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Assessing the impact of ventilation on the potential airborne infection risk in hospital lung function room

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SUMMARY

Controlling the spread of respiratory infectious diseases in healthcare settings is important to avoid nosocomial infection. We utilized computational fluid dynamics (CFD) simulation, real-time carbon dioxide (CO_2) monitoring, microorganism culturing, and microorganism sequencing to quantitatively assess the exposure risk of healthcare workers to infectious respiratory particles (IRPs) in one lung function room under two ventilation configurations. The original ventilation system supplied 2 air changes per hour (ACH) for fresh air and 2 ACH for recirculated air, while the retrofitted ventilation system supplied 6 ACH of fresh air. Indoor CO_2 concentration and microorganism concentration decreased after the retrofit. The ventilation modification significantly improved the discharge efficiency for 5 μm IRPs and 50 μm IRPs. The intake fraction of 5 μm aerosols and 50 μm aerosols for HCW decreased by 0.005% and 0.006%, respectively. This study also reviewed the effectiveness of the above methods when evaluating building retrofit.

KEYWORDS: Nosocomial infection, building retrofit, airborne microorganisms, CFD simulation, carbon dioxide monitoring

1 INTRODUCTION

The COVID-19 pandemic has posed considerable threats and challenges to global health services, especially in the medical environment. As an important component of respiratory departments, HCWs in the lung function room also bear a high risk of inhaling infectious respiratory particles (IRPs) exhaled by patients during lung function test (LFT). Routine LFTs, such as spirometry, need patients to take off the mask, communicate with HCWs, and repeatedly perform forced exhalation, which usually results in coughing and sputum emission (Hull et al. 2020). Currently, the influence of ventilation on exposure risk of HCWs to IRPs in the lung function room is not quantitatively assessed.

2 MATERIALS/METHODS

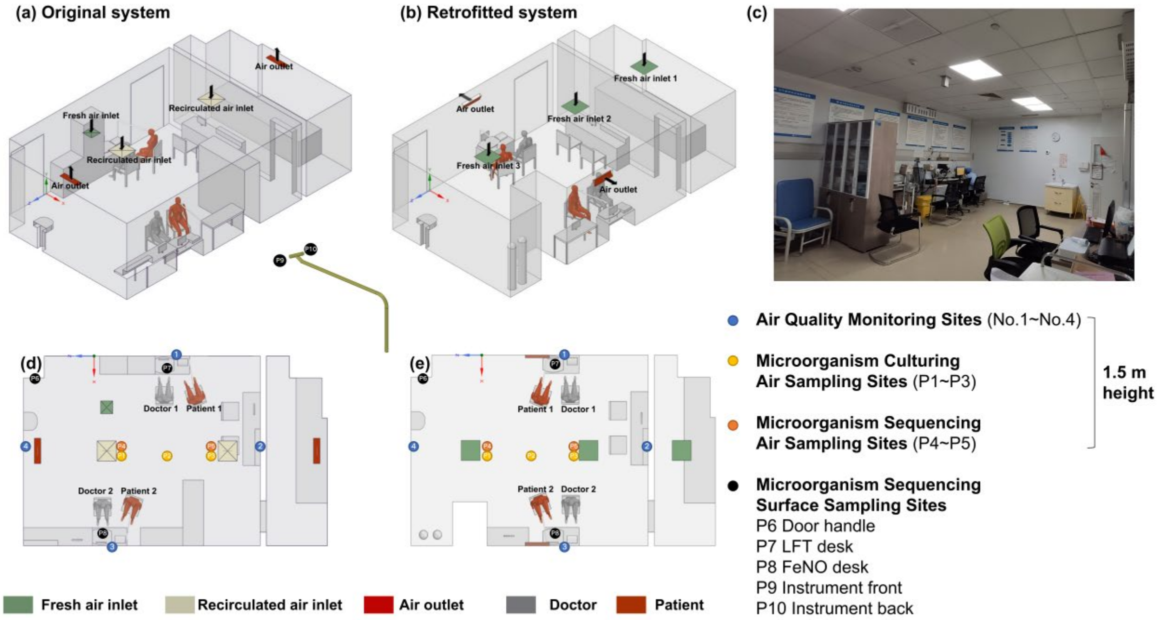

Figure 1. Lung function room model with (a) original ventilation system and (b) retrofitted ventilation system for CFD simulation, and with labeled sampling points under (d) original system and (e) retrofitted system

The selected lung function room in the hospital was a general rectangular-shaped room without any window. The dimensions of the testing room were 6.9 m (L) x 5.2 m (W) x 2.6 m (H) with a capacity of 2 treatment positions (1 HCW and 1 patient for every position), and the dimensions of the collocation room were 5.2 m (L) x 1.9 m (W) x 2.6 m (H). The original ventilation system included 1 small fresh air inlet (2 ACH), 2 recirculated air inlets (2 ACH), and 2 air outlets. The retrofitted ventilation system included 3 fresh air inlets (6 ACH) and 2 air outlets located above the working desks at treatment positions. Detailed descriptions are graphed in **Figure 1**.

3 RESULTS

When the fresh air change rate increased from 2 h^{-1} to 6 h^{-1} and stop using recirculated air, the intake fraction of 5 μm and 50 μm particles for doctor 1 increased by 0.077% and 0.022%, respectively. When the fresh air change rate increased from 2 h^{-1} to 6 h^{-1} and stop using recirculating air, the intake fraction of 5 μm and 50 μm particles for doctor 2 decreased by 0.005% and 0.006%, respectively

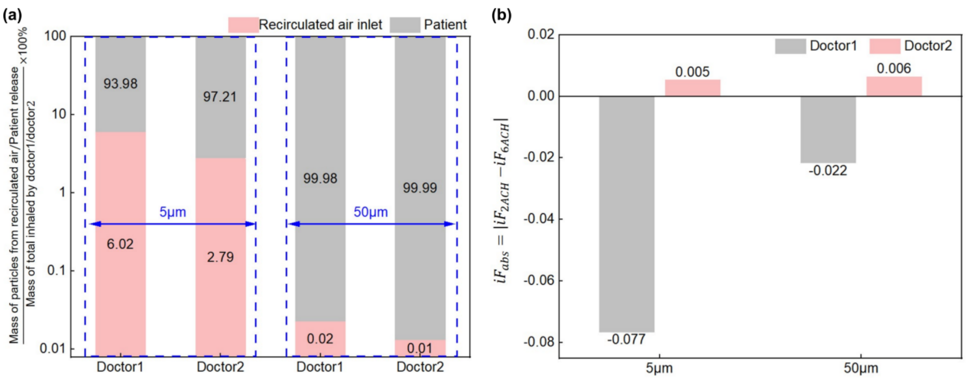

Figure 2. Size-resolved intake fraction of healthcare workers

The carbon dioxide concentration (all $p<0.01$) were inversely correlated with the amount of fresh air. Ventilation variation was found in indoor microorganism concentration. The indoor bacteria level under 6 ACH (mean: 118±40 CFU/m^3, 49-191 CFU/m^3) was significantly ($p<0.05$) lower (72.04% decrease) than that under 4 ACH (mean: 422±312 CFU/m^3, 120-1187 CFU/m^3). The indoor fungi level under 6 ACH (mean: 29±30 CFU/m^3, 0-99 CFU/m^3) was significantly ($p<0.01$) lower (62.34% decrease) than that under 4 ACH (mean: 77±24 CFU/m^3, 35-99 CFU/m^3). The concentration of airborne bacteria that can reach the small airways and even the alveoli was reduced by 68.15% and the concentration of airborne fungi was reduced by 70.37% (Guo et al. 2021). The diversity of aerosols was affected by the ventilation systems. Intra-group comparison of the surface fungi showed a higher chao1 index ($p<0.001$) and Shannon index ($p<0.05$) under 4 ACH than 6 ACH. Airborne bacteria ($p<0.01$) and fungi ($p<0.05$) showed a higher Shannon index under 6 ACH than 4 ACH but revealed no statistically significant difference in the chao1 index ($p>0.05$). Surface bacteria revealed no statistically significant difference in the chao1 index ($p>0.05$) and the Shannon index ($p>0.05$) under different ventilation systems.

4 CONCLUSIONS

Taken together, this is a study that quantitative and qualitatively assessed the exposure risk of HCWs in the lung function room and reviewed the evaluation techniques. The results of the study showed that the diversity of microorganisms was influenced by the ventilation system, specifically, the amount of fresh air. Architectural retrofit should not only take the ventilation system (air change rate) into account but also consider the filtration system and position of air vents and personnel. Meanwhile, adequate air and surface disinfection accompanied by limited patient flow would better reduce the risk of nosocomial infection and cross-infection. As each of CFD simulation, real-time carbon dioxide monitoring, microbial culturing, and microbial sequencing has limitations, techniques that can directly trace IRPs should be considered.

5 REFERENCES

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