# LABORATORY FACILITY DESIGN AND MICROBIAL INDOOR AIR QUALITY IN SELECTED HOSPITAL LABORATORIES

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**Abstract.** Hospital laboratory is one of workplace areas contaminated with a variety of biohazards. A cross sectional study was conducted to assess the microbial air quality and facility design in the laboratories of four selected governmental hospitals (Hospitals A, B, C, and D) in Bangkok, Thailand. One hundred eighty-eight indoor air samples were collected from 40 laboratory rooms to investigate bacterial and fungal counts using the Millipore air tester. Forty air samples were collected from the waiting areas of those laboratories, and 16 outdoor air samples were collected to use for comparison. Additionally, those laboratory facilities were assessed following biosafety facility design (10 items). Results indicated that the facility design of laboratory in the Hospital A met most of items of the biosafety facility criteria. The rest met only seven items of the criteria. Means ± standard deviation (SD) of bacterial counts of 253.1±247.7 cfu/$m^3$, 236.8±200.1 cfu/$m^3$, 304.4±264.2 cfu/$m^3$, and 146.7±127.0 cfu/$m^3$, and fungal counts of 500.8±64.2 cfu/$m^3$, 425.0±21.2 cfu/$m^3$, 357.0±121.2 cfu/$m^3$, and 355.7±86.8 cfu/$m^3$ were found in hospital laboratories A, B, C and D, respectively. The isolated colonies of bacteria and fungi were identified as group or genus. It was found that the most common bacteria was *Staphylococcus* spp (84.1%, 76.0%, 72.1% and 80.5%, respectively), whereas, the most common fungi were *Aspergillus* spp and septate hyphae fungi (42.0%, 37.5%, 39.5%, and 45.7%; *vs* 38.6%, 56.2%, 52.1%, and 37.2%, respectively). These data may be valuable to develop interventions to improve the microbial indoor air quality among hospital laboratories and for preventing the laboratory-acquired infections.

**Keywords:** biosafety, hospital laboratories, laboratory facility design, microbial indoor air quality

## INTRODUCTION

Indoor air quality is an important issue for both homes and workplaces. The related problems are some of the major risk factors for human health in both developing and developed countries (Douwes *et al*, 2003; Luksamijarulkul, 2011, 2012). The life-style of urban people, which has changed and increased the amount of time indoors has made clinicians face an increase of patients with indoor air quality related problems (Luksamijarulkul, 2011). In 2007, a WHO working group on dampness and mold met to identify the main health risks due

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to excess moisture, microbial growth, and contamination of indoor spaces, and to formulate WHO guidelines for protecting public health (WHO, 2008). Dampness and mold growth in the home and workplace environment have been associated with adverse respiratory effects (McNeel and Kreutzer, 1996; Szymanska, 2005; WHO, 2008), and high concentrations of bacteria or fungi in the air indicated overcrowding or poor ventilation (Seitz, 1989; Kodama and McGee, 1996).

A hospital laboratory is one of workplace areas potentially contaminated with various occupational hazards, including infectious materials, contaminated equipment, and blood and other body fluids from patients, including pus, urine, stool, sputum, secretions, or saliva. Laboratory personnel are likely to be exposed to health hazards in the laboratory environment and could be at risk for occupational infections (Sewell, 1995; Bennett and Parks, 2006; Vonesch *et al*, 2006). Additionally, many laboratory procedures probably generate low-particle size aerosols that could be inhaled into the lungs of exposed laboratory personnel (Sewell, 1995; Bennett and Parks, 2006).

A recent study suggested that inadequate ventilation, accidents with biological specimens, and inadequate disposal of biological wastes enhance the risk of TB infection among laboratory personnel (Deriemer *et al*, 2000). Another study in a hospital indicated that high microbial counts in air samples collected from hospital wards put hospital personnel at risk of air-borne and/or droplet infections (Luksamijarulkul *et al*, 2004a).There is limited research on laboratory facility design and microbial indoor air quality in governmental hospital laboratories in Bangkok. Studies that address these issues would be valuable to develop preventive interventions for improving microbial indoor air quality and the quality of working life among this group.

## MATERIALS AND METHODS

### Study design and study samples

During October 2008 to February 2009, a cross sectional study was conducted at four purposively selected governmental hospital laboratories in Bangkok (Hospitals A, B, C, and D) to investigate microbial indoor air quality and facility design of their laboratories. Hospital A is a large hospital with 1,150 patient beds and 19 laboratory rooms. This hospital is located near a busy traffic junction. The laboratory building is separated from other hospital buildings. Hospitals B and C are medium-sized hospitals. Hospital B has 550 patient beds and eight laboratory rooms located at the first floor of the fifth building of the hospital. Hospital C has 600 patient beds and six laboratory rooms located near the outpatient department setting on the first floor of the hospital building. Both hospitals (B and C) are located on busy traffic roadsides. Hospital D is a small hospital with 350 patient beds and five laboratory rooms located on the second floor of the hospital building. Details of laboratory-work types of the four studied hospitals are presented in Table 1.

The facility designs of these laboratory rooms were assessed using the checklist of the biosafety facility design criteria that followed the guidelines of US Government Biosafety in Microbiological and Biomedical Laboratories (Richmond and McKinney, 1999). For microbial indoor air quality assessment, duplicated indoor air samples were collected from 2-to-3 points in each laboratory room using Millipore air tester (M Air T™; Merck KGaA, Darmstadt, Germany).

Table 1
Number of studied laboratory rooms and indoor air samples collected among studied hospital laboratories.

| Types of studied hospital laboratories | Hospital A | | Hospital B | | Hospital C | | Hospital D | |
|---|---|---|---|---|---|---|---|---|
| | No. of lab rooms | No. of air samples | No. of lab rooms | No. of air samples | No. of lab rooms | No. of air samples | No. of lab rooms | No. of air samples |
| Clinical microscopy and hematology | 3 | 18 | 2 | 8 | 2 | 8 | 1 | 4 |
| Clinical chemistry | 4 | 20 | 1 | 4 | 1 | 4 | 1 | 4 |
| Serology/Immunology and blood bank | 5 | 27 | 2 | 8 | 2 | 8 | 2 | 6 |
| Microbiology and biosafety lab | 3 | 18 | 2 | 10 | 1 | 5 | 1 | 4 |
| Others (such as histology, genetic lab, blood donor room, etc) | 4 | 20 | 1 | 4 | 2 | 8 | - | - |
| Total | 19 | 103 | 8 | 34 | 8 | 33 | 5 | 18 |
| Out-side of laboratories (Waiting area) | - | 13 | - | 10 | - | 10 | - | 7 |
| Out-door | - | 4 | - | 4 | - | 4 | - | 4 |

One hundred three air samples from hospital laboratory A, 34 air samples from hospital laboratory B, 33 air samples from hospital laboratory C, and 18 air samples from hospital laboratory D were collected to assess bacterial and fungal counts. Forty indoor air samples were collected from the waiting areas of each hospital laboratory, and 16 outdoor air samples were collected to use for comparison with indoor air assessment in each hospital laboratory (Table 1).

**Methods of air sample collection and interpretation**

Indoor and outdoor air samples were collected during the hours from 9:00 AM to 12:00 AM, Monday and Wednesday using the Millipore air tester. The Millipore air tester system "is based on the Anderson principle, and uses a sieve with about 1,000 microperforations, which reduces the potential for overlapping colonies and minimizes the desiccation of the medium" (Millipore Technical Publications, 1999). The tester is small enough to be used in confined spaces, but powerful enough to sample up to 1,000 liters in just seven minutes.

In this study, 250 liters of air were collected. The air collection technique followed the active air sampling method (Fradkin, 1987; Pasquarella *et al*, 2008).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 hours, 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 1,000]/250

If the microbial count was more than 500 cfu/$m^3$, it was an indication of overcrowding or poor ventilation following the recommended guidelines of the American Conference of Governmental Industrial Hygienists (ACGIH) (Seitz, 1989).

**Data analysis**

Data were analyzed by SPSS program (IBM, Armonk, NY). The descriptive statistics including percentages, and mean and standard deviations were used for describing bacterial and fungal counts.

## RESULTS

**Laboratory facility design of the studied hospital laboratories**

The facility design of the four studied governmental hospital laboratories (A, B, C, and D) were assessed using the checklist of the biosafety facility design criteria. We found that the facility design of laboratory in the hospital A met most items of the biosafety criteria. The remaining hospitals met only 7 out of 10 items of the criteria. The most common insufficient facility designs included no eyewash station and no annual certification of biosafety cabinet maintenance. Additionally, there was no biohazard sign posted at the entrance to the microbiology laboratory or biosafety room. Details are shown in Table 2.

**Microbial indoor air quality in studied hospital laboratories**

Two hundred twenty-eight indoor air samples were collected from the four selected hospital laboratories (188 samples) and their waiting areas (40 samples) to investigate bacterial and fungal counts. We found that the means±SD of bacterial counts in hospital laboratories A, B, C, and D were 253.1±247.7 cfu/$m^3$, 236.8±200.1 cfu/$m^3$, 304.4±264.2 cfu/$m^3$, and 146.7±127.0 cfu/$m^3$, respectively. Those in the waiting areas of the studied laboratories were 500.8±64.2 cfu/$m^3$, 425.0±21.2 cfu/$m^3$, 357.0±121.2 cfu/$m^3$, and 355.7±86.8 cfu/$m^3$, respectively. Those in outdoor air samples were 345.0±120.2 cfu/$m^3$, 950.0±212.1 cfu/$m^3$, 420.0±254.6 cfu/$m^3$, and 120.0±84.9 cfu/$m^3$, respectively.

The highest mean count was found in hospital laboratory C, and the lowest level was found in hospital laboratory D. The clinical microscopy/hematology, clinical chemistry, and serology/immunology, and blood bank trended higher bacterial counts than other types of laboratories (Table 3).The bacterial mean counts in the waiting areas had higher levels than those in every laboratory room. When the indoor air bacterial counts were compared with the guidelines of the ACGIH, we found that 7.8%, 11.8%,12.1% and 5.6% of total air samples collected from each hospital laboratory had bacterial counts higher than the recommended indoor air level of the ACGIH (>500 cfu/$m^3$) (Table 3).

The means±SD of fungal counts in the hospital laboratory A,B, C, and D were 119.4±86.9 cfu/$m^3$, 175.3±101.2 cfu/$m^3$, 101.6±71.6 cfu/$m^3$, and 114.4±72.4 cfu/$m^3$, respectively. However, those in the waiting areas of the studied laboratories were 258.3±110.2 cfu/$m^3$, 247.5±83.0 cfu/$m^3$, 222.0±74.1 cfu/$m^3$, and 234.3±125.3 cfu/$m^3$, respectively. Those in outdoor air samples were 365.0±91.9 cfu/$m^3$, 630.0±268.7 cfu/$m^3$, 1,020±113.1 cfu/$m^3$, and 215.0±49.5 cfu/$m^3$ (Table 4).

The highest mean count was found in hospital laboratory B, and the lowest level was found in hospital laboratory

Table 2
Laboratory facility design of the studied hospital laboratories (only laboratory required biosafety, such as, laboratory for microbiology, pathology, and immunology).

| Items | Hospital A | Hospital B | Hospital C | Hospital D |
|---|---|---|---|---|
| 1. There is an eyewash station readily available. | +,- | - | - | - |
| 2. There is a biosafety level 2 (BSL2) laboratory which is separated from public areas. | +,- | +,- | +,- | +,- |
| 3. A biological safety cabinet is located away from doors, from windows that can be opened, from heavily traveled lab areas. | + | + | + | + |
| 4. There is an exhaust fan which is opened to reduce the microbial counts in air. | + | + | + | + |
| 5. The laboratory is designed to easily clean and there are some spaces between benches and cabinets accessible for cleaning. | + | + | + | + |
| 6. There are chairs and other furniture used in laboratory work made from non-fabric material that can be easily decontaminated. | + | + | + | + |
| 7. There is an illumination adequate for all activities. | + | + | + | + |
| 8. There is a sink for hand washing each laboratory. | + | + | + | + |
| 9. There is a BSC maintained properly and certified annually. | +,- | - | - | - |
| 10. There is a biohazard sign posted at the entrance to the microbiology laboratory or biosafety room. | +,- | - | - | - |

+ , presence; – , absence.

C (Table 4). When the indoor air fungal counts were compared with the guidelines of the ACGIH, we found that 1.9%, 5.9%, 3.0%, and 0% of total air samples collected, respectively, from each hospital laboratory had fungal counts higher than the recommended indoor air level of the ACGIH standard (>500 cfu/$m^3$). Details are shown in Table 4.

The isolated colonies of bacteria and fungi were identified as group or genus by Gram stain and with lacto-phenol cotton blue dye. We found that the most common bacteria was *Staphylococcus* spp (84.1%, 76.0%, 72.1%, and 80.5%) found in every studied laboratory, respectively; whereas, the predominant fungi were *Aspergillus* spp and septate hypha fungi (42.0%, 37.5%, 39.5%, and 45.7% *vs* 38.6%, 56.2%, 52.1%, and 37.2%, respectively). Details are shown in Table 5.

## DISCUSSION

Hospital laboratory with well-designed facilities could minimize risk of personnel injury and ensure safeguards against laboratory contamination of the

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

| Types of laboratory rooms | Hospital A | Hospital B | Hospital C | Hospital D |
|---|---|---|---|---|
| Clinical microscopy/Hematology | 266.4±218.4 (40-1,240) | 263.9±97.7 (20-800) | 280.0±21.2 (180-400) | 252.5±33.5 (20-500) |
| Clinical chemistry | 258.8±88.4 (40-610) | 270.0±91.9 (80-740) | 387.5±470.2 (40-1,600) | 360.0±56.6 (200-440) |
| Serology/Immunology/Blood bank | 215.5±81.3 (40-570) | 216.3±83.1 (20-800) | 224.3±58.5 (20-900) | 132.5±10.6 (40-100) |
| Microbiology/Biosafety | 174.7±73.2 (50-420) | 218.4±36.5 (40-600) | 122.5±33.5 (80-180) | 220.0±134.4 (60-560) |
| Others (such as Histology, Genetic etc) | 185.0±106.1 (50-550) | 85.0±35.4 (40-160) | 120.0±45.3 (20-340) | ND |
| Average for all laboratory rooms | ($n$ = 103) 253.1±247.7 (20-1,240) | ($n$ = 34) 236.8±200.1 (20-1,000) | ($n$ = 33) 304.4±264.2 (20-1,600) | ($n$ = 18) 146.7±127.0 (20-560) |
| No. (%) of air samples with bacteria > 500 cfu/m$^3$ | 8 (7.8) | 4 (11.8) | 4 (12.1) | 1 (5.6) |
| Out-side of laboratories (Waiting areas in the building) | ($n$ = 13) 500.8±64.2 (20-1,680) | ($n$ = 10) 425.0±21.2 (360-520) | ($n$ = 10) 357.0±121.2 (60-1,600) | ($n$ = 7) 355.7±86.8 (100-620) |
| No. (%) of air samples with bacteria > 500 cfu/m$^3$ | 5 (38.4) | 2 (20.0) | 1 (10.0) | 1 (14.3) |
| Out-door | ($n$ = 4) 345.0±120.2 (100-540) | ($n$ = 4) 950.0±212.1 (340-1,860) | ($n$ = 4) 420.0±254.6 (240-600) | ($n$ = 4) 120.0±84.9 (20-300) |

ND, not done; $n$, number of air samples.

outside environment (Deriemer *et al*, 2000). In the present study, three hospital laboratories (Hospitals B, C, and D) had no eyewash station and no annual certification of biosafety cabinet maintenance. Additionally, there is no biohazard sign posted at the entrance to the microbiology laboratory or biosafety room. Generally, laboratories should be designed for ease of cleaning, and hand-washing sinks and eyewash stations should be provided in every laboratory (Richmond and McKinney, 1999; Mulu and Kassu, 2005).

A previous study on risk factors found that the lack of biological safety cabinets (BSC), and insufficiently developed procedure and equipment operation skills were significant risk factors for laboratory-associated tuberculosis (Deriemer *et al*, 2000). The safety equipment included BSCs to remove or minimize exposure to hazardous biological materials or aerosols that are generated by many microbiological procedures, and the BSCs should be annually certified (Mulu and Kassu, 2005). Another study indicated that by improving administrative control and skills in the use of personal protective barriers could reduce the risk of tuberculosis infection among hospital personnel

Table 4
Mean ± standard deviation of fungal counts (cfu/$m^3$) in air samples collected from studied hospital laboratories.

| Types of laboratory rooms | Hospital A | Hospital B | Hospital C | Hospital D |
|---|---|---|---|---|
| Clinical microscopy/ Hematology | 115.6±33.9 (20-400) | 190.3±95.8 (60-1,080) | 125.0±28.3 (60-300) | 87.5±46.0 (40-300) |
| Clinical chemistry | 99.7±44.8 (22-300) | 270.0±190.9 (60-1,080) | 57.5±24.7 (20-160) | 175.0±27.1 (200-440) |
| Serology/Immunology/ Blood bank | 95.3±64.2 (60-570) | 69.0±19.8 (20-220) | 50.0±18.2 (20-160) | 75.1±14.1 (20-120) |
| Microbiology/Biosafety | 64.3±14.1 (20-150) | 168.4±58.9 (20-360) | 76.0±22.6 (20-180) | 82.5±10.6 (20-180) |
| Others (such as Histology, Genetic etc) | 107.5±31.8 (50-140) | 80.0±42.4 (40-120) | 86.0±31.1 (20-180) | ND |
| Average for all laboratory rooms | (*n* = 103) 119.4±86.9 (20-570) | (*n* = 34) 175.3±101.2 (20-1,080) | (*n* = 33) 101.6±71.6 (20-520) | (*n* = 18) 114.4±72.4 (20-440) |
| No. (%) of air samples with fungi > 500 cfu/$m^3$ | 2 (1.9) | 2 (5.9) | 1 (3.0) | 0 (0.0) |
| Out-side of laboratory (Waiting areas in the building) | (*n* = 13) 258.3±110.2 (30-900) | (*n* = 10) 247.5±83.0 (90-760) | (*n* = 10) 222.0±74.1 (60-760) | (*n* = 7) 234.3±125.3 (60-580) |
| No. (%) of air samples with fungi > 500 cfu/$m^3$ | 2 (15.4) | 1 (10.0) | 1 (14.3) | 1 (14.3) |
| Out-door | (*n* = 4) 365.0±91.9 (180-600) | (*n* = 4) 630.0±268.7 (180-1,460) | (*n* = 4) 1020.0±113.1 (840-1,200) | (*n* = 4) 215.0±49.5 (160-340) |

ND, not done; *n*, number of air samples.

Table 5
Percentage of isolated bacteria and fungi classified by selected hospital laboratories.

| Types of isolated micro-organisms | Percentage of isolated micro-organisms by laboratories of | | | |
|---|---|---|---|---|
| | Hospital A | Hospital B | Hospital C | Hospital D |
| Bacteria | (*n*=505 colonies) | (*n*=428 colonies) | (*n*=252 colonies) | (*n*=252 colonies) |
| *Staphylococcus* spp | 84.1 | 76.0 | 72.1 | 80.5 |
| Gram-negative rods | 13.5 | 21.7 | 26.2 | 15.0 |
| *Bacillus* spp | 2.4 | 2.4 | 1.7 | 4.4 |
| Fungi | (*n*=88 colonies) | (*n*=64 colonies) | (*n*=48 colonies) | (*n*=35 colonies) |
| *Aspergillus* spp | 42.0 | 37.5 | 39.5 | 45.7 |
| Septate hypha fungi | 38.6 | 56.2 | 52.1 | 37.2 |
| *Penicillium* spp | 6.8 | 4.7 | 4.2 | 11.4 |
| *Curvularia* spp | 4.5 | 1.6 | 4.2 | 5.7 |

(Luksamijarulkul *et al*, 2009).

This short-term study of microbial counts in indoor air samples, collected from four hospital laboratories in Bangkok, showed that the high mean counts of bacteria were found in hospital laboratories A, B, and C when compared with the level found in hospital laboratory D (253.1±247.7 cfu/$m^3$, 236.8±200.1 cfu/$m^3$, and 304.4±264.2 cfu/$m^3$, *vs* 146.7±127.0 cfu/$m^3$). Hospital laboratories A, B, and C are located at roadsides with heavy traffic flows; whereas, the hospital laboratory D is located at the roadside with a light traffic flow. Our findings were consistent with the bacterial counts in outdoor air samples, which were 345.0±120.2 cfu/$m^3$, 950.0±212.1 cfu/$m^3$, 420.0±254.6 cfu/$m^3$, and 120.0±84.9 cfu/$m^3$, respectively.

The area that was located near a busy traffic junction had high levels of outdoor microbial counts (Luksamijarulkul *et al*, 2004b). In addition, the present study also found that the clinical microscopy/hematology, clinical chemistry, and serology/immunology and blood bank trended to have higher bacterial counts than other types of laboratories. This may be dependent on the workloads and types of activities, the load of persons entering into the room, and the ventilation (Raaschou-Nielsen *et al*, 2001; Norris *et al*, 2002; Seino *et al*, 2005).

The means of the fungal counts were similar but somewhat lower than the bacterial counts (119.4±86.9 cfu/$m^3$, 175.3±101.2 cfu/$m^3$, 101.6±71.6 cfu/$m^3$, and 114.4±72.4 cfu/$m^3$, respectively), although those of fungal counts in outdoor air were rather high, especially outdoor air of hospital laboratory B and C (630.0±268.7 cfu/$m^3$ and 1,020±113.1 cfu/$m^3$, respectively). These findings may be due to the different conditions of humidity, temperature, wind velocity, and the ventilation affecting the mold growth (Jacobs, 1994; Peat *et al*, 1998; Yeo and Kim, 2002). Additionally, there are new construction sites at both hospitals B and C during the period of conducting this study.

The microbial isolates were identified by group or genus; it was found that the most common bacteria was *Staphylococcus* spp found in every studied laboratory, and the most common fungi were *Aspergillus* spp and septate hypha fungi. However, this bacterial air quality assessment and identification did not cover the anaerobic and higher bacteria. A previous study demonstrated that most *Staphylococcus* spp found in air environments was *S. epidermidis*–the normal flora of the human skin and respiratory tract (Kraidman, 1975). A study of roadside air samples under sky-train station in Bangkok also found that the predominant bacteria and fungi were *Staphylococcus* spp and *Aspergillus* spp (Luksamijarulkul and Kongtip, 2010). Similarly, a survey of airborne fungi in buildings and the outdoor environment in the United States found that *Aspergillus* spp was the most common fungi (Shelton *et al*, 2002).

When the indoor air bacterial and fungal counts were compared with the guideline of the ACGIH, we found that 5.6%-12.1% for bacterial count and less than 5.9% for the fungal count had levels higher than the recommended indoor air level (>500 cfu/$m^3$). High count of bacteria indicated overcrowding or poor ventilation (Seitz, 1989; Kodama and McGee, 1996). 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, such as young children, the elderly, and immune-

compromised persons (Jacobs, 1994; Douwes *et al*, 2003; Graham, 2004; Luksamijarulkul, 2012). However, the World Health Organization suggested that the microbial counts in the general workplace should be less than 300 cfu/$m^3$, and for individuals with immune-suppression, the microbial air count should be less than 100 cfu/$m^3$ (WHO, 1990).

Data from personal health records and interviews indicated that 20%-27.3% of studied laboratory personnel had regular air-quality related symptoms including running or stuffy nose, throat dryness or irritation, cough, sinus congestion, skin irritation, and others. In addition, 1-2 personnel of all studied hospital laboratories had a history of pulmonary tuberculosis during a 3-year routine health screening (data not presented). The preventive interventions, such as improving the air ventilation and the biosafety guidelines for laboratory practices were implemented in two hospital laboratories (A and B) to minimize risk of personnel injury and infections after this study was completed. The other two hospital laboratories (C and D) will implement in the future. In addition, a longitudinal study, or surveillance, could be undertaken, as well as other air quality indicators, especially, $PM_{10}$ and $PM_{2.5}$ levels should be included.

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