DOES AIR SUPPLY DIFFUSER POSITIONING AFFECT PARTICLE SETLEMENT ON PATIENTS? NUMERICAL ASSESSMENT IN ISOLATION WARD

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ABSTRACT

Isolation ward is a designated area in a healthcare facility to separate patients which aims to protect patients with infections or to quarantine patients infected with airborne infections. This article aims to propose the optimum ventilation strategy to reduce the particle settlement on patients, as well as in the vicinity of the isolation ward to reduce the probability of patients experiencing Hospital Acquired Infections (HAI). With the aid of Computer-Aided Design (CAD) software both baseline and proposed isolation ward 3D model are constructed while Computational Fluid Dynamics (CFD) software is utilized to simulate the airflow pattern and particle dispersion throughout the vicinity of isolation ward. The isolation ward CFD model was validated using onsite measurement data, prior to case studies. The validated CFD model of isolation ward is used to examine the particle dispersion and airflow pattern for both baseline and parametric cases. Based on the simulated results, it is identified that baseline model is able to provide an optimum ventilation rate due to its airflow eliminating particle concentration directly to exhaust grills.

KEY WORDS

Isolation ward, Hospital Acquired Infections, Computational Fluid Dynamics, Mobile Air Supply Unit, Ventilation Strategies.

1. INTRODUCTION

Isolation ward is a designated area within a healthcare facility which aims to separate the patients or individuals suffered from airborne infectious disease or to protect patients with low immune system. [1] There are two types of isolation ward which includes positive pressure isolation ward and negative pressure isolation ward. [1] Positive pressure isolation ward is designed to protect the immunocompromised patients from acquiring airborne infections such as patients who are experiencing second or third-degree burn, patients who had just undergo major surgery, i.e., transplantation surgery, neurosurgery, coronary bypass etc. [2] In contrast, negative pressure isolation wards aim to quarantine patients experienced with infectious disease and having high probability to spread to other patients and healthcare workers. The examples of airborne infectious disease are SARS-Cov-2, Middle East respiratory syndrome (MERS), etc. [3] It is important to maintain a good ventilation system in an isolation ward to prevent patients from experiencing Hospital Acquired Infections (HAI). Common examples of HAI include pneumonia, urinary tract infections, bloodstream infections. [4] Tan et al. (2023) reports that in USA, the costs spent due to HAI is estimated between 28-45 billion USD. [1] Even though with spending the costs for HAI treatment, it is estimated that 98,000 from 1.7 million patients hospitalized approximately 5.8 % patients died from HAI. [5] Based on study conducted by Liu et al. (2022), when vertical downward air supply diffuser installed in a negative pressure isolation ward, the airborne particle concentration when patients are in lying positions reduced to 14.2 %. [6] However, there remains a gap of airborne particle concentration reduced when mounting the air supply diffuser on the wall and wall-mounted air supply diffuser with tilted 15 ^{o} . This study aims to propose the optimum position of mounting the air supply diffuser which optimizes the ventilation rate to reduce the airborne particle concentration in the vicinity of isolation ward. This study also aims to ensure the safety of the patients in isolation ward by mitigating the risk of patients experiencing HAI.

2. METHODOLOGY

2.1 Details of the isolation ward

The 3D model of an isolation ward was constructed using SolidWorks, a type of Computer Aided Design (CAD) software. In the isolation ward, it is equipped with a single bed, air supply diffuser, exhaust grills and single patient bed. The dimensions of the isolation ward are having a dimension of 4.0 m (L) x 2.5 m (W) x 2.65 m (H) which aligns with the study defined by Tan et al. (2023) [1] and Aganovic & Cao (2017)[7] . The height of 1.73 m, is set to the human manikin which it represents standard men's adult height [8]. Table 1 below shows the details of the object dimensions in the isolation ward. The dimensions of patients and medical staff are summarized in table 2.

Table 1: Details dimensions of isolation ward

Objects	Dimensions (m)
Isolation Ward	4.0 (L) x 2.5 (W) x 2.65 (H)
Air Supply Diffuser	0.6 (L) x 0.6 (W)
Exhaust Grills	0.3 (L) x 0.3 (W)
Single patient bed	1.9 (L) x 0.6 (W) x 0.85 (H)
Patient	As summarized in table 2
Medical Staff	As summarized in table 2

Table 2: Details dimensions of human manikin

Manikin	Name	Dimension (m)
Medical staff & Patient	Body Head Left & right hand. Left & right leg.	0.3 (L) x 0.2 (W) x 0.675 (H) 0.15 (L) x 0.2 (W) x 0.305 (H) 0.1 (L) x 0.1 (W) x 0.575 (H) 0.1 (L) x 0.2 (W) x 0.75 (H)

2.2 Validating Airflow Model and Verifying Mesh Independence

To improve the results of the airflow velocity distribution throughout OR, the study identify that there are turbulence models that are commonly used in CFD such as standard k-∊ model, standard k-ω model, Renormalized group (RNG) k-∊ model, Shear Stress Transport (SST) k-ω model etc. [9] Teodosiu et al.(2014) mentions that a suitable turbulence model is required to evaluate the ventilation efficiency in an indoor space using CFD based on indoor parameters, criteria and validation of numerous results. [10] Li et al.(2020) also mentions that selection of turbulence model is crucial because it affects the simulation accuracy.[11] To obtain a suitable turbulence model for indoor space, a set of simulations using different turbulence model is set up to compare the values with measured data from previous studies. Based on research, it states that the relative error between measured and simulation data must not exceed 10 % to be valid for an indoor space. [12] In the study conducted by Wong et al. (2019), they reported that there are two turbulence models which have relative errors of less than 10 % which are RNG k-∊ model and SST k-ω model with 8 % and 9 % respectively. [13] However, RNG k-∊ model will be chosen as a baseline study due to its lowest number of relative errors.

For the aspect of mesh elements, Ng et al.(2009) suggested that tetrahedral mesh elements to be used to perform an analysis on the airflow distribution and particle dispersion throughout the isolation ward due to its flexibility and capability o conform the intricate 3D geometry [14] Kumar et al .(2014) suggests that the Grid Convergence Index (GCI) for the study must be less than 5 % in order to result a small and negligible numerical error in predicted outcome [15] Based on the study performed by Wong et al (2019) using the 3.2 million mesh elements in an indoor environment, it is identified that the GCI of the mesh elements is 4.01 % which is valid to be used for the case study. [16]

3. RESULTS AND DISCUSSIONS

This case study highlights the airflow patterns in the OR which are to be affected by obstacles such as surgical lamps, medical staff, medical equipment, equipment table and operating table. Large obstacles could significantly reduce the airflow velocity in certain areas of the OR and cause inadequate ventilation in the OR. Based on results, it is suggested that baseline 3D model is optimum due to its ability to supply air and sweeps the airborne contaminant particle from the top directly to the exhaust grills. As compared to the two parametric case studies, when the air supply diffuser is mounted directly on the wall, which supplies the air in a horizontal direction and airborne contaminant particle might settle directly on the body of the patient. Besides that, when the air supply diffuser is mounted on the wall, the horizontal airflow might be blocked by the obstacles such as the medical staff manikin and patient bed causing the airflow distribution to be less adequate in the vicinity of the isolation ward.

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