Thermal environment perceptions considering length of stay for cardiovascular inpatients in hospitals: a statistical approach

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Abstract. Cardiovascular patients are one of the highest population groups affected by elevated external temperatures. Many research studies highlight the impact of three main indicators: mortality rates, morbidity, and admissions to hospitals. Most research determined that cardiovascular patients were among the top admissions to hospitals. The external temperature needs to be evaluated while the patients are hospitalised to reveal the extent of its impact. This study also seeks to evaluate the impact of the length of stay periods on the perceived thermal environment of cardiovascular inpatients when the external temperatures are elevated particularly in summer periods. To do so, longitudinal data analysis of indoor air temperatures, relative humidity and outdoor air temperatures linked with recorded patients’ responses, was undertaken for three months in cardiology and cardiac surgery wards in a hospital in Saudi Arabia, i.e. a hot, arid desert climate (BWh) based on the Köppen Geiger climate zones map. Patient questionnaires were administrated during the daytime, specifically the afternoon hours to obtain the best results when outdoor temperatures exceeded 40°C. The gathered data was analysed using several statistical tests for correlations and differences to validate the results. The patients who were hospitalised for more than one week and one month felt more neutral compared to other shorter periods of stay; this was interpreted as patients having sufficient time acclimatise to their environment.

1. Introduction
1.1. Impact of climate change on health
Rising global environmental temperatures due to climate change is an acknowledged phenomenon that threatens human health on many levels. Research shows that anticipated adverse effects on health are substantial with prolonged exposure to elevated indoor environmental temperatures linked to increased heat-related mortality. The severity of the direct and indirect impacts of climate change on ill health may be classified as high, medium, and low as summarised by the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) in 2014 [1]. In recent years, the variation in global climatic conditions has contributed significantly to health issues across the world. However, cases of health concerns resulting from changes in climate are relatively small compared to cases resulting from other stressors, although it is not appropriately quantified. Increasing temperatures have increased the risk of heat-related illness and deaths [1].

Climate change not only affects the air temperature but is unbounded to other weather variables such as humidity, barometric pressure and ultraviolet radiation (UV-R). Thus, it is still unclear why elevated external temperature changes reveal consistent adverse health across regions around the world [2]. The IPCC report is a substantial resource that shows the direct impact of climate change on human health. Several indicators have been used in the interdisciplinary research to quantify the consequences of climate change on human health, namely, mortality rates including heat-waves [3], and [4], morbidity including heat-related illness [5], and [6] and increasing admission rates to hospitals when the outdoor temperatures increased [7].

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1.2. The Effect of extreme temperatures on cardiovascular patients

Extremes of temperature are described in the literature using a number of different terms such as elevated, high, increased, or extreme temperatures on the hot side, and cold, moderate, temperate on the cold side, often resulting in significant ambiguity. Studies have shown that these anticipated health effects are substantial, and the consequences extend to indoor exposure. The most vulnerable groups are infants, the elderly, people suffering from cardiac or respiratory diseases, and people in non-air-conditioned spaces [8]. Sudden elevation of the environmental temperature are linked to increases in heat-related mortality, but biological and social adaptation is most difficult in areas that experience dynamic changes in climate conditions compared to areas with stable conditions [1].

Since the focus of this paper is on the significant impacts of hot climates on cardiovascular patients, the consequences of rising temperatures due to climate change in indoor environments are obvious in some cases but need more investigation in occupied buildings. Temperature bands in warm climates must be determined in terms of their risks and whether the findings may be applied to other climates. Regarding the most sensitive type of buildings, such as hospitals, more efforts are required to evaluate the consequences inside the hospital for patients during hospitalisation and how patient thermal comfort levels are linked to rising outside temperatures.

1.3. Objectives

This research investigates the impact of length of stay on perceived indoor air temperatures (Tₐ), the thermal sensation vote (TSV), and the thermal preference vote scale (TPV) for cardiovascular patients during hospitalisation. To do so, the first priority is to isolate indoor temperatures as a dominant variable when determining thermal comfort in hospitals by attempting to record the (TSV) for inpatients and linking them to length of stay periods. Hence, the length of stay (LoS) bands might affect the (Tₐ), and whether the patients are more acclimatized to the indoor environment when they stay longer than those who stay for shorter periods. In patient rooms, more specifically, hot climates and the resulting indoor environment will reveal the major issues that patients encounter during their hospitalisation regarding thermal environment. The objectives of this study are:

(1) To determine if inpatients are enabled to achieve acceptable thermal comfort levels during the daytime by comparing the TSV, TPV with Tₐ and LoS, and,

(2) To measure inpatient satisfaction with their thermal environment.

2. Methodology

The prediction of optimal thermal comfort temperatures in HVAC controlled buildings can be determined through three methods according to de Dear and Barger [9]. This study endeavoured not to link the outdoor climate with the indoor climate. The presented outdoor data was just to support the literature that shows the link between increasing outdoor temperatures and particular groups of patients such as cardiovascular patients. Regarding the common used index, the Predicted Mean Vote (PMV) devised by Fanger in early 1970s, has many limitations especially in sensitive environments such as hospitals although it was not devised for non-healthy populations in its original form. Assessment of thermal comfort in hospitals among different occupants, including patients, has encountered several issues especially when the PMV model is examined for patients due to the acuity of medical conditions, low activity rates, and reduced clothing. So, this study sought to link the LoS bands to the thermal sensation scale (TSV) mentioned in ASHRAE-55 and the Bedford preference scale [10].

2.1. Location and climate

This study was undertaken at the King Abdullah Medical City (KAMC), Makkah, Saudi Arabia during May, June, July, and August in 2018. The KAMC was selected due to the specialist cardiac and cardiology surgery wards in this medical centre. Makkah meets the climatic characteristics of a hot, arid desert climate (BWh) on the Köppen Geiger climate zones map [11]. The annual mean temperature was 31.9°C while the mean maximum/minimum temperatures were 38.6/25°C between June and August 2018. The average humidity was 46% and varied from 34% (June) to 60% (December) in the same year.
2.2. Physical measurements
Longitudinal data analysis of the indoor air temperature ($T_a$) °C, and indoor relative humidity (Rh) % were recorded simultaneously with subjective responses for three consecutive summer months (June, July, and August) in 2018. Raspberry Pi +3 data-loggers were installed in 15 patient rooms in cardiology and cardiac surgery wards. The outdoor temperature and outdoor humidity were monitored by a weather station mounted at the top of facilities management building, a few minutes walking from the selected wards. A summary of both indoor/outdoor environmental data during the study periods is presented in (Table 1).

| Parameter | $T_a$ (°C) | Rh % | $T_{out}$ (°C) | Rh$_{out}$ % |
|-----------|------------|------|---------------|--------------|
| June      | 24.3 ± 2.5 | 30.1 ± 7.6 | 39 ± 5.1 | 23.4 ± 7.9 |
| July      | 23.8 ± 1.7 | 36.8 ± 8.3 | 37.1 ± 4.9 | 25.3 ± 15.5 |
| August    | 23.9 ± 2.1 | 34.5 ± 4.3 | 37.2 ± 4.5 | 24.7 ± 12.2 |

$T_{out}$: outdoor temperature, Rh$_{out}$: outdoor relative humidity.

2.3. Subjective measurements
The research proposal was approved by the Institutional Review Board (IRB) in KAMC, and informed consent was sought from each patient or his/her relative in case of difficulty in reading or writing. Questionnaires were handed to patients in the first instance to answer the questions, and in case of inability to write, the patients were interviewed either by the researcher or his/her accompanying relative. The questionnaire was developed based on different common indices and scales according to ASHRAE-55 [12] and ISO 7730:2005 [13]. It was originally written in English and then translated into Arabic, the predominant language of the majority of patients. Table 2 and 3 list the patients involved in the study based in their willingness to participate, and also indicates the duration of their stay in hospital.

| Age group | 18-24 | 25-34 | 35-44 | 45-54 | 55-64 | 65-74 | 75 or older | Total |
|-----------|-------|-------|-------|-------|-------|-------|-------------|-------|
| Male      | 1     | 2     | 7     | 12    | 15    | 10    | 4           | 51    |
| Female    | 0     | 2     | 3     | 1     | 7     | 7     | 2           | 22    |
| Total     | 1     | 4     | 10    | 13    | 22    | 17    | 6           | 73    |

| Bands     | 1 day | 2-3 days | 4-6 Days | > week | > month |
|-----------|-------|-----------|-----------|--------|--------|
| Patients (n) | Male | 2         | 15        | 8      | 22     | 4       |
| Female    | 3     | 4         | 7         | 7      | 1      |         |

2.4. Thermal sensation vote (TSV) and Thermal preference vote (TPV)
The indoor environment was considered to be thermally comfortable if the total percentage of occupant votes (TSV) was 80% or more in the vicinity of (-1 ≤ TSV ≤ +1). The ASHRAE-55 [12] TSV ordinal scale has seven-points from -3 to +3 as shown in table 4, and is most widely used to predict the occupant perception of their thermal environment. The TSV also has been incorporated in the international indoor human occupancy standards such as ISO 7730:2005 [13]. On the other hand, the TPV ordinal scale was developed by Bedford in his work in 1958 [10].
3. Results and discussion

Several statistical tests for parametric and non-parametric analysis were applied to measure the strength of the correlations and to determine the statistically significant differences between the group means. The LoS was also examined with $T_a$, TSV, and TPV to identify any potential relationships for more detailed investigation.

3.1. The relationship between TSV, TPV and $T_a$

In order to assess the relationship between TSV and $T_a$, a simple linear regression was applied to the data to measure the linearity (Fig. 1a). The TSV had a poor correlation with $T_a$ by computing the Pearson test for parametric data ($r = 0.00$) so $T_a$ is not an appropriate predictor variable of the TSV to generate a suitable equation to estimate the neutral temperature for the selected population. Figure 1a shows patient votes were randomly distributed around all the TSV units without any obvious influence from $T_a$. This disparity demonstrated that patients had dissimilar thermal needs during their treatment and recovery, and the votes just expressed their immediate responses to their room temperatures at the moment of completing the questionnaire. For the TPV, patients who voted (0) neutral point, were unlikely to require any changes in their surrounding temperature [14]. As expected, the TPV showed no significant correlation with $T_a$ ($r = 0.00$) (figure 2b). Thus, $T_a$ essentially varied from the mean of 24.12 °C with a standard deviation of 2.87. Since this study was conducted during the hot summer months, the effect of selected months (June, July, and August) was investigated by classifying the patients votes by month. This showed that the influence of the month was very small with an insignificant $p$-value $> 0.05$ for either TSV or TPV.

![Figure 1. Linear regressions models for TSV, TPV with $T_a$ (95% confidence bands).](image-url)
3.2. The relationship TSV, TPV and LoS
Prior to linking the TSV and TPV to the LoS, $T_a$ was appraised among LoS categories to reveal any significant differences in the mean $T_a$ of each LoS category. To do so, a one-way ANOVA test was applied to determine any significant differences in the means of each group or band. No statistically significant differences were noticed as the p-value was higher than 0.05 indicating that the alternative hypothesis was accepted. Due to the common issue of the ordinal scale, the Kruskal-Wallis difference test for non-parametric analysis was applied using the TSV as a dependent variable DV and LoS as an independent variable IV over five bands. As a result, there were statistically significant differences among the LoS bands for patients ($H(4)= 18.37$, p-value $< 0.00$) where $H$ refers to the statistical difference and number (4) represents the degree of freedom ($K - 1$, $K$ number of category levels). This meant that patients felt comfortable around the (0) neutral point when they stayed for longer periods, (Figure 2a) indicating that the 2-3 day, 4-6 day, > week, and > month categories were very close to the neutral point of the TSV, respectively. Longer stays gave the patients an opportunity to adapt to their environment because the slow adaptability of patients considering their different treatment and recovery stages. In contrast, the TPV did not yield any major differences in the LoS categories by repeating the Kruskal-Wallis test ($H(4)= 1.58$, p-value = 0.81). It is reasonable that every patient wishes to select (4) comfortable on the TPV (Fig. 1b) but the differences in the TSV were attributed to patients actual feeling once the questionnaire was filled out. For sub-samples such as the impact of gender on the LoS, the Wilcoxon rank sum test was applied to reveal if males or females experienced more rapid acclimatization processes, but the results indicated the distinction among gender type was not significant (p-value = 0.36).

![Figure 2. Strip plots for TSV and TPV with LoS.](image)

3.3. Comfort temperature bands
93% of patients rated the indoor environment is comfortable and thermally satisfied meaning that the neutrality temperature bands ($20.63 - 26.62^\circ C$) for cardiovascular patients during hospitalisation were defined based on the TSV votes that were in the range of (-1 ≤ TSV ≤ +1). Thermal acceptability and distribution of votes are shown for reference in table 5.

| Scale unit | -3 | -2 | -1 | 0  | +1 | +2 | +3 |
|------------|----|----|----|----|----|----|----|
| Number of votes | --- | 4  | 24 | 21 | 23 | 1  | --- |

Table 5. Votes distribution among each unit scale. (bold: refers to acceptability limits.)
4. Conclusion
This study attempted to highlight the impact of cardiovascular patients’ length of stay (LoS) on their experience of the indoor environment by environmental monitoring of indoor air temperature and relative humidity in parallel with completing the questionnaires during the hot summer periods of Makkah in Saudi Arabia. Patients who stayed longer were more acclimatised to the indoor environment while the preference scale did not support the relationship to the LoS categories. 93% of votes reported that the patients were comfortable during hospitalisation, thus the cardiac and cardiac surgery wards met the requirements of acceptable indoor human occupancy in ASHRAE-55 and ISO 7730:2005 while neglecting Fanger’s model where doubts are expressed in the literature about its suitability to assess the thermal comfort of non-healthy populations.

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