comparison to the microclimate at the meteorological station (Table 2). Mean indoor temperature (28.14^{0}C rainy season, 29.56^{0}C dry season) remained close to the comfort zone defined by the upper limit for 90% acceptability of the ASHRAE 55:2013 standard (29.09^{0}C rainy season, 29.10^{0}C dry season) by far exceeding those defined by the low limit (24.09^{0}C rainy season, 24.10^{0}C dry season) (Table 2). Mean indoor relative humidity levels stood within a range of unhealthy levels (81.10% rainy season, 67.84% dry season) while mean indoor wind speed indicated weak airflows (0.35 m/s rainy season, 0.80 m/s dry season).

Table 2. Descriptive statistics of the recorded environmental data and modelled comfortable temperature range.

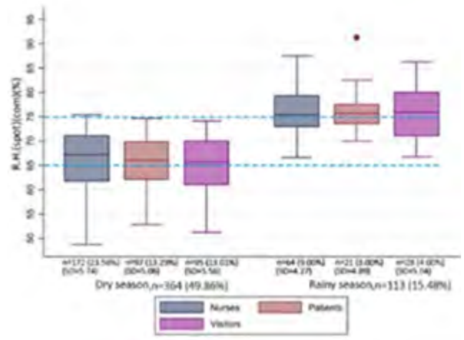
Environmental variable	Rainy season	Dry season
	Mean (SD)	Mean (SD)
TAext(His)(^{0}C)	25.35 (3.14)	28.48 (5.53)
TAext(S1(^{0}C)	27.42 (2.33)	28.87 (1.96)
TAext(Meteo)(^{0}C)	-	26.11 (1.16)
TA(in)(^{0}C)	28.14 (1.11)	29.56 (1.30)
Tcom(low limit) (ASHRAE 55:2013)	24.09 (0.03)	24.10 (0.01)
Tcom(upper limit) (ASHRAE 55:2013)	29.09 (0.03)	29.10 (0.01)
RHext(His)(%)	87.80(10.85)	75.01 (17.51)
RHext(S1)(%)	80.07 (7.93)	66.22 (8.84)
RHext(Meteo)(%)	-	82.76 (9.60)
RH(in)(%)	81.07 (6.89)	67.84 (7.51)
WS(His)(m/s)	3.96 (2.21)	4.16 (2.53)
WS(in)(m/s)	0.35 (0.35)	0.80 (0.62)

Among many participants, a vote of neutrality of thermal sensation was not necessarily matched with a vote of comfort and acceptability of the thermal conditions. Therefore, the sensation votes were combined with both comfort and acceptability votes to determine the context-specific comfort zone. Votes of comfort and content were linked with median Top(spot) values standing from 29.50 to 31°C, median RH(spot) values varying from 65 to 75% and median WS(spot) values in the 0.40-0.55 m/s region with patients expressing the lowest tolerance levels of indoor temperature and airflows (Figure 6a). 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 showed that exposure to higher levels of indoor temperatures increases sensitivity to discomfort with the acceptable range of Top(spot) values being lower during the dry season (28.20-29.38°C). Similarly, the acceptable range of RH(spot) values was lower during the rainy season (66.25-69.75%). However, cumulative proportions remained lower than 50%. Acceptable indoor airflows stood at 0.90 m/s during both seasons.

a) indoor operative temperature (°C)



b) indoor relative humidity (%)



c) indoor wind speed (m/s)

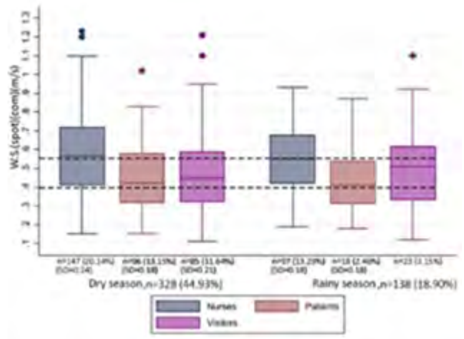


Figure 6. Boxplot of comfortable thermal conditions: a) indoor operative temperature (°C)(Top(spot)); b) indoor relative humidity (%); c) indoor wind speed (m/s). Source Author.

Night-time overheating, which was calculated according to the low limit for 90% acceptability ASHRAE 55:2013 model, was more severe in all case-study buildings than daytime overheating, especially during the dry season. Differentiations in indoor thermal exposure between the interviewed nurses and the rest of the occupants introduced a statistically significant variation only in terms to their exposure to higher levels of indoor RH(spot) and WS(spot) values (Figure 7). Temperature-related preference votes were slightly influenced by Tem(out) and RH(out) values only among nurses and patients, while changes in RH(spot) values had a more severe impact on temperature-related sensation votes than the Top(spot) values, especially among nurses and patients and higher WS(spot) values improved the perception of comfort only among patients (Figure 8).

DISCUSSION

The high levels of awareness for adaptive behaviours among all occupant types were not reflected in their realised adaptive actions. “Soft” interventions that can provide rehydration and outdoor cooling opportunities are likely to reduce thermal discomfort in overheated hospital spaces with limited resources. However, the lack of significant thermal exposure variation among nurses, who had higher capacity for adaptive behaviours, showed that environmental engineering drivers of differentiations in thermal exposures cannot be ignored. Their positive impact is likely to be stronger among patients, whose dissatisfaction with existing environmental controls might be the highest while their thermal adaptability remains the lowest; thus, increasing their vulnerability to thermal distress. Contrary to this project’s findings, patients in hospitals in high-income countries expressed during thermal comfort surveys the highest levels of satisfaction with indoor environments (De Giuli, et al., 2013; Del Ferraro, et al., 2015, Verheyen, et al., 2011).

Estimating indoor overheating in hospital spaces in both temperate and equatorial climates according to the existing adaptive thermal comfort indexes resulted in overestimating thermal discomfort in inpatient and outpatient facilities (Ferraro, et al., 2015; Alotaibi, et al., 2020; Azizpour, et al., 2013). Furthermore, the lack of both air-conditioning and climate-responsive design for the reinforcement of passive cooling can exacerbate the impact of indoor thermal conditions in crowded indoor spaces with hot-humid conditions limiting the applicability of existing adaptive thermal comfort indexes that consider outdoor temperatures as the main predictor of indoor overheating. According to the only available data about recorded overheating in occupied hospital spaces with restrained resources, waiting rooms in the rural health centres in Giyani, South Africa were severely overheated (Wright, et al., 2017).

The range of acceptable temperatures in air-conditioned hospital spaces across the equatorial zone lied between 23.20 to 35^{o}C in Kuala Lumpur, Malaysia (Yau & Chew, 2014; Khalid, et al., 2019; Azizpour, et al. 2013) and from 20.00 to 29.30^{o}C in Thailand (Sattayakorn, et al., 2017) and in naturally ventilated waiting rooms in Madagascar stood between 24.50 and 27.50^{o}C (Nematchoua, et al., 2017). Although differences in physiological thermoregulation and acclimatisation at a personal level, operational requirements, building services, and outdoor climates increase incomparability of the existing evidence, this project's findings indicated high thresholds of thermal discomfort. Despite the recorded high levels of acclimatisation, monitored indoor thermal conditions in the case-study wards demonstrated significant overheating that was incompatible with their clinical purpose.

Similar to this project’s findings, higher sensitivity in thermal discomfort has been found during seasons with more extreme thermal conditions in hospital spaces in the Netherlands (Derks, et al., 2018) and in hospital spaces in Iran (Pourshaghaghy, et al., 2012). As several studies have shown, tolerance to higher temperatures increases at lower humidity levels and higher airflows (Cândido, et al., 2011). In overheated naturally ventilated multi-bed wards across the equatorial zone, a holistic understanding of thermal discomfort that integrates the influence of both humidity and airflow can extend the spectrum of possible interventions. Furthermore, in hospital spaces, ventilative cooling, thermal comfort and infection control are intertwined. Although the effectiveness of infection control through natural ventilation remains a controversial issue (Atkinson, et al., 2009), optimal ventilation performance through personalised control combined with minimization of the duration of the exposure, and the viral dose, can strengthen the protection against airborne infection and mitigate thermal discomfort.

CONCLUSIONS

Climate-resilient hospital buildings compose climate-resilient health systems (WHO, 2015). In naturally ventilated wards with limited resources and hot-humid conditions, the integration of occupant adaptive behaviours in established safe healthcare practices can alleviate unequal vulnerabilities to thermal discomfort while strengthening the hospital’s role in climate-resilient health systems. Furthermore, by increasing the space cooling potential of natural ventilation, carbon emissions from air-conditioning can be reduced.

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Nomenclature

TAext(His)(^{0}C)= historical outdoor air temperature; TAext(S1(^{0}C)= outdoor air temperature at hospital’s site; TAext(Meteo)(^{0}C)= outdoor air temperature at local meteorological station; TA(in)(^{0}C)= indoor air temperature; Tcom(low limit)= comfortable indoor temperature according to the low limit with 90% acceptability model of the ASHRAE 55:2013; Tcom(upper limit)= comfortable indoor temperature according to the UPPER limit with 90% acceptability model of the ASHRAE 55: 2013; RHext(His)(%)= historical relative humidity; RHext(S1)(%)= outdoor relative humidity at hospital’s site; RHext(Meteo)(%)= outdoor relative humidity at local meteorological station; RH(in)(%)= indoor relative humidity; WS(His)(m/s)= historical outdoor wind speed; WS(in)(m/s)= indoor wind speed; Top(spot)(^{0}C)= operative temperature around occupant; RH(spot)(%)= relative humidity around occupant WS(spot) (m/s)= wind speed around occupant; Trm= running mean outdoor temperature.; Tmrt(spot)= mean radiant temperature around occupant.

REFERENCES

Alotaibi, B. S., Lo, S., Southwood, E., Coley, D. (2020). “Evaluating the suitability of standard thermal comfort approaches for hospital patients in air-conditioned environments in hot climates”. *Building and Environment*, 169. https://doi.org/10.1016/j.buildenv.2019.106561

American Society of Heating, Refrigerating and Air Conditioning Engineers (2013). *ASHRAE Standard 55-2013: Thermal Environmental Conditions for Human Occupancy*. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Atkinson, J., Chartier, Y., Pessoa-Silva, C. L., Jensen, P., Li, Y. and Seto, W. H. (2009). *Natural ventilation for infection control in health care settings*. Geneva: World Health Organisation. http://apps.who.int/iris/bitstream/handle/10665/44167/9789241547857_eng.pdf;jsessionid=8ED78D89F1ED9755F19340C0A7EC225C?sequence=1

Azizpour, F., Moghimi, S., Salleh, E., Mat, S., Lim, C.H., Sopian, K. (2013). "Thermal comfort assessment of large-scale hospitals in tropical climates: A case study of University Kebangsaan Malaysia Medical Centre (UKMMC)". *Energy and Buildings*, 64, 317–322. https://doi.org/10.1016/j.enbuild.2013.05.033

Baird, G. (1969). "Air change and air transfer in a hospital ward unit". *Building Science*, 3, 113-124.

Borgeson, S. & Brager G. (2008). *Occupant control of windows: accounting for human behaviour in building simulation.* Berkeley: Center for the Built Environment (CBE). https://escholarship.org/uc/item/5gx2n1zz

Cândido, C., de Dear. R., Lamberts, R. (2011). "Combined thermal acceptability and air movement assessments in a hot humid climate". *Building and Environment,* 246(2), 379-385. https://doi.org/10.1016/j.buildenv.2010.07.032

Carmichael, C., Bickler, G., Kovats, S., Pencheon, D., Murray, V., West, C., Doyle, Y. (2013). "Overheating and hospitals – What do we know"? *Journal of Hospital Administration*, 2 (1), 1-8. http://www.sciedupress.com/journal/index.php/jha/article/view/1651

Chartered Institution of Building Services Engineers (CIBSE) (2006). *Environmental Design CIBSE Guide A*. Chartered Institution of Building Services. https://www.academia.edu/15694416/Environmental_design_CIBSE_Guide_A

De Giuli, V., Zecchin, R., Salmaso, L., Corain, L., De Carli, M. (2013). "Measured and perceived indoor environmental quality: Padua hospital case study". *Building and Environment*, 59, 211–226. https://doi.org/10.1016/j.buildenv.2012.08.021

Derks, T.H., Mishra, A.K., Loomans, M.G.L.C., Kort, H.S.M. (2018). "Understanding thermal comfort perception of nurses in a hospital ward work environment". *Building and Environment*, 140, 119–127. https://doi.org/10.1016/j.buildenv.2018.05.039

Eijkelenboom, A.M. and Bluyssen, P. (2019). "Comfort and health of patients and staff related to the physical environment of different departments in hospitals: a literature review". *Intelligent Buildings International.* https://doi.org/10.1080/17508975.2019.1613218

Ferraro, S.D., Iavicoli, S., Russo, S., Molinaro, V. (2015). "A field study on thermal comfort in an Italian Hospital considering differences in gender and age". *Applied Ergonomics*, 50, 177–184. https://doi.org/10.1016/j.apergo.2015.03.014

Hoyt, T., Schiavon, S., Piccioli, A., Cheung, T., Moon, D., Steinfeld, K. (2017). *CBE thermal comfort tool, center for the Built Environment, University of California Berkeley.* https://comfort.cbe.berkeley.edu/

Khalid, W., Zaki, S. A., Rijal, H. B., Yakub, F. (2019). Investigation of comfort temperature and thermal adaptation for patients and visitors in Malaysian hospitals. *Energy and Buildings*, 183 (4), 84–99. https://doi.org/10.1016/j.enbuild.2018.11.019

Kigali Cooling Efficiency Program. (2018). *Global Climate Impact from Hospital Cooling*. Kigali Cooling Efficiency Program. https://www.k-cep.org/wpcontent/uploads/2018/10/Kigali_CEP_GlobalHospitalCooling_102418.pdf

Keyhole, Inc. (2001). Google Earth [Computer software]. Google.

Koettek, M., Grieser, J., Beck, C., Rudolf, B. and Rubel, F. (2006). "World map of Köppen- Geiger climate classification updated". *Meteorologische Zeitschrift*, 15, 259-263. https://www.weather.gov/media/jetstream/global/Koppen-Geiger.pdf

Koutroumpi, Stavroula K. (2020). Identifying gaps of knowledge about thermal comfort in naturally ventilated wards in hot-humid settings. *Global Journal of Engineering Sciences*, vol.6 (2),2020. https://irispublishers.com/gjes/abstract/identifying-gap-of-knowledge-about-thermal-comfort-in-naturally-ventilated-wards-in-hot-humid.ID.000632.php

Lehmann, E.L., (2006). *Nonparametric: Statistical Methods Based on Ranks*. Springer-Verlag.

McHugh, M. (2018). "Cramér's V coefficient", in Frey, B. B. *The SAGE encyclopaedia of educational research, measurement, and evaluation*. SAGE Publications, Inc.

Chu, S. and A. Majumdar (2012). "Title of examples for journal papers reference style". *Nature*, 488(2), 294–303. https://doi.org/10.1111/bjh.16749

Chu, S. and A. Majumdar (2012). "Title of examples for journal papers reference style". *Nature*, 488(2), 294–303. https://doi.org/10.1111/bjh.16749

Nematchoua, M. K., Ricciardi, P., Reiter, S., Asadi, S., Demers, C. M.H. (2017). "Thermal comfort and comparison of some parameters coming from hospitals and shopping centres under natural ventilation: The case of Madagascar Island". *Journal of Building Engineering*, 13, 196-206. https://doi.org/10.1016/j.jobe.2017.07.014

Pourshaghaghy, A. and Omidvari, M. (2012). "Examination of thermal comfort in a hospital using PMV–PPD model". *Applied Ergonomics*, 43 (6), 1089–1095. https://doi.org/10.1016/j.apergo.2012.03.010

QSR International (2017). NVivo 11 [Computer software].

Sattayakorn, S., Ichinose, M., Sasaki, R. (2017). “Clarifying thermal comfort of healthcare occupants in tropical region: A case of indoor environment in Thai hospitals”. *Energy and Buildings*, 149, 45-57. https://doi.org/10.1016/j.enbuild.2017.05.025

Shi, Z., Qian, H., Zheng, X., Lv, Z., Li, Y., Liu, L., Nielsen, P. V. (2018). “Seasonal variation of window opening behaviours in two naturally ventilated hospital wards”. *Building and Environment*, 130, 85–93. https://doi.org/10.1016/j.buildenv.2017.12.019

Short, C.A., Lomas, K.J., Giridharan, R., Fair., A.J. (2012). Building resilience to overheating into 1960s UK hospital buildings within the constraint of the national carbon reduction target: adaptive strategies. *Building and Environment*, 55, 73–95. https://doi.org/10.1016/j.buildenv.2012.02.031

StataCorp LLC (2019). STATA (SE 16) [Computer software].

Sterling, E.M., Arundel, A, Sterling, T.D. (1985). Criteria for human exposure to humidity in occupied buildings (part 1). *AHRAE Transactions*, 91 (1), 612-622. http://sterlingiaq.com/photos/1044922973.pdf

Verheyen, J., Theys, N., Allonsius, L., Descamps (2011). “Thermal comfort of patients: objective and subjective measurements in patient rooms of a Belgian healthcare facility”. *Building and Environment*, 46, 1195–1204. https://doi.org/10.1016/j.buildenv.2010.12.014

World Health Organization. (2015). *Operational framework for building climate resilient health systems*. World Health Organization. http://webcache.googleusercontent.com/search?q=cache:QjytSRM8yzQJ:https://www.who.int/activities/supporting-countries-to-protect-human-health-from-climate-change/climate-resilient-health-systems&hl=en&gl=uk&strip=0&vwsrc=0

World Health Organisation. (2020). *Guidance for Climate-Resilient and Environmentally Sustainable Health Care Facilities*. Geneva. https://www.who.int/publications/i/item/9789240012226

Wright, D.B. & London, K. (2009). *First (and second) steps in statistics (2nd ed.)*. SAGE Publications

Wright, C.Y., Street, R.A., Cele, N., Kunene, Z., Balakrishna, Y., Albers, P.N. (2017). Indoor temperatures in patient waiting rooms in eight rural primary health care centres in Northern South Africa and the related potential risks to human health and wellbeing. *International Journal of Environmental Research and Public Health*, 14 (1), 1-11. https://res.mdpi.com/ijerph/ijerph-14-00043/article_deploy/ijerph-14-00043.pdf

	A.T.S.V.	A.T.C.V.	A.T.P.V.	A.R.H.S.V.	A.R.H.C.V.	A.R.H.P.V.	A.W.S.S.V.	A.W.S.P.V.
Opening windows								
Patients rainy season (n=50)						0.70 (5) (p.value<0.001)	0.54 (4) (p.value<0.01)	0.45 (2) (p.value<0.01)
Opening doors								
Nurses dry season (n-146)	0.38 (6) (p.value<0.01)	0.30 (3) (p.value<0.01)	0.51 (5) (p.value<0.001)		0.32 (3) (p.value<0.01)		0.42 (5) (p.value<0.001)	
Switching on fans								
Patients dry season (n=137)		0.52 (4) (p.value<0.001)	0.42 (5) (p.value<0.001)		0.43 (4) (p.value<0.001)	0.27 (4) (p.value<0.001)	0.37 (5) (p.value<0.01)	
Water consumption								
Patients dry season (n=50)				0.52 (5) (p.value<0.01)				
Visitors rainy season (n=48)			0.51 (4) (p.value<0.01)					
Food consumption								
Patients rainy season (n=50)	0.50 (5) (p.value<0.01)			0.56 (5) (p.value<0.01)	0.49 (3) (p.value<0.01)	0.66 (5) (p.value<0.001)		0.47 (2) (p.value<0.01)

Red for very strong correlations (0.70) I Pink for strong correlation (0.50-0.69) I Light pink for moderate correlation (0.30-0.49) I Light blue for weak correlation (0.20-0.29)

Figure 5. Matrix of Cramer's V effect size in statistically significant bivariate correlations between thermal comfort votes and adaptive behaviours in different samples of occupant types who participated in the T.C.Is. Source: Author.

	Top.(spot)(ºC)		R.H.(spot)(%)		W.S.(spot)(m/s)	
	median dif.	Wilcoxon rank-sum test	median dif.	Wilcoxon rank-sum test	median dif.	Wilcoxon rank-sum test

Overall (n=730)	-0.05	do not reject Ho (exact Prob.>0.05)	2.19	reject Ho (exact Prob.<0.001)	0.09	reject Ho (exact Prob.<0.001)
Total satisfied with environmental controls (n=578)	-0.14	do not reject Ho (exact Prob.>0.05)	2.59	reject Ho (exact Prob.<0.001)	0.09	reject Ho (exact Prob.<0.001)
Total close (<=1.50m) to a window area with open windows(n=338)	-0.22	do not reject Ho (exact Prob.>0.05)	3.26	reject Ho (exact Prob.<0.001)	0.08	reject Ho (exact Prob.<0.001)

Figure 7. Results of the Wilcoxon rank-sum test (Ho: null hypothesis of equality in variance) between the nurses and the rest of the hospital occupants, who participated in the T.C.Is., in three different samples of the Top.(spot)(^{0}C), R.H.(spot)(%) and W.S.(spot)(m/s) values . Source Author.

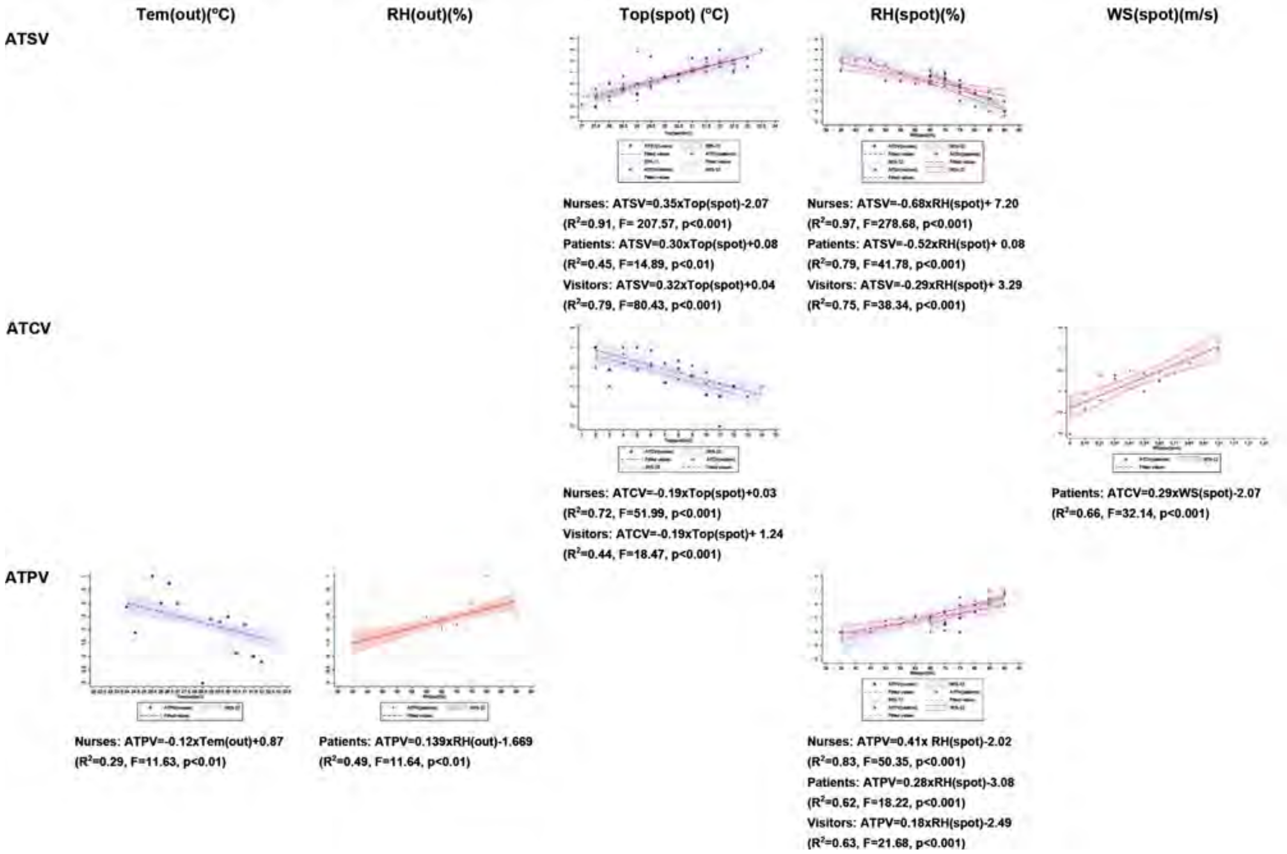

Figure 8. Scatterplots with fitted lines (95% confidence bands) of linear regression between the reported thermal comfort votes from nurses, patients and visitors and the recorded environmental conditions. The data have been grouped into bins. Source Author.