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Analytical and subjective interpretation of thermal comfort in hospitals: A case study in two sterilization services

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ABSTRACT

Hospital facilities are normally very complex, which combined with patient requirements promote conditions for potential development of uncomfortable working conditions. Thermal discomfort is one such example. This study aimed to determine levels of thermal comfort, sensations, and preferences, from a field investigation conducted in two sterilization services (SS) of two hospitals from Porto and Aveiro, Portugal. The analytical determination and interpretation of thermal comfort was based upon assumptions of ISO 7726:1998 and ISO 7730:2005. The predicted mean vote (PMV) and predicted percentage of dissatisfaction (PPD) indices were obtained by measurement and estimation of environmental and personal variables, respectively, and calculated according to ISO 7730 equations. The subjective variables were obtained from thermal sensation (subjective PMV) and affective assessment (subjective PPD), reported by a questionnaire based upon ISO 10551:1995. Both approaches confirmed thermal discomfort in both SS (codified as SS1 and SS2). For all areas, PMV and PPD exceeded in all periods of the day the recommended range of -0.5 to $+0.5$ and $<10\%$, respectively. No significant differences were found between day periods. The questionnaire results showed that SS2 workers reported a higher level of thermal discomfort. There were no significant differences between PMV and thermal sensations, as well as between PPD and affective assessment. The PMV/PPD model was found suitable to predict thermal sensations of occupants in hospital SS located in areas with a mild climate in Portugal.

Hospitals are particular workplaces, designed almost exclusively to the needs of users, often causing their workers to suffer from poor environmental working conditions (Carvalhais et al., 2011). Hospitals are complex facilities due to various types of uses of indoor spaces (Balaras et al., 2007). In a paradoxical way, the hospital environment has risks that may pose immediate threats, subsequently producing sooner or later health problems to individuals who maintain direct contact and/or daily life within this environment. The work in hospitals is likely to damage health, resulting in occupational accidents and diseases. It is well established that inappropriate thermal comfort conditions in a building do not usually produce serious illness but exert a significant impact on well-being and daily performance of its occupants (Mendes et al., 2014), leading to greater

work inefficiency and higher possibility of personnel errors occurring.

The occupants of hospitals have different thermal comfort requirements. The most important consideration is patient welfare, but others include health care staff and visitors. At times, any or all of these populations may occupy the same space (Lomas and Giridharan, 2012). The proper setting of thermal comfort parameters provides a suitable environment for personnel (Pourshaghaghyan and Omidvari, 2012). Some investigators examined the desired thermal conditions for hospital occupants, including patients and health care professionals (Fransson et al., 2007; Skoog et al., 2005). To satisfy as many people as possible, common indices are used, such as the predicted mean vote (PMV) (Hoof et al., 2010; International Organization for Standardization [ISO], 2005) and the predicted percentage of

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dissatisfaction (PPD) (Hoof et al., 2010; ISO, 2005), being most frequently used in current standards to assess and predict general, or whole-body, thermal comfort (Hoof et al., 2010). Despite an increasing number of studies in the thermal environment field, data on indoor thermal comfort conditions for hospital occupants are sparse (Khodakarami and Nasrollahi, 2012). Some studies compared questionnaire results with the PMV–PPD model, and Verheyen et al. (2011) noted that this model was capable of adequately predicting thermal sensation in a hospital context.

In Portugal, the parameters specified in national legislation relating to thermal environment in occupational context are restricted to values of temperature and humidity, recommended by Decree Law No 243/86 of August 20, 1986. Other related legislated parameters are more focused on energy consumption as opposed to occupational comfort of occupants. It is known that inadequate thermal environments aggravate the impact of air pollutants on occupants' health (Mendes and Teixeira, 2014) and, in some cases, promote the presence of contaminants in the air to be inhaled (Mendes et al., 2014). In hospitals, sterilization services (SS) are areas where health risks associated with mixed exposures may potentially occur, due to the use of steam, temperature, and chemicals such as ethylene oxide (EO), among other methods, in the sterilization process. In addition to the legal compliance of legislated thermal parameters, this study aimed to determine levels of thermal comfort by using objective and subjective approaches in two hospital SS.

Materials and methods

Sterilization Services (SS)

This field study was carried out in two SS of two hospitals from Porto and Aveiro districts, Portugal (SS1 and SS2), during summer seasons of 2012 and 2014, respectively. Structural and functional characterization of the SS was made. Both SS have centrally controlled heating, ventilating, and air conditioning (HVAC) systems. In SS1 the floor is concrete with vinyl covering, walls are covered with tiles, and the roof is concrete with a plasterboard false ceiling. In SS2 the roof is concrete with

a plasterboard false ceiling and the floor and walls are tiled. In both hospitals, this service centralizes the sterile processing activities, in which reusable medical devices, surgical instruments, and equipment are processed and issued for diagnostic and surgical patient care procedures. In the receiving, decontaminating, and cleaning areas, all contaminated instrument sets are brought following initial cleaning and prepared for decontamination. Instruments are cleaned and prepared for final decontamination process in a washer-decontamination unit. Both SS have a pass-through capability from the receiving/decontamination area into the assembly area. In the assembly area instruments are assembled into sets, placed in sterilization containers or packs, and prepared for the sterilization process. In the sterilization area, packaged instrument sets from the assembly area are loaded onto sterilization transport carts, placed into sterilizer units, carts are removed from the sterilizer, and items are allowed to dry and cool. Then sterile items are transported to the sterile storage area.

Both SS use steam and EO for sterilization. The use of saturated steam under pressure in an autoclave achieves the destruction of microorganisms by the irreversible denaturation of enzymes and structural proteins (Rutala and Weber, 2004). The temperature at which denaturation occurs varies inversely with the amount of water present. Sterilization in saturated steam is the most frequently used sterilization method in hospitals and requires precise control of time, temperature, and pressure. Regarding EO, its efficiency depends on the concentration of gas, humidity, time of exposure, temperature, and nature of the load. In particular, it is necessary to ensure that the nature of the packaging is such that the gas exchange occurs. It is also important to maintain sufficient humidity during sterilization and also to record the gas concentration, temperature, and humidity for each cycle. This sterilization method is mainly used for heat-sensitive material, but due to the highly flammable and potentially explosive nature of EO, in addition to toxicity and carcinogenicity (Rutala and Weber, 2004), the whole process needs to be controlled and considered a specific assessment of occupational exposure.

The measurements were performed in three areas (decontaminating area [A], cleaning and assembly area [B], and sterilization area [C]), in three periods of the day (morning, afternoon, and night). Those areas were chosen because workers stay there most of their work time. The SS1 operates continuously and has three shifts (8 a.m.–2 p.m., 2 p.m.–10 p.m., and 10 p.m.–8 a.m.); SS2 has two shifts (8 a.m.–2 p.m. and 2 p.m.–10 p.m.).

Analytical assessment of thermal comfort

For the calculation of PMV index (which predicts the mean response of a larger group of people according to 7-point thermal sensation scale) and PPD index (a quantitative measure of thermal comfort of a group of subjects at a particular thermal environment) (ISO, 2005), environmental and personal parameters were determined (by measurement and estimation, respectively) at the same time, following ISO 7730:2005 and ISO 7726:1998. The areas as a homogeneous and steady-state environment were tested according ISO 7726:1998 (ISO, 1998) specifications with a TSI 8345-M-GB thermo-anemometer. Based on this analysis of environments classification, measurements of environmental variables followed the recommendations of ISO 7726:1998 for positioning of measuring equipment. Moderate environments (class C comfort standard) were considered. In SS1, measurements of the environmental variables were conducted with a Delta Ohm HD32.1 data logger that measured air velocity (v_{ar}), relative humidity (RH), dry bulb temperature (t_a), and globe temperature (t_g) and in SS2 measurements were performed with a TSI 8345-M-GB thermo-anemometer (v_{ar}) and a Quest Area Heat Stress Monitor model HS-32 (t_a , t_g , RH). All the equipment was calibrated in an accredited calibration lab and the criteria specified in ISO 7726:1998 were accomplished. The equipment was placed taking into account the activities performed in each area at a height of 0.6 m above the floor (sitting, abdomen level) or 1.1 m (standing, abdomen level), with the sampling points no closer than 1 m to a wall, a window, or a door. After 20 min of equipment stabilization in each area, measurements were recorded over 10 min. The personal parameters were estimated according to ISO

7730:2005 (ISO, 2005) and confirmed by observation. Occupants' daily activity was considered to be a metabolic rate (M) of 1.6 met.

In a hospital environment, staff clothing is predefined and thus presumed similar. Their clothing was considered to have a thermal insulation (I_{cl}) of 0.7 clo (underpants, working uniform [shirt and trousers], socks, shoes). PMV and PPD indices and mean radiant temperature (t_r) were calculated by a validated computer program for calculating PMV and PPD, based on Annex D of the ISO 7730:2005 (ISO, 2005).

Subjective assessment of thermal comfort

Assessment of subjective variables was based on responses to a questionnaire survey, which was administered simultaneously with the environmental variables measurements. In total, 37 respondents participated in the survey in both hospitals (all health care staff members who were developing their activities during the monitoring period, corresponding to a response rate of 100%). Subjective data were recorded using a questionnaire based on ISO 10551:1995 (ISO, 1995). The questionnaire developed for this survey was divided into three main sections containing a total of 11 questions: (1) demographic information; (2) judgment of personal thermal state (thermal sensation, thermal preference and affective assessment); and (3) judgment of thermal ambience (personal acceptability and personal tolerance). The dominant gender of the sample was female (56.76%). The average age of the sample was 44.68 years.

Statistical analysis

All tests considered a 95% confidence interval. The normality Shapiro–Wilk test, the Student's t -test for paired samples, and analysis of variance (ANOVA) were applied. The software IBM SPS (Statistical Package for the Social Sciences) 20th version and MS Excel 2013 were used for the analysis.

Results

Table 1 presents the calculated values of PMV and PPD indices and other thermal parameters by day period in both SS. The t_a values ranged from 23.4°C (morning) to 25.4°C (night) in SS1 and from 24.8°C (night) to 25.6°C (afternoon) in SS2.

Table 1. Environmental parameters and PMV/PPD indices by hospitals and areas.

| Area | Day period | Air temperature (°C) | | Relative humidity (%) | | Air velocity (m/s) | | PMV | | PPD (%) | |
|------|---|--|--------------|--------------------------------|-------------|--------------------------------|-------------|--------------------------------|------|--------------------------------|------|
| | | SS1 | SS2 | SS1 | SS2 | SS1 | SS2 | SS1 | SS2 | SS1 | SS2 |
| A | Morning | 23.70 ± 0.20 | 24.92 ± 0.15 | 55.4 ± 1.20 | 58.5 ± 0.96 | 0.17 ± 0.16 | 0.03 ± 0.05 | 0.83 | 1.10 | 19.5 | 30.3 |
| B | | 23.40 ± 0.10 | 25.51 ± 0.04 | 58.6 ± 0.60 | 57.3 ± 1.09 | 0.16 ± 0.12 | 0.02 ± 0.03 | 0.77 | 1.18 | 17.6 | 34.4 |
| C | Afternoon | 25.50 ± 0.10 | 25.00 ± 0.11 | 53.3 ± 0.90 | 57.8 ± 0.97 | 0.03 ± 0.05 | 0.01 ± 0.02 | 1.08 | 1.08 | 29.8 | 29.6 |
| A | | 24.40 ± 0.50 | 25.60 ± 0.20 | 51.8 ± 2.30 | 56.9 ± 1.48 | 0.16 ± 0.12 | 0.06 ± 0.07 | 0.86 | 1.17 | 20.6 | 33.6 |
| B | Night | 24.30 ± 0.30 | 25.52 ± 0.09 | 51.7 ± 1.20 | 56.4 ± 0.67 | 0.16 ± 0.14 | 0.05 ± 0.06 | 0.87 | 1.16 | 21.0 | 33.3 |
| C | | 24.20 ± 0.10 | 25.41 ± 0.85 | 54.8 ± 0.50 | 57.7 ± 0.48 | 0.09 ± 0.04 | 0.09 ± 0.12 | 1.00 | 1.00 | 26.2 | 26.1 |
| A | Difference between day periods Evaluation criteria | 25.40 ± 0.10 | 25.19 ± 0.03 | 56.3 ± 1.10 | 53.9 ± 0.76 | 0.13 ± 0.08 | 0.06 ± 0.05 | 0.98 | 1.10 | 25.3 | 30.6 |
| B | | 24.00 ± 0.20 | 24.81 ± 0.03 | 57.3 ± 1.10 | 54.6 ± 0.80 | 0.19 ± 0.17 | 0.04 ± 0.06 | 0.84 | 1.15 | 20.0 | 33.0 |
| C | | 24.80 ± 0.40 | 25.52 ± 0.40 | 55.6 ± 1.60 | 56.8 ± 1.59 | 0.11 ± 0.09 | 0.00 ± 0.00 | 0.93 | 1.17 | 23.2 | 33.9 |
| | | Not significant ($p = .775$) | | Not significant ($p = .297$) | | Not significant ($p = .700$) | | Not significant ($p = .962$) | | Not significant ($p = .963$) | |
| | | 18–22 ^a (25 ^b) | | 50–70 ^a | | <0.20 ^b | | –0.5 to +0.5 ^c | | <10 ^c | |

Note. Values are mean ± SD (standard deviation).

^a DL No 243/86 of August 20, 1986 (Portuguese Legislation).

^b CR 1752 (European Committee for Standardization, 1998).

^c ISO 7730:2005 (Category B) (International Organization for Standardization, 2005).

^d Under specific climatic conditions.

Regarding RH values, in SS1 these ranged from 51.7 (afternoon) to 58.6% (morning) and in SS2 from 53.9 (night) to 58.5% (morning). The v_{ar} values varied from 0.03 to 0.19 m/s in SS1 and from nondetectable to 0.09 m/s in SS2.

Results regarding PMV/PPD, ranged from 0.77/17.6% (morning) to 1.08/29.8% (morning) in SS1 and from 1/26.1% (afternoon) to 1.18/34.4% (morning) in SS2. By utilizing a seven-sensation scale, the predicted thermal sensation through the analytical approach in both SS was “slightly warm.” There were no significant differences between day periods for all environmental variables and PMV/PPD indices given in Table 1. Regarding the subjective approach, Figure 1 and Figure 2 show the thermal sensations and thermal preferences, referred by participants in both SS, respectively. Concerning thermal sensation, Figure 1 demonstrated that workers tend to feel more comfortable in SS1 than in SS2 (46.1 SS1 vs. 0% SS2); “slightly warm” sensation was reported more often by SS2 workers (31.8 SS1 vs. 44.5% SS2), followed by “warm” sensation (11.1 SS1 vs. 44.4% SS2). In relation to the thermal preferences during the same period, the majority of SS2 workers, preferred to change the environment to “slightly cooler” (31.9 SS1 vs. 55.6% SS2). In SS1, 40.1% of the participants would not change anything in their environment (neither cooler nor warmer). The questionnaire analysis yielded other results regarding personal acceptability, personal tolerance, and affective assessment, which are presented in Figure 3. In general, SS1 workers tolerate, accept, and are more satisfied with their thermal environment than SS2 staff. The majority of SS1 workers considered the environment “acceptable” (81.7%), “perfectly bearable” (71.1%), and “comfortable” (56.4%). Regarding SS2, the majority of workers classified the environment as “unacceptable” (54.5%), “fairly difficult to bear” (45.5%), and “uncomfortable” (36.4%), respectively. In comparing both approaches, results are displayed in Figure 4 and Figure 5, and data indicated that in general workers felt uncomfortable. Despite SS2 workers reporting a higher level of thermal discomfort, there were no significant differences between PMV and thermal sensations, or between PPD and affective assessment.

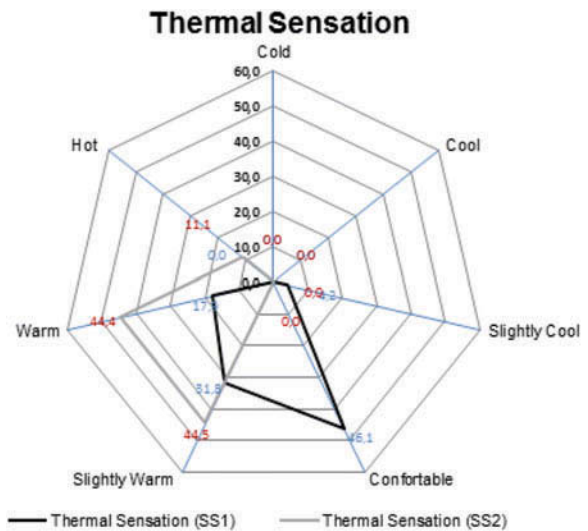


Figure 1. Thermal sensations reported by workers in SS1 and SS2.

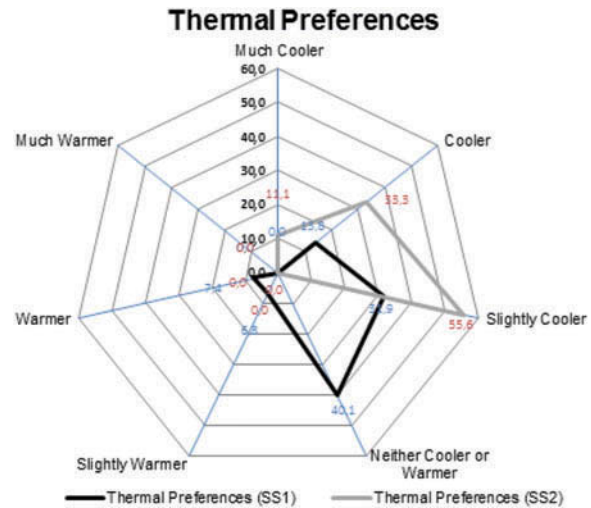


Figure 2. Thermal preferences reported by workers in SS1 and SS2.

Discussion

For both SS, t_a values were higher than those recommended by national legislation in all areas and day periods. This might be produced by an inefficient operation of the HVAC system (Balaras et al., 2007). On the other hand, the obtained RH values comply with legal requirements, as did v_{ar} . Air movement within a space may lead to draft sensation, but may also yield improved comfort under warm conditions. Thus, if in cool environments some restrictive requirements of air velocity are necessary to avoid the sensation of draft, in

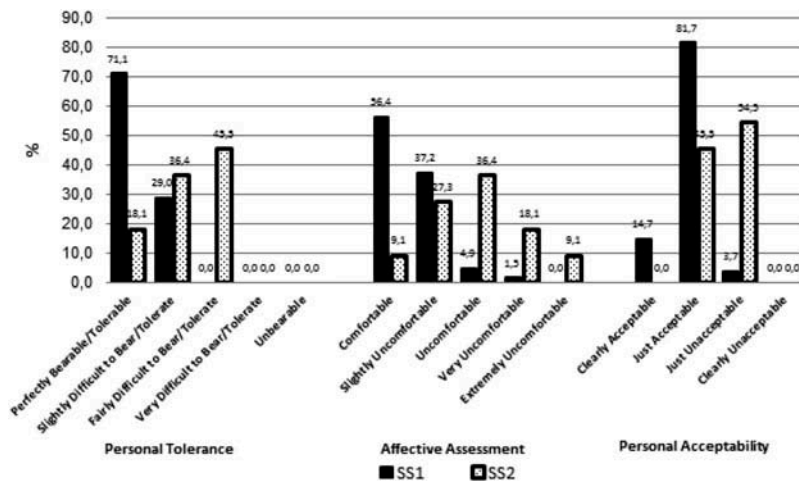


Figure 3. Personal tolerance, affective assessment, and personal acceptability reported by workers in SS1 and SS2.

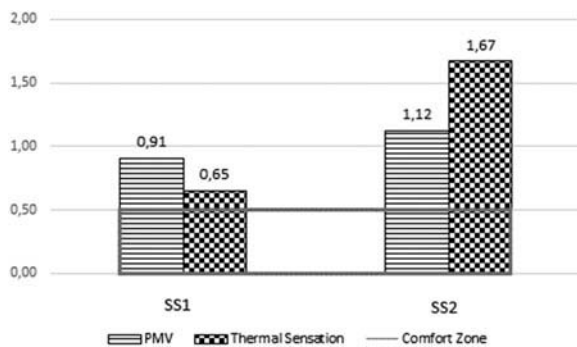


Figure 4. PMV and thermal sensations by sterilization service ($p = .162$).

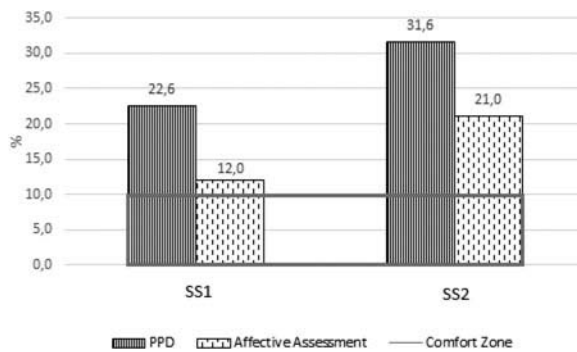


Figure 5. PPD and affective assessment by sterilization service ($p = .076$).

warm environments it may be beneficial for human comfort (Olesen and Parsons, 2002).

PMV and PPD indices exceeded in all periods of the day the recommended range of -0.5 to $+0.5$ and $<10\%$, respectively (Category B) (International Organization for Standardization, 2005). Similar results were

reported by Pourshaghaghay and Omidvari (2012), who determined that PMV was higher than 0.5 in all sections of the hospital building studied, in both winter and summer seasons. Although there were no marked differences between SS, it seems that in general, SS2 displayed the poorer thermal conditions according to the data obtained (higher PMV). In general, in this study the objective approach gave systematically higher discomfort levels than the subjective approach, which is in agreement with adaptive theory (Azizpour et al., 2013; Carvalhais et al., 2011). However, Verheyen et al. (2011) noted the opposite trend where PMV index was lower than reported thermal sensation, maybe due to the fact that the subjects under examination were not young and healthy. A possible misinterpretation of the questionnaires also needs to be taken into account and may have influenced the results. Fransson et al. (2007) showed that the best way to determine and predict thermal sensation was to combine measurement of environmental and subjective variables. Differences between the two approaches might be justified by the inaccuracy of the estimation of personal parameters such metabolic rate and thermal insulation. Part of the inaccuracy of the methods for metabolic rate determination, is produced by the limited task description (Havenith et al., 2002). However, several extensive field studies summarized by Dear and Brager (1998) showed that in buildings running with centrally controlled HVAC systems, the PMV model approximates the observed thermal comfort of occupants quite closely.

Conclusions

There were no significant differences between PMV/PPD indices in SS1 and SS2 and between thermal sensations and affective assessment reported by workers. In both SS the PMV index predicted the sensation as “slightly warm.” However, the real sensations noted by workers indicated that they felt “warm” in SS2. The assessment and interpretation of the thermal environment by analytical and subjective approaches revealed that in general occupants felt uncomfortable with respect to thermal conditions. The PMV/PPD model was found suitable to predict thermal sensations of occupants in hospital SS located in a typical Mediterranean climate. In sensitive areas such as SS, other risk factors for not feeling well may also occur. It would be an interesting study to examine the relation of thermal parameters with microbiological contamination or even with chemical exposure associated with the use of volatile compounds in the sterilization process.

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