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The Effects of Diffuser Location on Thermal Comfort in Hospital Recovery Rooms

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ABSTRACT

It is evident from the existing research that poor thermal comfort can adversely affect the health and productivity of the occupants. The analysis of thermal comfort is even more significant in the health care environments where the occupants are potentially more vulnerable due to poor individual health (patients) and/or extended exposure to such conditions (staff). This study focuses on the evaluation of thermal comfort in hospitals' recovery rooms considering both health care staff and patients. To do so, this study examines the impact of the location of air supply and return/exhaust grilles on the perceived thermal comfort at different locations in the room. The Computational Fluid Dynamics (CFD) analysis was utilized to evaluate the airflow profile in the room and obtain values for the local air speed. Based on the simulated air speeds, the Predicted Mean Vote (PMV) criteria were calculated at 36 different points within the room to analyze the effect of air diffusers' location. The study concludes that there is a negligible effect of the diffuser location on thermal comfort, provided that the ventilation system's design guidelines have been followed.

INTRODUCTION

With an average person spending approximately 90% of their time indoors, the analysis of indoor environment holds significant importance in regard to occupants' health and productivity (US EPA 1989). Among multiple parameters governing the quality of indoor environment, thermal comfort can significantly affect the health wellbeing and productivity of the occupants (Al horr et al. 2016; Akimoto et al. 2010). The relevance of thermal comfort is enhanced even further, when evaluated in the context of healing environments such as patient care rooms in hospitals (Berg, 2005). Typically, the occupants in such spaces are either patients or healthcare workers. Patients, who are already struggling with an ailment may develop additional physical and/or psychological stress due to uncomfortable thermal conditions in the room. In addition, the staff who also spend a substantial amount of time in such environment are highly susceptible to the adverse effects of uncomfortable thermal conditions. Additionally, the examination of thermal comfort may help with the optimization of heating and cooling system usage (Yang et al. 2014). The study presented here focusses on the evaluation of thermal comfort in a hospital recovery room and examines the impact of the location of air supply and return diffusers on thermal comfort.

Historically, the assessment of indoor air quality (IAQ) in health care environments has been overshadowed by other significant aspects such as pathogen transport and infection propagation (Khodakarami and Nasrollahi 2012). Similar trend may be noticed in terms of building design standards for hospitals where hygiene and safety are considered major governing parameters pertinent to IAQ. This is perfectly justified as the health and recovery of patients holds utmost importance in health care environments. However, patient care units and recovery rooms fall under a category of spaces that are not only used by patients but other groups such as health care staff workers and visitors. With regard to thermal comfort in healthcare facilities, there exists a considerable volume of literature focusing on the assessment of thermal comfort and its governing factors such as air temperature, humidity, and air speed. Balaras et al. (2007) conducted a study on operating rooms, and noted that thermal comfort affects the health, safety and working conditions of the healthcare staff in these rooms. Based on review of international

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regulations and standards, they indicatedthe indoor temperature in the range of 20 – 24 ^{0}C to be usually desirable, which may be increased or decreased based on the healthcare requirements of patients. They also noted that, higher temperatures may result in more favorable conditions for pathogen growth and propagation. Similarly, Derks et al. (2018) analyzed the thermal perception of nursing staff in hospitals based on their self-assessed impact of thermal conditions on work performance. Their study revealed that typical thermal settings in hospital can cause a warm thermal sensation for nurses, which in turn, compromises their work performance.

In terms of the methodology adopted for these studies, two primary research paths have been used in the past including subjective analysis and quantitative analysis. Subjective analysis is based on the collection of data regarding the personal perception of thermal comfort by occupants (Abbritti et al. 1992, Derks et al. 2018), whereas the quantitative studies evaluate thermal comfort using analytical models based on the physical properties of the indoor environment (Aryal and Leephakpreeda 2015). Despite of thermal comfort being subjective to personal perception, the above-mentioned quantitative models have successfully provided a reasonable estimation of thermal perception in occupied zones (Cheng et al. 2012). One such highly regarded and validated model was proposed by Fanger in 1970, known as the Predicted Mean Vote (PMV) model (Fanger 1970). This model along with other calculation methods have been extensively used in the past decades to establish design guidelines governing thermal comfort, which essentially provide standardized design parameters pertaining to the design of ventilation and HVAC system.

Additionally, the major design parameters of temperature, humidity, and ventilation ACH (air change per hour), have already been standardized for hospital environments. However, the local air velocity experienced by occupants is yet to receive much attention. Such perception is dependent upon several factors including air velocity leaving the supply diffusers and the position of these diffusers with respect to occupants (Huo et al. 2010). Typically, design standards for thermal comfort prescribe a maximum velocity of 160 FPM (0.8 m/s) at the supply outlet with no occupant control but does not provide definitive guidelines regarding the placement and positioning of these outlets (ANSI/ASHRAE Standard 55-2017). Wu et al. (2010) studied the impact of diffuser design on thermal comfort, and concluded that the indoor ventilation pattern, which influences the indoor thermal environment, is affected by the location of diffusers. They used computational modeling in conjunction with on-site measurements in a confined space, to evaluate the variations in thermal comfort under a full-scale air-conditioning system. Using a similar methodology, Mahdi et al. (2017) evaluated the effect of changes in air grille location on thermal comfort and air flow patterns. This study found the best-case scenario with respect to thermal comfort is when both supply and return air grilles are placed in the same direction. Jadidi et al. (2018), on the other hand, evaluated the effect of the distance between supply and return diffusers, in addition to the height of return grille on thermal comfort and the energy performance of the system. They observed thermal comfort conditions and energy savings of 15.2% when the supply and return grilles were placed at maximum possible distance and the return grille was placed at a height of 1.3 m.

This study evaluates the role of the relative location of supply and return diffusers on the thermal comfort perceived around the room at different locations, using CFD. The scope of study is primarily in-patient rooms where the occupancy can be variable, considering the uncertainty associated with the location of visitors and health care staff in these spaces.

METHODOLOGY

For the purpose of this study, CFD has been used to model the airflow profile inside the patient recovery room, using the commercially available ANSYS FLUENT software version 2019 R2. The aim was to evaluate the air velocities perceived around the room under different scenarios of diffuser placement. A total of 9 cases were setup, representing different arrangement of supply and return grilles, as presented in Table-1. The details of the model are provided in the following section:

Model Setup

The patient room considered for this study is measured 20 ft (6.1m) by 20 ft (6.1m), with a floor to ceiling height of 10 ft (3.05m). The room ventilation i.e., air supply and return are assumed to be achieved using single grilles, placed at opposite sides of the room. All the grilles were modeled as 24” (0.61m) by 16” (0.41m), providing a face area of 2.62 sq. ft (0.244 sq. m). The ceiling grilles were placed at the opposing corners of the room with a diagonal distance of 20 ft (6.1m) between them. For the wall grilles, supply diffuser was modeled at a height of 8 ft (2.46m) from the floor and return grille at a height of 8 in.

(0.2m) from the floor. The supply and return grilles were placed, centered on the opposite walls of the room.

Lastly, the floor grilles were centrally placed at the opposite ends of the floor, at a distance of 6 in. (0.15m) from the respective opposite walls. A graphical representation of the modeled room is provided in figure – 1.

Table -1: List of Analyzed Cases

CASE 1	Ceiling Supply	Ceiling Return
CASE 2	Ceiling Supply	Wall Return
CASE 3	Ceiling Supply	Floor Return
CASE 4	Wall Supply	Wall Return
CASE 5	Wall Supply	Ceiling Return
CASE 6	Wall Supply	Floor Return
CASE 7	Floor Supply	Floor Return
CASE 8	Floor Supply	Ceiling Return
CASE 9	Floor Supply	Wall Return

For the purpose of CFD analysis, the modeled room was discretized using a linear mesh structure. A total of 28,966 nodes and 148,750 elements were used to represent the control volume, as shown in figure – 2. The simulations were setup as steady state using the pressure-based solver. For the model solution, a second order upwind scheme was implemented for the spatial discretization of momentum and energy along with SIMPLE algorithm used for pressure – velocity coupling. The turbulence modeling was done using the Realizable k-epsilon model with standard wall functions. The convergence criteria were set as 10^{-3} for the components of the continuity, momentum, and turbulence equations, and 10^{-6} for the energy, resulting in over 1000 iterations to convergence in each case.

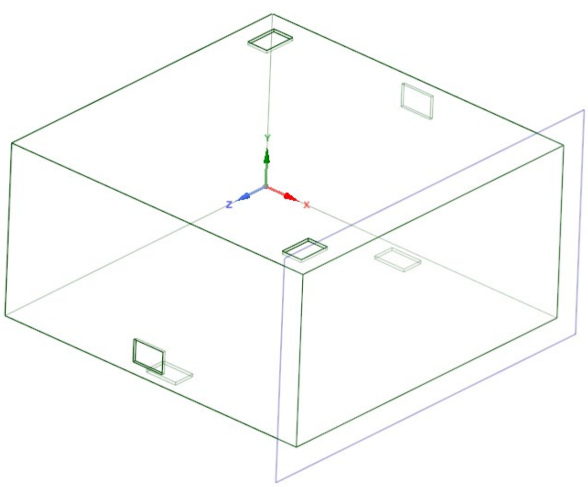

Figure 1 Graphical representation of room geometry

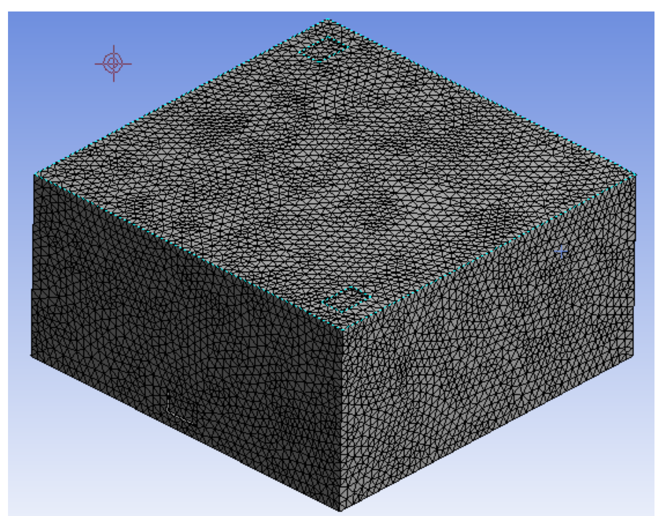

Figure 2 Mesh structure of modeled geometry

Boundary Conditions:

With the primary focus of the study being the evaluation of air velocity profile in the room, all the surfaces were modeled as adiabatic, assuming negligible heat flow across the system boundaries. The airflow rate was evaluated based on ASHRAE Standard 170-2017, Ventilation of Health Care Facilities. Space classification of 'Recovery Room' was used for the purpose of this study, with the ventilation requirement of 6 ACH. Based on these requirements, the supply boundary condition was modeled as mass flow inlet with the mass flow rate as 0.23 kg/s (400 CFM). The return grille was modeled as a pressure outlet with an absolute negative pressure of 25 Pa (1" wc.). The size of supply grilles was decided based on the leaving air velocity of 150 FPM (0.762 m/s). Based on the above-mentioned boundary conditions, all 9 cases (Table –1) were simulated to convergence, providing air velocity profiles around the room. The airflow profiles for case-1 and case -8 are presented in figure –3 for reference. In order to evaluate thermal comfort around the room, local air velocity data was collected for a total of 36 equally spaced grid points around the room. The measurement grid was placed at a height of 4 ft. (1.22 m) from the floor, with the objective to achieve measurement of thermal comfort at the height of the occupant.

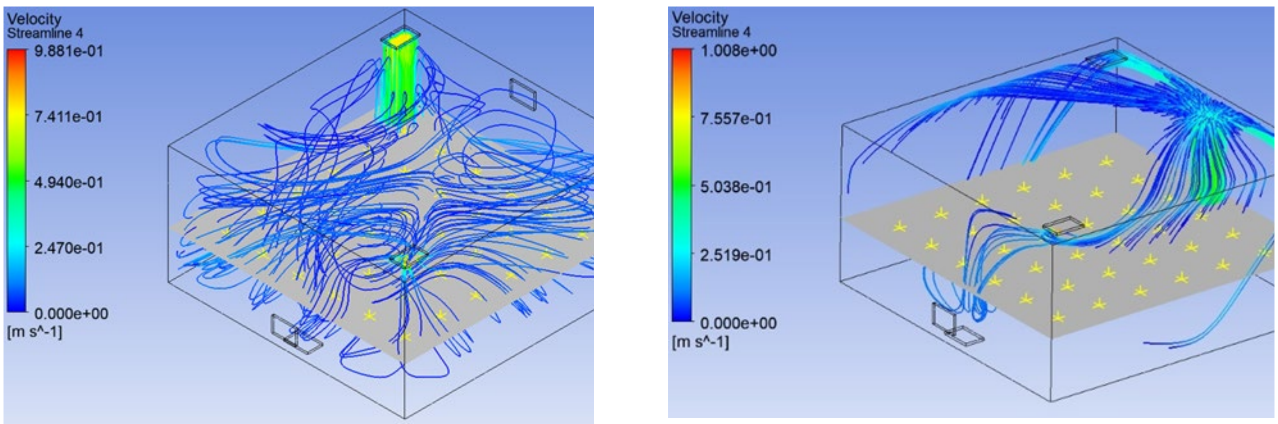

Figure 3 Velocity profiles for Case 1 (Left) and Case 8 (Right) with the measurement grid shown

Thermal Comfort calculations:

The PMV criteria were utilized for the purpose of the calculation of thermal comfort (Fanger 1970). Since the purpose of the study is to evaluate the impact of diffuser location on the perceived thermal comfort of occupants, the PMV criteria have been evaluated based on the variations in local air velocities in each case. Other governing factors were assumed constant as follows: the air temperature was assumed equal to the mean radiant temperature (MRT) as 23.89 °C (75 °F), with relative humidity assumed constant as 50%. The activity level was assumed to be 1.0 MET, representative of a quietly seated condition whereas the clothing was assumed (as per typical summer indoor conditions) as trousers and long sleeve shirt resulting in 0.61 clo. Center for the Built Environment (CBE) thermal comfort tool was utilized to evaluate PMV values for all 36 grid points, under the 9 simulation cases. The calculations were based on the simulated local air velocity values and the assumed values of other governing factors. The results of the calculations are provided in the following section:

RESULTS

The CFD simulations were conducted to evaluate local air velocities at the occupant height around the room. The simulated velocity values were measured at the 36-point grid placed at the height of 4 ft. (1.22 m) from the floor. The distribution of local air velocity values for each case is presented in figure -4. Using these velocities, the PMV values were calculated at each of these 36 points. These calculated PMV values are provided in figure 5, where they are plotted for each case.

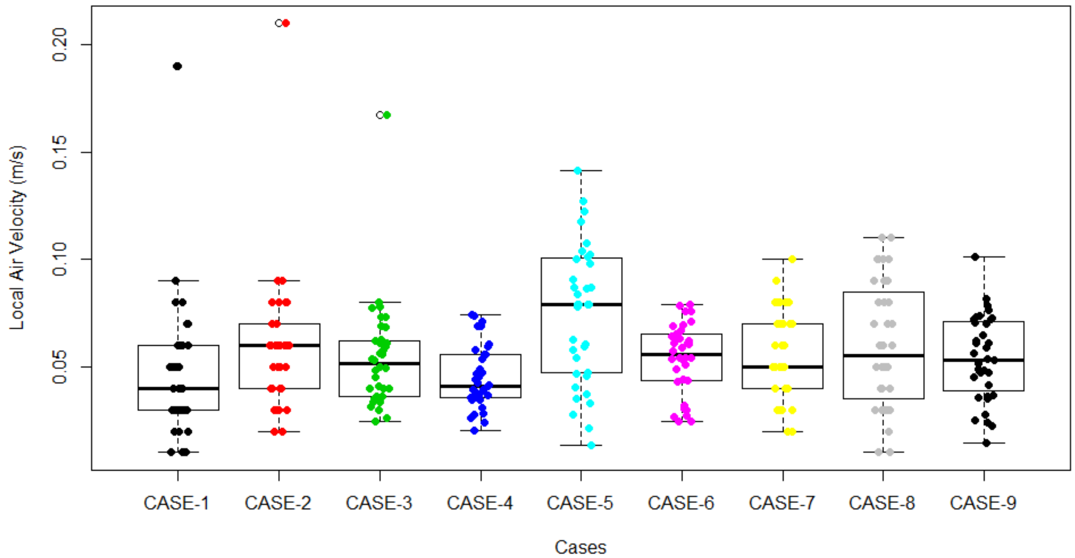

Figure 4: Box plot of air velocity distribution for each of the 9 analyzed cases

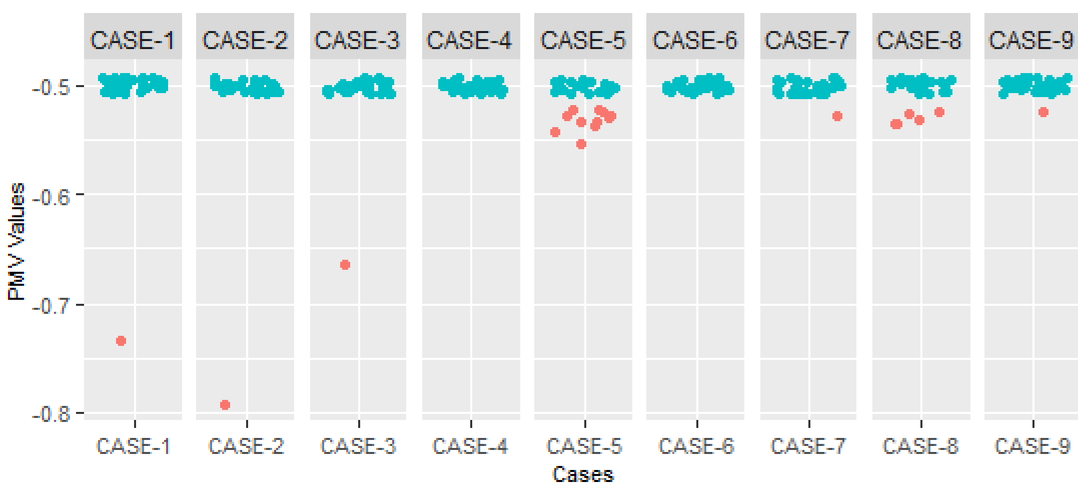

Figure 5: PMV values measured at 36 grid points for each of 9 simulated cases

As evident from Figure 5, the PMV values for the majority of data points lie within the thermal comfort criteria range (-0.5 < PMV < 0.5). The best-case scenarios proved to be Case 4 (Wall Supply, Wall Return) and Case 6 (Wall Supply, Floor Return), where 100% of grid points were noted to fall within the thermal comfort criteria range. These were followed by Case 1 (Ceiling

Supply, Ceiling Return), Case 2 (Ceiling Supply, Wall Return), Case 3 (Ceiling Supply, Floor Return), and Case 7 (Floor Supply, Floor Return) and Case 9 (Floor Supply, Wall Return), where acceptable thermal comfort was achieved for more than 95% of the 36 data points. The worst performing cases were found to be Case 5 (Wall Supply, Ceiling Return) and Case 8 (Floor Supply, Ceiling Return) with 72% and 89% of data points falling within the thermal comfort range, respectively. The lack of thermal comfort in these cases was found due to higher than acceptable air velocities at these points. The reason behind the higher velocities in these cases may be attributed to the two factors: First, the measurement grid is close to the supply air location under these cases, and second, the movement of air in these cases is in the upward direction, causing a higher turbulence in the airflow pattern. Additionally, it was noted that the ceiling supply cases provided with the most uniform airflow distribution with minimal variation in air velocities evaluated at the 36 grid points.

In summary, the effect of the relative location of supply and return grilles on the thermal comfort around the room is found to be negligible, with only a few outliers in certain cases, as discussed above. This is assuming that the guidelines of 160 FPM pertinent to the supply air velocity are being followed in conjunction with the provision of maximum distance between supply and return grilles.

CONCLUSION:

This study analyzed the effect of air supply and return diffusers' location on the thermal comfort in a hospital recovery room for patients, healthcare workers and visitors. Our analysis shows that diffusers location appears to have a negligible impact on thermal comfort in the room, provided that the guidelines for air delivery speed and relative arrangement of diffusers have been followed. It is recommended that the supply diffuser location should be placed in a manner to minimize the possibility of a direct encounter between the occupant and the airflow. This is to avoid direct exposure of occupants to higher than acceptable local air velocities which might result in compromised thermal comfort. Additionally, a greater distance between the supply and return grilles was noted to minimize the air bypass, thus providing better cooling or heating efficiency in the room. Moreover, this study concludes that the decision regarding the location of air grilles in the room does not have a significant impact on thermal comfort of occupants. Alternatively, this decision should be governed primarily by other relevant criteria such as pathogen propagation, and heating/cooling efficiency. Further research is required to optimize the location of grilles based on the above-mentioned air velocity criteria, in association with thermal comfort. That being said, such research can be highly case dependent, being influenced by the room geometry and furniture placement in the room.

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