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Indoor air quality at different sites of a governmental hospital, Thailand

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Abstract

Objective: To assess indoor air quality at different sites of a governmental hospital in the northern region of Thailand.

Methods: This is a cross-sectional study of 208 indoor air samples collected from out-patient departments (OPDs), internal medical wards (IMWs), and intensive care units (ICUs) to investigate bacterial count (104 samples) and fungal count (104 samples). Groups or genus of isolated bacteria and fungi were preliminarily identified by Gram's stain and lacto-phenol cotton blue. Indoor temperature, relative humidity and CO_2 level were measured in the same time. Outdoor air samples were collected for comparison. Data were analyzed using descriptive statistics.

Results: Mean and standard deviation of temperature in OPDs was 24.9±1.2°C, that in IMWs was 31.0±0.3°C, and that in ICUs was 25.8±0.9°C (outdoor = 31.4±0.1°C). Relative humidity showed 60.4±3.6 %, 63.8±1.9%, and 60.9±3.0%, respectively (outdoor = 59.9±0.9%). Mean CO_2 levels of 859.6±422.2 ppm., 320.3±28.2 ppm., and 408.1±13.1 ppm. (outdoor = 295.0±2.3 ppm.) were demonstrated. Means of bacterial counts were 329.8±207.6 cfu/m^3 in OPDs, 376.7±80.2 cfu/m^3 in IMWs, and 299.2±118.2 cfu/m^3 in ICUs (outdoor air = 347.7±86.9 cfu/m^3). Means of fungal counts were 146.7±82.3 cfu/m^3, 303.6±54.6 cfu/m^3, and 215.7±80.0 cfu/m^3, respectively (outdoor air = 301.2±85.3 cfu/m^3). Approximately 12.3%, 11.5%, and 29.5% of air samples collected from OPDs, IMWs and ICUs had bacterial counts higher than 500 cfu/m^3, whereas, only 1 air sample collected from IMW had fungal count higher than 500 cfu/m^3. Focusing on indoor air in ICUs, 47.6% and 19.1% of air samples had bacterial and fungal counts higher than 300 cfu/m^3. The most common isolated bacteria and fungi were *Staphylococcus* spp., and *Aspergillus* spp., respectively.

Conclusion: This study revealed high bacterial contamination in indoor air at different sites of the hospital, especially in ICUs. The predominant isolated bacteria contaminated in air were *Staphylococcus* spp. which was one of common pathogens causing nosocomial infections. These are valuable data for developing interventions to improve indoor air quality which may affect the patient's health and the quality of working life of health care personnel, especially nurses in the hospital.

Introduction

Indoor air quality (IAQ) is one of major environmental problems related to human health. It can affect the health, comfort, well-being, and productivity of the building occupants [1]. Microbial indoor air comes from hundreds of bacterial and fungal species that grow indoors when sufficient moisture is available. Exposure to microbial contaminants is clinically associated with respiratory symptoms, allergies and asthma, and can affect the immunological system [2-4]. World Health Organization (WHO) estimates that 30% of the buildings may have IAQ related problems[5]. In 2007, a WHO working group on dampness and mould met to identify the main health risks due to excess moisture and microbial growth and contamination of indoor spaces, and to formulate WHO guidelines for protecting public health [6]. Dampness and mold growth in the home and workplace environment have been associated with adverse respiratory effects [6-8], and high concentration of bacteria or fungi in air indicated overcrowding or poor ventilation [9,10]. Preventing or minimizing persistent damp and microbial growth on interior surfaces and building structures is the most important means of avoiding harmful effects of indoor air on health [3].

Hospital is one of workplace areas contaminated with a variety of occupational hazards including infectious materials or contaminated equipments, blood and other body fluids from patients. Healthcare workers probably exposed to health hazards in the hospital environment, especially bioaerosol and to be at risk for infections [10,11]. Many medical procedures probably generate low particle size aerosols to be inhaled into the lungs of any exposed laboratory, dental and other healthcare personnel [10,12,13]. A recent study has shown that inadequate ventilation, inappropriate use of personal protective barriers, and inadequate disposal of biological wastes enhance risks of tuberculosis infection in hospital personnel [12,14,15]. Additionally, indoor air quality in the hospital may affect to hospital-acquire

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infections, sick hospital syndrome and various occupational hazards to health among personnel and patients [16]. However, there is a limited study on microbial indoor air quality and microbial groups in a governmental hospital in the northern Thailand. The findings may be valuable to develop the preventive intervention for improving indoor air quality which may affect the patient's health and the quality of working life of health care personnel, especially nurses in this hospital.

Materials and methods

Study design and study samples

During May to July 2016, a cross-sectional design was carried out among a governmental hospital in the northern Thailand to investigate indoor air quality including bacterial and fungal counts, temperature, relative humidity, and CO_2 level. A studied hospital is a provincial hospital with 750 patient-beds. This hospital is located near a busy traffic junction. In total 208 indoor air samples were collected from the different hospital sites including out-patient departments (OPDs), internal medical wards (IMWs), and intensive care units (ICUs) to investigate bacterial count (104 samples) and fungal count (104 samples). Eight outdoor air samples (4 samples for bacterial count and 4 samples for fungal count) were collected for comparison with indoor air assessment. Details are presented in Table 1. Additionally, temperature, relative humidity, and CO_2 level were assessed in the same point and the same time of air sample collection.

Methods of air sample collection and interpretation

Indoor air in OPDs and outdoor air samples were collected during the hours from 9 a.m. to 3 p.m. on Friday. Indoor air samples in internal medical wards and ICUs were collected during the hours from 9 a.m. to 3 p.m. on Saturday, outdoor air samples were collected for comparison. All air samples were collected using the Millipore air tester. The Millipore air tester system is based on the Anderson principle, followed the active air sampling method [17], and uses a sieve with about 1,000 microperforations, which reduces the potential for overlapping colonies and minimizes the desiccation of the medium. The tester is small enough to be used in confined spaces, but powerful enough to sample up to 1000 liters in just seven minutes. In this study, 250 liters of air was collected. The plate count method was used to estimate bacterial or fungal counts. General bacteria were cultured in plate count agar at 37°C for 48 hrs, and general fungi were cultured in a Sabouraud 4% dextrose agar, at room temperature, for 5 days with daily observation. After incubation, the bacterial and fungal colonies were counted and calculated to express as colony forming unit/m^3 (cfu/m^3) by the following formula:

Total counts (colony forming unit/m^3 or cfu/m^3) = [Total colonies x 1000]/250

The isolated colonies of bacteria and fungi were identified group or genus by gram stained and with lacto-phenol cotton blue dye following Larone's guide [18].

Interpretation for microbial indoor air quality

If the microbial count was more than 500 cfu/m^3, it was an indication of overcrowding or poor ventilation following the recommended guideline of the American Conference of Governmental Industrial Hygienists (ACGIH) [9]. However, bacterial counts or fungal counts should be less than 300 cfu/m^3 for general offices [2,5].

Ethical approval

This study is a part of the research protocol submitted and approved by Ethics Committee for Human Research, Faculty of Public Health, Mahidol University and Ethics Committee of the studied hospital before data collection (COA. No. MUPH 2013-148 on 17 Oct, 2014).

Data analysis

Data were analyzed by computer program SPSS version 18. The descriptive statistics including percentage, mean and standard deviation was used for describing bacterial and fungal counts.

Results

Indoor air quality: Temperature, relative humidity and CO_2 concentration

A total sample of indoor air in a studied hospital included 57 samples from OPDs, 26 from IMWs, and 21 from ICUs. Results showed that mean temperature of OPDs was 24.9±1.2°C, that of IMWs was 31.0±0.3°C, and that of ICUs was 25.8±0.9°C, respectively. For relative humidity, they were 60.4±3.6 %, 63.8±1.9%, and 60.9±3.0%, respectively. And CO_2 concentration, the means of 859.6±422.2 ppm., 320.3±28.2 ppm., and 408.1±13.1 ppm. were found in OPDs, IMWs, and ICUs, respectively. Details are shown in Table 2.

Table 1. Number of studied wards and indoor air samples collected among studied wards in a hospital

Studied departments or wards	No. of air samples for Bacteria Fungi	Points of air sampling in departments or wards
OPDs		
1	18 18	Air samples were collected at the nurse station, medical examination room, patient observation room, and patient waiting areas (central air conditioning system and sometimes with poor ventilation tested by a smoke tube)
2	17 17	
3	20 20	
		Air samples were collected at the nurse station, and patient-bed section (naturally ventilated and supplemented with electric ceiling fans)
Medical wards		
Female medical wards	16 16	
(1, 2, 3)	11 11	Air samples were collected at the nurse station, and patient-bed section (central air conditioning system)
Male medical wards (1,2)		
ICUs		
1	7 7	
2	7 7	
3	7 7	
Total	104 104	

Indoor air quality: Bacterial and fungal counts in air samples

For microbial indoor air quality, results showed means of bacterial counts 329.8 ±207.6 cfu/m^3 in OPDs, 376.7±80.2 cfu/m^3 in IMWs, and 299.2±118.2 cfu/m^3 in ICUs (outdoor air = 347.7±86.9 cfu/m^3). For fungal counts, they were 146.7±82.3 cfu/m^3, 303.6±54.6 cfu/m^3, and 215.7±80.0 cfu/m^3, respectively (outdoor air = 301.2±85.3 cfu/m^3). Details are shown in Table 3. When we analyzed microbial counts in detail classified into 3 levels, <300 cfu/m^3, 300-500 cfu/m^3, and >500 cfu/m^3, and compared with the recommended level of American Conference of Governmental Industrial Hygienist (ACGIH) committee recommendations (≤500 cfu/m^3). It was found that 12.3% of air samples collected from OPDs, 11.5% collected from IMWs, and 29.5% collected from ICUs had bacterial counts higher than the recommended indoor air level of the ACGIH (>500 cfu/m^3). As well as, 0.0%, 3.8%, and 0.0% of air samples collected from OPDs, IMWs, and ICUs had fungal counts higher than the recommended indoor air level of the ACGIH (>500 cfu/m^3). Focusing on indoor air in ICUs, 47.6% and 19.1% of air samples had bacterial and fungal counts higher than 300 cfu/m^3. Details are shown in Table 4.

The isolated colonies of bacteria and fungi were identified into group or genus by gram stained and with lacto-phenol cotton blue dye. It was found that the most common bacteria was *Staphylococcus* spp. (65.0%, 63.4%, and 58.8%) found in OPDs, IMWs, and ICUs, whereas, the predominant fungi were *Aspergillus* spp. and septate hypha fungi (47.0%, 42.5%, and 48.6% VS 23.7%, 25.0%, and 25.7%, respectively). However, *Penicillium* spp. were found 22.5%, 27.5%, and 22.9%, respectively. Focusing on *Staphylococcus* spp., the predominant species was *Staphylococcus aureus*. Details are shown in Table 5.

Discussion

Poor indoor air quality in hospital may cause sick hospital syndrome including respiratory symptoms, skin symptoms, and non-specific symptoms. It may lead to hospital-acquired infections in patients and healthcare personnel [21]. Hospital environments may be dynamic environments affected by weather conditions, indoor

Table 2. Mean ± standard deviation of temperature, % of relative humidity and CO_2 concentration (ppm.) in air samples collected from studied hospital

Studied wards	No. of samples	Temperature (°C)	% of Relative Humidity	CO_2 (ppm.)
OPDs				
1	18	25.3±1.3	59.5±3.4	779.3±104.3
2	17	23.9±0.8	62.1±3.1	1351.2±451.1
3	20	25.4±0.9	59.8±3.7	545.5±83.1
Total	57	24.9±1.2	60.4±3.6	859.6±422.2
Medical wards				
FMW 1	5	31.2±0.4	63.9±2.2	267.4±20.8
FMW 2	5	31.8±0.2	64.0±2.4	275.0±20.7
FMW 3	6	29.6±0.4	64.5±2.2	419.7±61.2
MMW 1	5	31.6±0.1	63.3±1.5	328.4±14.8
MMW 2	6	30.9±0.4	63.3±1.1	310.8±23.6
Total	26	31.0±0.3	63.8±1.9	320.3±28.2
ICUs				
1	7	26.8±1.0	59.0±3.5	426.4±21.9
2	7	25.8±0.4	63.4±1.8	410.9±12.5
3	7	24.7±1.2	60.4±3.6	386.9±4.8
Total	21	25.8±0.9	60.9±3.0	408.1±13.1
Outdoor	2	31.4±0.1	59.9±0.9	295.0±2.3

Table 3. Mean ± standard deviation of bacterial counts (cfu/m^3) in air samples collected from studied hospital

Studied wards	No. of Air samples	Bacterial counts	Fungal counts
OPDs			
1	18	306.0±100.0	152.4±89.5
2	17	304.2±77.1	134.2±64.8
3	20	272.9±324.8	152.2±91.3
Total	57	329.8±207.6	146.7±82.3
Medical wards			
FMW 1	5	423.2±76.8	354.4±47.4
FMW 2	5	367.2±56.9	374.4±33.7
FMW 3	6	358.0±112.5	282.7±81.7
MMW 1	5	370.4±63.0	282.4±46.4
MMW 2	5	364.8±91.8	224.0±64.0
Total	26	376.7±80.2	303.6±54.6
ICUs			
1	7	405.0±137.1	162.6±50.8
2	7	172.3±74.8	208.7±91.1
3	7	320.4±142.8	275.9±98.0
Total	21	299.2±118.2	215.7±80.0
Outdoor	4	347.7±86.9	301.2±85.3

Table 4. Number and percentage of high level of bacterial and fungal counts (cfu/m^3) in air samples collected from a studied hospital

Studied wards	No. of Air samples	Bacterial counts (cfu/m^3)			Fungal counts (cfu/m^3)		
		≤ 300	301-500	>500	≤ 300	301-500	>500
OPDs							
1	18	7	10	1	16	2	0
2	17	9	7	1	16	1	0
3	20	10	7	5	20	2	0
Total	57	26 (45.6)	24 (42.1)	7 (12.3)	52 (91.2)	5 (8.8)	0(0.0)
Medical wards							
FMW 1	5	1	3	1	1	3	1
FMW 2	5	0	5	0	0	5	0
FMW 3	6	2	3	1	4	2	0
MMW 1	5	0	5	0	3	2	0
MMW 2	5	1	3	1	4	1	0
Total	26	4 (15.4)	19 (73.1)	3(11.5)	12 (46.2)	13 (50.0)	1(3.8)
ICUs							
1	7	0	6	1	7	0	0
2	7	7	0	0	6	1	0
3	7	4	2	1	4	3	0
Total	21	11 (52.4)	8 (38.1)	2 (9.5)	17 (80.9)	4 (19.1)	0 (0.0)
Outdoor	4	0 (0.0)	3 (75.0)	1 (25.0)	1 (25.0)	2 (50.0)	1(25.0)

Table 5. Percentage of isolated bacteria and fungi classified by selected departments in a studied hospital

Types of isolated micro-organisms	Percentage of isolated micro-organisms by wards		
	OPDs	Medical wards	ICUs
Bacteria	(n=160 colonies)	(n=90 colonies)	(n=80 colonies)
Staphylococcus spp.*	104 (65.0)	57 (63.4)	47 (58.8)
Gram negative rods	37 (23.1)	21 (23.3)	22 (27.5)
Gram positive bacilli	19 (11.9)	12 (13.3)	11 (13.7)
Fungi	(n=80 colonies)	(n=40 colonies)	(n=35 colonies)
Aspergillus spp.	38 (47.5)	17 (42.5)	17 (48.6)
Septate hypha fungi	19 (23.7)	10 (25.0)	9 (25.7)
Penicillium spp.	18 (22.5)	11 (27.5)	8 (22.9)
Others	5 (6.3)	2 (5.0)	1 (2.8)

*Most of them (51-58% of *Staphylococcus* spp. in each ward) were *S. aureus*

ventilation system in the hospital, season, number of patients, visitors and occupants, and out-door air contaminants [22]. This cross-sectional study was only a short-term assessment of indoor air quality including indoor temperature, relative humidity, CO_2 concentration, and microbial count (bacterial and fungal counts) in different hospital areas or wards. Additionally, a characterization of microbial genus or groups was preliminarily identified. The study found that mean temperature and mean relative humidity of OPDs was 24.9±1.2°C and 60.4±3.6 %, those of IMWs were 31.0±0.3°C and 63.8±1.9%, and those of ICUs were 25.8±0.9°C and 60.9±3.0%, respectively. The temperature and relative humidity in IMWs were higher than those in OPDs and ICUs due to no use of air conditioners in IMWs during indoor air study. They were open-air. For CO_2 concentration, the means of 859.6±422.2 ppm., 320.3±28.2 ppm., and 408.1±13.1 ppm. were found in OPDs, IMWs, and ICUs, respectively. The OPDs had the highest level of CO_2 concentration due to the higher patients and their relatives waiting for seeking the doctors and treatment. This evidence supported the higher number of persons or activities having the higher CO_2 concentration in the air environments and insufficient ventilation of indoor air, and it probably affected patients and hospital personnel who took a long time of exposure [20].

Results for microbial indoor air quality assessment showed that means of bacterial counts were 329.8±207.6 cfu/m^3 in OPDs, 376.7±80.2 cfu/m^3 in IMWs, and 299.2±118.2 cfu/m^3 in ICUs. For fungal counts, they were 146.7±82.3 cfu/m^3, 303.6±54.6 cfu/m^3, and 215.7±80.0 cfu/m^3 found in OPDs, IMWs, and ICUs, respectively. The higher levels of bacterial and fungal counts were found in air samples collected from IMWs probably due to the open-air wards on the time of air sample collection and the effect of the higher bacterial and fungal counts in outdoor air (347.7±86.9 cfu/m^3 and 301.2±85.3 cfu/m^3, respectively), whereas, the OPDs and ICUs used the air conditioners. The total number of microorganisms would be reduced after starting the air conditioning system in few minutes [21].

When we analyzed microbial counts in detail classified into 3 levels, <300 cfu/m^3, 300-500 cfu/m^3, and >500 cfu/m^3, and compared with the recommended level of American (ACGIH) (≤500 cfu/m^3) and WHO (≤300 cfu/m^3 for general officers). It was found that 12.3% of air samples collected from OPDs, 11.5% collected from IMWs, and 29.5% collected from ICUs had bacterial counts higher than the recommended indoor air level of the ACGIH (>500 cfu/m^3). As well as, 0.0%, 3.8%, and 0.0% of air samples collected from OPDs, IMWs, and ICUs had fungal counts higher than the recommended indoor air level of the ACGIH (>500 cfu/m^3). However, 47.6% and 19.1% of air samples collected from ICUs had bacterial and fungal counts more than 300 cfu/m^3. These evidences supported that hospital personnel and patients admitted in ICUs might be at risk for air-borne or droplet infections due to the poor ventilation in ICUs. Moreover, indoor air with bacterial or fungal counts more than 100 cfu/m^3 might affect patients with immunosuppression [2,5].

The high level of bacterial counts indicated overcrowding or poor ventilation or unsanitary condition of indoor air in some areas of the studied wards [9.10]. Although most airborne bacteria and fungi do not present a health hazard, these micro-organisms may affect human health with a wide range of adverse health effects including respiratory infections, allergies and others in some individuals, especially susceptible persons, young children, elderly, and immune-compromised persons [4,19,22,23]. Several factors influenced the microbial load in indoor air, such as the number of occupants, the air conditioning systems, and the ventilation; and some physical factors including heat, temperature, and humidity were reported [24-26]. Occupants are a potential source of microorganisms as they shed the microorganisms from the skin and respiratory tract [5,19]. Additionally, Fungal counts in some areas, especially in IMWs were relatively higher levels. The control of temperature and relative humidity should be done. Temperatures below 16°C and above 25°C caused a reduction in the concentration of airborne fungi. Maintaining the relative humidity between 30-60% would help control mold, dust mites, and cockroaches [27-29].

The isolated colonies of bacteria and fungi were identified group or genus. It was found that the most common bacteria were *Staphylococcus* spp. (65.0%, 63.4%, and 58.8%) found in OPDs, IMWs, and ICUs, likely the study of Sudharsanam *et al* (2012) [26] and Verde *et al* (2015) [16]. However, this bacterial air quality assessment and identification did not cover the anaerobic and higher bacteria. Whereas, the predominant fungi were *Aspergillus* spp. and septate hypha fungi (47.0%, 42.5%, and 48.6% VS 23.7%, 25.0%, and 25.7%, respectively). And *Penicillium* spp. were found 22.5%, 27.5%, and 22.9%, respectively. A survey of airborne fungi in buildings and outdoor environment in the United States (2002) found that *Aspergillus* spp. was the most common fungi [30] which was similar in the present study. The preventive interventions, such as improving the air ventilation and the biosafety to minimize risk of personnel injury and infections after this study should be considered. In addition, a longitudinal study, or surveillance might be done and other air quality indicators, especially, PM_{10} and $PM_{2.5}$ levels should be included. The intervention program for reducing the microbial concentration in the air should emphasize the ventilation strategy, the cleaning program on surface environments, medical instruments and air conditioners in the studied wards.

Conclusion

This study revealed high bacterial contamination in different wards of a studied hospital. The predominant isolated bacteria and fungi contaminated in air samples were *Staphylococcus* spp. and *Aspergillus* spp., respectively. These are valuable data for developing interventions to improve indoor air quality which may affect the patient's health and the quality of working life of health care personnel, especially nurses in this hospital.

Conflicts of interest

We declare that we have no conflict of interest.

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