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Indoor air quality varies with ventilation types and working areas in hospitals

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A B S T R A C T

This study aimed to investigate the distributions of indoor air pollutants in different areas of hospitals, and examine how they might be associated with various types of air conditioning systems. We measured CO, CO_2, O_3, TVOC, HCHO, $PM_{2.5}$, PM_{10}, airborne bacteria and fungus at 96 sites in 7 different work areas under 4 major types of air conditioning systems from 37 hospitals, randomly selected throughout Taiwan. Statistical analysis showed that there were higher levels of CO_2 and TVOC in wards ($p < 0.05$); pharmacy departments also had higher levels of TVOC, compared to those of other areas. The average concentrations of CO, O_3, HCHO, $PM_{2.5}$, PM_{10}, bacteria and fungi did not differ statistically among various work areas. The CO level was particularly higher at the hospitals with mechanical air-conditioning systems, regardless of whether the hospitals used an air handling unit (AHU) system, fan coil unit (FCU) system or mixed type ($p < 0.05$). This could be higher outdoor CO levels in hospitals with central air conditioning, and outdoor CO might have been drawn into indoors through ventilation system. Yet, the $PM_{2.5}$, PM_{10} and fungal concentrations were higher at the hospitals with non-central air conditioning systems ($p < 0.05$). Environments equipped with central air conditioning systems appear apt to lower indoor aerosol but show no particular benefit for controlling indoor CO concentrations in hospitals. Future investigation should be designed to explore how different work areas and ventilation types could better manage indoor air quality, and therefore, benefit occupant health.

1. Introduction

Air quality at hospitals is likely to be a significant risk factor for the health consequences of both the working staff and patients who visit the environment. Infection is a universal event in hospitals, so many studies have investigated the levels, sources and characteristics of bioaerosol in hospitals [1–4]. Li et al. also reviewed the relationship between bioaerosol and ventilation, and suggested that ventilation could play an important role in regulating the levels of bioaerosol in hospitals [5]. However, medicines, medical treatments and cleaning in hospitals can also affect indoor air quality (IAQ). Many hospitals use cleaning solution and detergent to reduce the risk of infection, thus, increasing the levels of total volatile organic compounds (TVOCs) [6]. In hospitals, medical treatment and using HCHO solution may contribute to higher HCHO level in the air [7,8]. Building decorations are important sources of TVOC and HCHO in indoor spaces [9–12]. Humans walking indoors can affect the level of particulate matter (PM) in the air [13]. Moreover, outdoor air is an important source of pollution affecting IAQ [14], such as carbon monoxide (CO), PM, ozone (O_3), etc. Numerous studies have demonstrated that exposure to CO, O_3 and particulate matter increases the risk of sick building symptoms (SBS) [15–18]. Some studies have also indicated that HCHO and TVOC exposure can increase the risk of allergic diseases or cancer [19,20]. Therefore, it is necessary to investigate the characteristics of non-biological pollutants in hospitals.

Previous research has demonstrated that characteristics and distributions of IAQ can vary throughout a hospital since medical activities and materials vary across different work areas [1,21]. However, such studies have only investigated the IAQ in intensive care units (ICU) and operation rooms in hospitals [2,4]. Although some articles have discussed the IAQ in different work areas in

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hospitals, they have only investigated the levels and sources of fungi, TVOC or PM [3,4,6,22]. A few studies have measures biological and non-biological pollutants at the same time, and further investigated the distributions and sources of different work spaces in hospitals.

Ventilation type can be categorized into natural and mechanical ventilation systems. Mechanical ventilation includes central air conditioning (such as Air Handing Unit (AHU), Fan Cooling Unit (FCU) and AHU mix FCU) and non-central air conditioning (such as window type and single-split type). In general, central air conditioning with filtration system can be used to remove outdoor air pollutants or raise IAQ. In hospitals, air conditioning can affect the transmission and distribution of infectious agents. Li et al. in the review suggested that ventilation was significantly associated with the levels of microbiologic pollutant [5]. Chuaybamroong and his colleagues also indicated that high ventilation rate can dilute the levels of airborne microbes [23]. Wu indicated that there was lower level of bioaerosol in offices with AHU compared with those with FCU [24]. Zuraimi also found that there were higher ratios of indoor and outdoor $PM_{2.5}$ and ozone in child care centers with nature ventilation than those with machine ventilation [12]. However, no specific studies seem to have associated the IAQ in hospitals with different air conditioning system.

Few studies have adopted a comprehensive and systematic approach to examining the general IAQ in hospital environments. However, such information is a fundamental for designing better IAQ guidelines for environments of great diversity and importance. Thus, the purpose of this study is to investigate the distributions and sources of biological and non-biological pollutants in different work areas, and assess the effects of different types of air conditioning in hospitals.

2. Materials and methods

2.1. Hospital selection and building characteristic questionnaire

Thirty-seven hospitals in Taiwan were randomly selected from the governmental registry, and 2 to 4 sites within each hospital were also identified for IAQ measurement between November 2007 and January 2008. The sampling sites included nurse stations, pharmacy departments, clinics, clinic waiting areas, lobbies, meeting rooms and wards; the sample sizes were 12, 5, 23, 24, 21, 11 and 3, respectively. One outdoor site was always included to represent where the outdoor air entered. The situation of the air conditioning system was investigated according to a standardized checklist. The four major air conditioning systems included mixed AHU/FCU, AHU, FCU, and window type or single-split type, and the number was 22, 4, 5 and 6, respectively.

2.2. Indoor and outdoor air quality measurement

Indoor and outdoor levels of CO, carbon dioxide (CO_2), O_3, TVOC, HCHO, particulate matter diameter below 2.5 μm ($PM_{2.5}$), particulate matter diameter below 10 μm (PM_{10}), fungi and bacteria were monitored. The real-time concentrations of CO, CO_2, O_3 and TVOC were measured continuously for at least 8 h (09:00–17:00) while a DNHP tube was used to sample HCHO for 1 h at each site. $PM_{2.5}$ and PM_{10} were continuously measured using a real-time analysis instrument for 24 h.

CO and CO_2 were examined by a Q-TRAK Indoor Air Quality Monitor (Model 7575, TSI Corporation, Shoreview, USA). The O_3 level was monitored by an ozone instrument (Ozone Monitor, Model 202, Colorado, USA). A real-time RAE/PGM-730 instrument was used to measure the levels of TVOC (Model ppbRAE 3000, ProRAE Corporation, San Jose, USA). Before analyzing the HCHO, 5 ml of acetonitrile was added to the DNPH tube and subjected to ultrasonic shaking for 30 min. Samples were analyzed by HPLC (High-Performance Liquid Chromatography) with an ultraviolet detector at 254 nm (L-2420, HITACHI, USA). The levels of $PM_{2.5}$ and PM_{10} were determined by a DUST-TRAK Aerosol Monitor (Model 8520, TSI Corporation, Shoreview, USA). Airborne fungi and bacteria were sampled every 3 h. Airborne bacteria and fungi with Tryptic Soy Agar (TSA) and Malt Extract Agar (MEA), respectively, were measured by a Burkard sampler at 10 l/min for 30 s. The bacteria were cultured at 30 °C for two days, while the fungi were cultured at 25 °C for five days.

2.3. Statistical analysis

Overall concentration variations were analyzed by one-way analysis of variance (One-way ANOVA) for different work areas and types of air conditioning systems. Fisher's test was used to examine the difference of pollutant levels using different air conditioning systems and work areas. A linear regression model was used to analyze the relationship between levels of indoors and outdoors pollutant. Statistical significant was set at $p < 0.05$.

3. Results

3.1. IAQ in different working areas

In all sampling sites, the average concentrations of indoor CO, CO_2, O_3, TVOC, HCHO, $PM_{2.5}$, PM_{10}, bacterial and fungal pollutant were 2.7 ± 1.2 ppm, 670 ± 190 ppm, 0.03 ± 0.01 ppm, 0.55 ± 0.52 ppm, 0.02 ± 0.01 ppm, 14.4 ± 15.9 $\mu g/m^3$, 25.2 ± 17.2 $\mu g/m^3$, 572 ± 769 CFU/m^3 and 426 ± 746 CFU/m^3, respectively. The average levels of all pollutant were below Taiwan IAQ standard values. Table 1 shows that the average levels of CO_2, TVOC and bacteria in the wards were above Taiwan IAQ standard values. We also found that the average levels of CO_2, dCO_2 and TVOC were significantly different among all working areas ($p < 0.05$). Using Fisher's test, higher CO_2 levels were found at wards than those of other working areas, except for meeting rooms; the dCO_2 level was not significantly different from those of other spaces, except for pharmacy department; finally, TVOC levels in wards were higher than any other area.

3.2. IAQ under different air conditioning systems

Table 2 shows the indoor air pollutant levels for buildings with different air conditioning systems, also measured by one-way ANOVA. Levels of average indoor CO_2, O_3, TVOC, HCHO and bacteria did not differ significantly, but the mean indoor levels of CO, $PM_{2.5}$, PM_{10} and fungi were significant different among all air conditioning system. We further used Fisher's test to examine the difference of pollutant levels using different air conditioning systems. Our data showed that the CO levels were higher in hospitals with AHU mix FCU compared to those with window or single-split type, and the levels of $PM_{2.5}$, PM_{10} and fungi were higher in hospitals with window or single-split type than those with spaces with central air conditioning. On the other hand, the levels of outdoor air pollutants did not vary significantly in buildings with different types of air conditioning systems.

3.3. Effects of outdoor air pollutant to IAQ under different air conditioning systems

The levels of CO, $PM_{2.5}$, PM_{10} and fungi were different in hospitals with central and non-central air conditioning, and this study further investigated the potential pollution sources by the ratios