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Theoretical investigation and experimental validation on transient variation of particle concentration in a simulated consulting room in hospital

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ABSTRACT

At present, the ceiling cassette fan-coil unit (CCFU) is widely used in Chinese hospitals. However, enough attention has not been paid on filter installation in CCFU. This will cause secondary pollution inside the CCFU, which may increase the risk of nosocomial infection. With the increasingly serious condition of atmospheric pollution and the complexity for coexistence of bacteria and virus in hospital, it is urgent for owners and operators of hospital to select suitable filters for CCFU. In this study, three kinds of air filters (G4, M5 and F7) were installed in a consulting room, respectively. Indoor air was re-circulated by CCFU. The performance of air filter was evaluated by monitoring the decay rate of particle concentration within a period corresponding to the average regular consulting time. It is found that the overall particle removal efficiency (via filter-integrated CCFU) (OPRE) increases with the increase of filter's classification level. Upgrading the G4 filter to M5 or F7 filter can significantly reduce indoor particle concentration. Compared with F7 filter, the performance improvement of the M5 filter is mainly obtained for particles with diameter 0.85–3.5 μm. As far as the dynamic variation of particle concentration in the period studied is concerned, there is an exponential relationship between OPRE and clean air delivery rate (CADR). Since the concentration of bacteria is correlated to that of particles with diameter close to 3 μm, it is suggested to install M5 filter for this application, which provided the basis for selection of filter in CCFU for hospitals.

1. Introduction

Nowadays people in industrial countries usually spend more than 90% time indoors, which means most of the air people breathe is indoor air [1,2]. They will be exposed to particles which come from outdoors and indoors, such as smoking, cooking, infiltration of ambient air, settling and re-suspension of particles and other indoor activities [3–10]. Study shows that ultrafine particles account for 19–76% of indoor particles in terms of number concentration. 10–30% of diseases are caused by particles [11]. Short-term exposure to particles can prolong the hospitalization period and increase the mortality rate for people with cardiovascular and respiratory diseases. Meanwhile, it can also cause chronic bronchitis and asthma. On the contrary, long-term exposure to particles is one of the important factors for the increased lung cancer mortality [12–15].

It is a common phenomenon that bacteria disseminate in the consulting room [16]. Although direct contact is the main route for the spread of infectious disease in hospital, the contribution of airborne transmission is still underestimated [17]. For example, microbe such as foot-and-mouth disease virus may deposit on the surface of aerosols, and then may be transported with the airborne route [18]. Therefore, the threat for airborne transmission of diseases cannot be ignored. And it is necessary to investigate the effective filtration measures of airborne particles in hospital. Jiang et al. [19] compared the performance of six commonly used methods including ultraviolet rays, symclosene, peracetic acid, hydrogen peroxide, moxa stick and air purifier. They found that the durability of the air purifier was the best, so it was suitable to be applied in hospital where the indoor environment with low

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bacterial concentration should be kept for a long period. Zhuang et al. [20] found that the increased flow rate through the split-type air-conditioning unit can influence the indoor air quality moderately. Yu found that air cleaning technology was one of the main measures to remove airborne bacteria [21].

Although the airborne particles can be removed by installation of air filter, the particle removal performance in the room is influenced by various factors which include the characteristic of the indoor pollutant source, the outdoor particle concentration, the ventilation system, the air filter used, the infiltration rate and the deposition feature of particles [22]. Offermann et al. evaluated the performance of different air filters in terms of the decay rate with the cigarette smoke. It was found that the filtration performance of HEPA filter was the best [23]. By continuous monitoring the performance of four HEPA filters in the room where people smoke inside, Batterman et al. found that the particle removal efficiency was related to the particle diameter and the occupancy status indoors [24]. Cheng et al. investigated that the filtration efficiency of air purifier for pollen and fungal spore [25]. The found that when the door and the window in the unoccupied room were closed, the overall particle removal efficiency in the room could be expressed with the effective clear air delivery rate.

Although hospital-acquired infection with airborne transmission of diseases appears frequently and efficient air filter can be used to remove airborne particles, little attention has been paid on the role of ceiling cassette fan-coil unit (CCFU) for overall particle removal performance in the consulting room of the hospital. Nassif [26] and Zaatari [27,28] measured the performance of CCFU in practical application. Feng [29] and Noh [30] considered the influence of filter installed in the CCFU on the interior flow field of the room by simulation. The effects of different ventilation systems and different filters on indoor particle concentration under long-term operating conditions were studied by Walker [31] and Park [32]. Cao [33] studied the influence of the filter installed in the fan coil unit on the indoor particle concentration. Siegel [34] argued that most of the existing filter measurements were conducted in laboratory, while field tests were rare. But the field measurement was helpful in exploring the fundamental factors of filter performance.

In order to maintain sustainable operation of CCFU and avoid secondary contamination inside CCFU, it is imperative to install air filter inside CCFU for purification of indoor air. Moreover, theoretical model and experimental validation are still lacking. Miller-Leiden et al. [35] divided the particle filtration process into two stages which corresponded to the transient and the steady-state stages. However, most of the existing researches on overall particle removal efficiency were based on the steady-state stage. During the stay of patient inside the consulting room, the variation of particle concentration is transient. Therefore, the theoretical model for transient variation of airborne particles will be studied and validated. Moreover, Lighthart and Shaffer [36,37] found that the size of bacterium in the air was mainly from 0.3 μm to 15 μm. Later they proposed that the aerodynamic diameter of bacterium attached to the particle was mainly 3 μm. It should be mentioned that although the size of the virus itself was very small (such as 0.01–0.1 μm), it will be attached to the carrier particle. The carrier particle contains nutritious material for survival and growth of virus. It is released into the air by the human activity and mechanical force. So the size of virus entering into the air is not related to the size of the virus itself, instead it is dependent on the mechanical force of the air flow or other acting forces [38]. So the aerodynamic diameter of the carrier particle is more meaningful. In this study, the improvement of indoor environment in the consulting room by installing different types of air filter in CCFU will be investigated. The concentration of airborne particles corresponding to the equivalent diameter of microorganism will be paid special attention to. It is aimed to provide the guidance for selection of air filter in the consulting room in hospitals.

2. Experiment and test method

2.1. Site characteristics

Measurement was conducted in a simulated consulting room in August 2015 at Changzhou, China. Outdoor air velocity and wind pressure were small. So the impact of the infiltration was ignored in the experiment. The size of the room is 7.7 m × 4.1 m × 3.3 m (L × W × H). One CCFU with the type Midea KF-72QW/Y-B (R2) was installed in the room. There was no dedicated outdoor air system. For the CCFU, there was one return air grille and four supply air outlets. The angle between the supply air and the ceiling was 60°. Fig. 1 shows the shape of the indoor unit. The schematic diagram of the consulting room is illustrated in Fig. 2. The patient and the doctor sit in a way to simulate the consulting process.

2.2. Experimental conditions

Measurement was carried out under four different conditions, which is illustrated in Table 1. Mode 1 means operation without filter. Mode 2, 3 and 4 mean operations with G4, M5 and F7 filters, respectively. Table 2 presents the characteristic of filtration efficiency for different conditions according to EN 779-2012. Arrestance is a measure for the ability of air filter (G type) to remove synthetic dust from the air. Average efficiency describes the filtration performance of air filter with 0.4 μm particles. According to our survey, the consulting process usually takes 10–30min for each patient. At first, the indoor particle concentration was kept to the outdoor value before each measurement. When the CCFU was turned on, the indoor particle concentration was sampled for 30min in each test.

2.3. Characteristic of room ventilation

The size of the air filter is the same as that of the return air inlet of CCFU. It was installed carefully in the CCFU. The indoor temperature was set to be the same value before each measurement. Air was drawn into CCFU through the return air inlet and the filter, and then blown out from the outlet. There was no mechanical outdoor air system. After people entered into the room, and closed the door and the window, the indoor environment was not affected by ambient atmosphere. Based on the measured velocities and the cross-sectional area at supply air outlet, the flow rate was obtained.

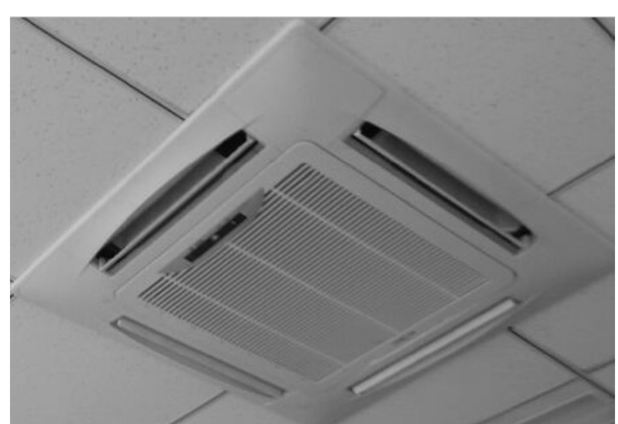

Fig. 1. The shape of the CCFU.