Environment and Pollution; Vol. 3, No. 4; 2014
ISSN 1927-0909 E-ISSN 1927-0917
Published by Canadian Center of Science and Education

Indoor Air Quality of Typical Malaysian Open-air Restaurants

Yusri Yusup[1], Mardiana Idayu Ahmad[1] & Norli Ismail[1]

[1] Environmental Technology, School of Industrial Technology, Universiti Sains Malaysia, Penang, Malaysia

Correspondence: Yusri Yusup, Environmental Technology, School of Industrial Technology, Universiti Sains Malaysia, 11800 Penang, Malaysia. Tel: 60-4-653-5201. E-mail: yusriy@usm.my

Received: May 21, 2014 Accepted: June 11, 2014 Online Published: August 18, 2014

doi:10.5539/ep.v3n4p10 URL: http://dx.doi.org/10.5539/ep.v3n4p10

Abstract

This paper reports the indoor air quality state of typical open-air restaurants in Malaysia. The measured air pollutant parameters include respirable coarse particulate matter (PM10), carbon monoxide (CO) and microorganisms (bacteria and fungi). We determined the effects of occupancy, number of vehicles on nearby roads, temperature, wind speed and relative humidity on the indoor concentrations of PM10, CO and microorganisms. The indoor air quality of the restaurants tested was moderate, only in the 75th percentile, and the CO concentrations were slightly elevated indoors. Among the ambient parameters measured, only wind speed and temperature affect the PM10 concentrations. The indoor and outdoor values of wind speed and temperature were similar. We observed a strong positive correlation between the PM10 concentrations and concentration of airborne microorganisms. Further microbiological analyses showed that Gram-positive bacteria were abundant compared to Gram-negative bacteria. Gram-positive cocci (micrococci, streptococci, staphylococci and diplococci) were the dominant microbial morphologies, followed by pathogenic Gram-negative enterobacteriaceae and Gram-positive bacilli.

Keywords: indoor air quality, PM10, CO, bacteria, fungi

1. Introduction

Indoor air quality in working, dining and residential locations concerns a considerable number of people because they spend increasing fractions of their lives indoors (Lee & Chang, 2000; Zhao & Wu, 2007). Both scientific and public interest in indoor air pollutants have recently increased due to the negative impact of poor air quality on environmental and occupational health (Rajasekar & Balasubramanian, 2011).

Criteria air pollutants, such as particulate matter (PM) and carbon monoxide (CO), are important indicators of both indoor and outdoor air quality due to their harmful effects on human health. PM originates from a variety of sources and may contain particles with different shapes, sizes and physicochemical compositions (El-Fadel & Massoud, 2000). PM has been linked to cardiovascular and respiratory diseases (Wan Mahiyuddin et al., 2013). Coarse particulate matter (PM10) consists of particles with aerodynamic diameters between 2.5 and 10 µm. Indoors, this class of PM, also known as respirable particulate matter (RSP), originates from cooking and smoking activities (Wallace, 1996). Table 1 lists studies reporting particulate matter concentrations (including PM10 and PM2.5, which have particle aerodynamic sizes of < 2.5 µm) in different building types. CO is a colourless, tasteless and odourless gas generated from the incomplete combustion of fuel and biomass, e.g., in gas stoves, and it causes asphyxiation at high concentrations. Although not a criteria pollutant, airborne microorganisms, or bio-aerosols, are also an important air quality parameter (Reanprayoon & Yoonaiwong, 2012), especially in restaurants, where they can increase the risk of food contamination and may originate from occupants, microbial growth and organic waste (Fabian et al., 2005).

Table 1. Respirable particulate matter (PM10 and PM2.5) concentrations in different building types from published literature (n is number of data points)

Study	Building type	Season	Sampling duration	Pollutant	n	Mean	Median	*S.D.	Range
(Baek, 1997)	Restaurant	Summer & Winter	2 hr	[a]RSP	24	171	159	101	33-475
(Fromme, 2007)	Classroom	Winter	8 hr	PM2.5	79	23.0	19.8	-	-
			8 hr	PM10	79	105	91.5	-	-
		Summer	8 hr	PM2.5	74	13.5	12.7	-	-
			8 hr	PM10	74	71.7	64.9	-	-
(Lee, 2001)	Restaurant (Chinese hot pot)	-	1 hr	PM2.5	-	81.1	-	10.0	49.1-136.5
		-	1 hr	PM10	-	105.3	-	19.9	39.3-129.5
(Bohac, 2010)	Restaurants (before ban)	-	10 min	PM2.5	62	77.1	52.1	-	-
	Restaurants (after ban)	-	10 min	PM2.5	62	2.9	1.9	-	-
(Asadi, 2011)	Hotel	-	-	PM10	-	-	-	-	59-94
(Li, 2001)	Shopping malls	-	1 hr	PM10	-	-	-	-	35-380
(Guo, 2004)	Wet markets	-	2 hr	PM10	24	-	-	-	49-167

* Standard Deviation

- Data not available

a Respirable suspended particulates (or respirable particulate matter)

In Malaysia and many other Asian countries, numerous restaurants and cafes are open or semi-open air buildings and often situated beside roads, factories and construction sites. The served food is commonly exposed to air, which could be contaminated due to poor indoor and outdoor air quality. Studies of indoor air quality in these dining establishments are scarce, and thus, no guidelines or best practices can be developed. This study attempts to investigate the indoor air quality state of three typical open-air restaurants by conducting an assessment of respirable coarse particulate matter (PM10), carbon monoxide (CO) and PM-laden microorganisms together with ambient temperature, wind speed, relative humidity, number of occupants and number of vehicles on nearby roads.

The objectives of this study are (1) to assess PM10 and CO concentrations at three open-air restaurants, (2) to quantify and identify airborne microorganisms and (3) to determine the relationships between the concentrations of PM, CO and airborne microorganisms and ambient (or surrounding) wind speed, temperature and relative humidity.

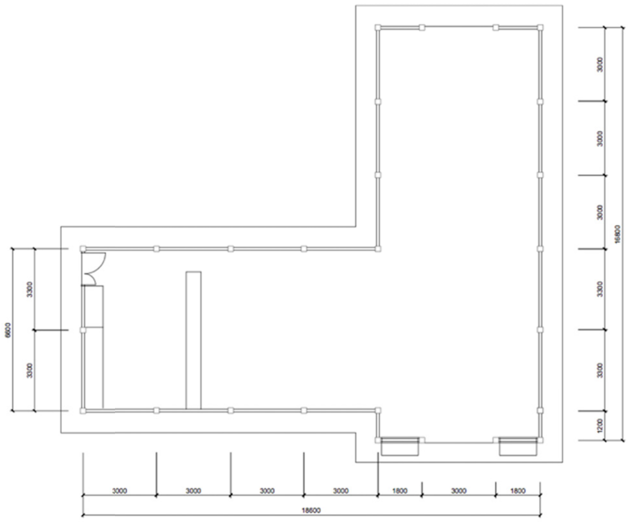
2. Materials and Methods

2.1 Site Description

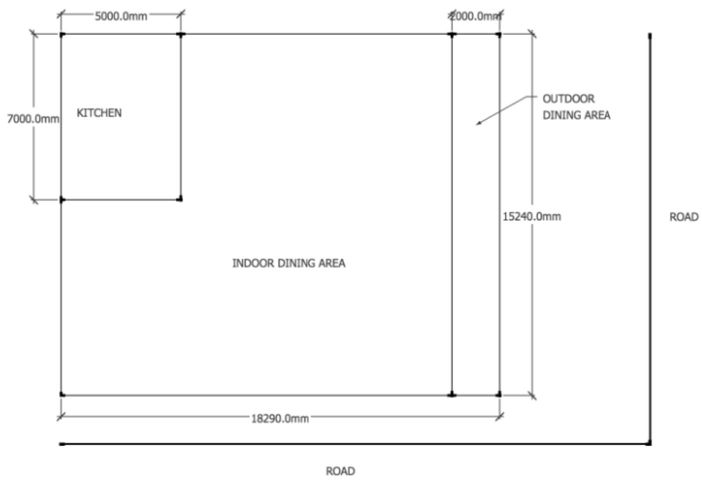
Restaurant #1 (RF): Open-air Restaurant Far from a road

This open-air canteen had 28 tables with four chairs each and seated a maximum of 112 occupants at a time. The restaurant consisted of a 26 m^2 kitchen and a 164 m^2 dining area, for a total area of 190 m^2. The floor of the cafe was made of tiles; the layout of the cafe is illustrated in Figure 1 (a). There were six ceiling fans. Most of the walls enclosing the cafe were not solid, and the windows were mostly open. The cafe had four full-time workers. The cafe opened from 08:00 LST to 16:30 LST (local standard time) during work days only (normally from Monday to Friday). In the kitchen, there were four gas stoves, and the styles of cooking were open-wok frying and deep-frying. Food was served on countertops and tables, mostly with no covers. This canteen-type establishment is common in Malaysia.

(a)



(b)



(c)

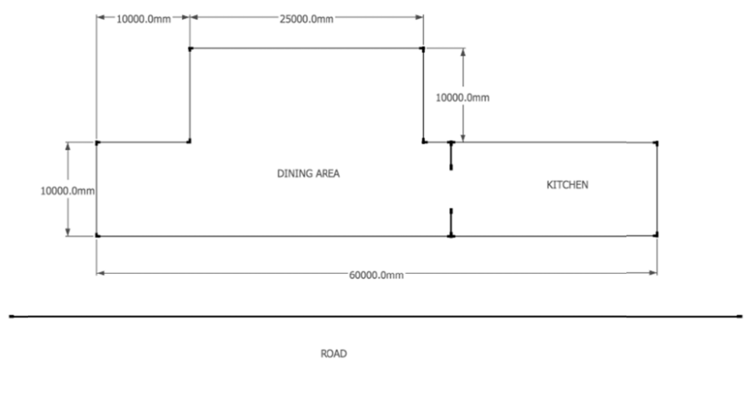


Figure 1. (a) Floor plan of restaurant RF (open-air Restaurant Far from a road) (b) floor plan of restaurant RBR (open-air Restaurant Beside a Road) (c) floor plan of restaurant RNR (open-air Restaurant Near a Road) and the location of roads for (b) and (c); dimensions are in mm

Restaurant #2 (RBR): Open-air Restaurant beside a Road

This 30-table Thai food restaurant was situated beside a busy four-lane highway. The restaurant had an area of 240 m^2 (60 m × 40 m) and was located 5 m from the road (Figure 1 (b)). This restaurant was also located near a car workshop. Restaurant 2 was open for 9 hr a day from 17:00 LST to 02:00 LST. For ventilation purposes, the restaurant employed five standing fans. The floors were made of cement. The restaurant employed ten workers, including waiters and cooks, and the kitchen contained four gas stoves for cooking. The kitchen was openly connected to the dining area. This restaurant sporadically used charcoal burners for seafood barbecues, but the main styles of cooking were open-wok frying and deep-frying.

Restaurant #3 (RNR): Open-air Restaurant Near a Road

This restaurant had 70 tables with four chairs each, able to cater to a maximum of 280 occupants. The total area of the restaurant was 279 m^2 (Figure 1 (c)). The floor was made of tile, and for ventilation, there were 11 ceiling fans. The restaurant had ten full-time workers and remained open 24 hr daily. In the kitchen, there were five gas stoves, and the style of cooking was deep-frying. The kitchen was separated from the dining area by a wall. Food was served on a countertop with covers. "Sheesha" (or water-pipes) were available only between 18:00 to 00:00 LST daily.

2.2 Measurements of Coarse Particulate Matter (PM10) and Carbon Monoxide (CO)

Dustmate (Turnkey Instruments, UK) was used to measure the concentrations of PM10 in the indoor air. Dustmate operates by continuously pulling in air samples through a nephelometer, a light-scattering based sensor. The nephelometer analyses the particles passing through its laser beam to determine particle concentrations and relative size fractions. The particle size range of Dustmate is 0.5 - 20 µm, and the detection limit of PM10 is 0.01 $\mu g/m^3$. The Dustmate sampled air at a flow rate of 0.6 L/min. Readings were taken at an interval of 5 min over a total sampling period of 30 min for RF and 2 hr for RBR and RNR.

A Crowcon Tetra gas detector (Crowcon Detection Instruments, UK) was used to measure carbon monoxide (CO) concentrations in parts per million (ppm). The Crowcon Tetra can measure CO in the range 0 - 500 ppm with a resolution of 0.1 ppm.

The Dustmate was stationed at a height of 1 m above the ground. This height was chosen to ensure the samples collected were representative of the air breathed by a seated person (Baek et al. 1997). At site RF, this was performed thrice a day at 08:00 LST (morning; occupants are present), 11:00 LST (late morning; occupants are present) and 18:00 LST (evening; cafe closed, occupants not present). At site RBR, measurements were taken from 21:00 LST to 23:00 LST and at site RNR, from 17:30 LST to 19:30 LST. All measurements were collected within four weeks from the initial sampling time for each location. Both indoor and outdoor measurements were taken, where the "indoor" location was a point in the centre of the restaurant, while the "outdoor" location was a point 2 m from the edge of the restaurant's boundaries.

A gravimetric measurement of PM10 using MiniVol Portable Air Sampler (Airmetrics, USA) was also employed to calibrate the Dustmate measurements. In this study, we used a size-selector impactor of < 10 µm with a sampling flow rate of 5 L/min for 2 hr. A 5-decimal analytical balance (OHAUS Discovery, USA) was used to measure the initial and final weight of Pallflex® fibre glass filter papers (Pall, USA).

Gravimetric-based PM measurements are more accurate than light-scattering based measurements (Cambra-López et al. 2012). We found that the relation between PM10 concentration using Dustmate (light-scattering) and MiniVol (gravimetric) is linear (Figure 2) and can be expressed by Equation (1).

$$C_{PM10,corrected} = 0.54(C_{PM10,Dustmate}) + 40 \quad (1)$$

where C is the PM10 concentration. Subsequent PM10 Dustmate results were corrected using Equation (1).

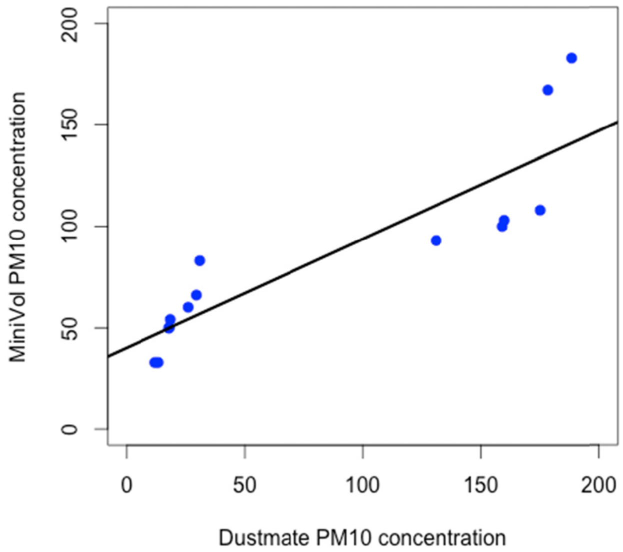


Figure 2. Calibration/corrective line (the solid line, Eq. (1): $C_{PM10,corrected} = 0.54\ (C_{PM10,Dustmate}) + 40$) of light-scattering based measurement (Dustmate) against gravimetric-based measurement (MiniVol); $R^2 = 0.76$ and highest p-value = 3.157E-5

2.3 Ambient Parameter Measurements

For restaurant RF, the temperature (°C) was collected at 10-min intervals for an hour from a MKIII-LR weather station (Rainwise, USA) located nearby. The measurement range of the temperature sensor was -54 - 74°C, and its accuracy was ±0.5°C.

For restaurants RBR and RNR, wind speed and relative humidity were measured at intervals of 15 min for 2 hr in addition to temperature. Wind speed was measured using a hot-wire thermo-anemometer (Testo 405; Testo, USA). The detectable wind speed range was 0 - 10 m/s, with a resolution of 0.01 m/s. A humidity-temperature sensor (model 44550; Extech Instruments, USA) was used to measure relative humidity and temperature. For relative humidity, the instrument's resolution was 0.01% with a detectable range of 20 - 90%. For temperature, the resolution was 0.01°C with a detectable range of -10 - 50°C.

For sites RBR and RNR, vehicles on the nearby road were counted every 15 min for 2 hr and averaged. The number of occupants for all sites was counted for the entire sampling duration: 30 min at restaurant RF and every 15 min over the 2 hr measurement period at restaurants RBR and RNR. For RBR and RNR, the occupancy measurements were averaged.

For restaurant RF, the activities of a nearby construction site were also qualitatively observed. The types of activities at the construction site included loading and unloading of material, hammering, drilling, welding and transportation of materials.

2.4 Sampling and Analysis of Biological Indicators

Samples of airborne microorganisms in restaurant RF were collected using the exposed petri plate method (Benson 2001). Petri plates filled with nutrient agar were exposed to air for 5 min at a height of 1 m. Samples were collected three times a day.

Bacteria were cultured, and their morphology was determined by Gram staining. Total bacteria and fungi were enumerated and reported as colony forming units per plate (CFU per plate). Different bacteria were isolated and cultured individually on separate petri dishes using the streaking method according to the standard laboratory operating procedures detailed in Microbiological Applications (Benson, 2001) and incubated for two days at 35°C (Lee et al., 2002). This incubation temperature was chosen based on a preliminary study that identified the optimal incubation temperature of the bacteria present in the samples. After two days, the petri dishes were removed from the incubator, and the growth patterns and morphologies of the cultured bacteria were studied to identify potentially pathogenic species.

Gram staining was carried out on the cultured bacteria according to the method described in Microbiological Applications (Benson, 2001) to determine bacteria morphology and Gram characteristics. Staining was repeated for each separate bacterial colony that was cultured. The glass slides with the bacterial smears were then examined under an immersion oil microscope (Nikon Eclipse E200, Japan) and reported based on their genus level and Gram characteristics.

2.5 Data and Statistical Analyses

Exploratory and statistical analyses were completed using RStudio© (R Development Core Team 2012). Sample populations were compared using t tests according to Welch's t test methodology. RStudio© was also used to conduct linear regression analyses and correlation analyses, and the Pearson correlation coefficients ($1 > R > -1$) between all parameters measured were calculated. A correlation coefficient of ($R \approx 1$) indicates a strong positive relationship, whereas a correlation coefficient of ($R \approx -1$) indicates a strong negative relationship. A value of ($R \approx 0$) indicates a weak relationship.

3. Results

We found that the indoor median and mean PM10 (96 µg/m^3 and 120 µg/m^3, respectively) and CO (2.7 ppm and 3.1 ppm, respectively) concentrations in the open-air restaurants studied were lower than the standards of Malaysia's Department of Occupational Safety and Health (DOSH) (8 hr average PM10 = 150 µg/m^3) and Department of Environment (24 hr average PM10 = 150 µg/m^3; 8 hr average CO = 10 ppm). For PM10, the 75th percentile (3rd quartile) concentration value was slightly above the PM10 limit (see Figure 3 (a) and Table 2).

Table 2. Range of indoor and outdoor air PM10 and CO concentrations collected at three open-air restaurants; n is number of data points

[1]Location	PM10 concentration (µg/m^3)						
	n	Min	1st quartile	Median	Mean	3rd quartile	Max
RF	24	25	60	77	97	110	280
RBR (overall)	19	18	98	130	210	250	900
Indoor	11	30	100	130	190	200	500
Outdoor	8	18	100	150	250	290	900
RNR (overall)	20	12	30	55	98	160	350
Indoor	10	19	53	130	120	180	240
Outdoor	10	12	20	33	76	62	350
[1]Location	CO concentration (ppm)						
	n	Min	1st quartile	Median	Mean	3rd quartile	Max
RF	-	-	-	-	-	-	-
RBR (overall)	19	<LOD	0.9	2.5	2.8	3.8	11.3
Indoor	11	<LOD	1.9	2.7	2.7	3.8	5
Outdoor	8	<LOD	0	1.9	2.9	3.8	11.3
RNR (overall)	20	<LOD	0.38	1.15	2.15	2.68	9.8
Indoor	10	<LOD	1.1	2.8	3.5	5	9.8
Outdoor	10	<LOD	0.3	0.4	0.8	1.3	2.4

[1] RF - Open-air Restaurant Far from a road (averaging time 30 min)

RBR - Open-air Restaurant beside a Road (averaging time 15 min)

RNR - Open-air Restaurant near a Road (averaging time 15 min)

LOD - Lower than Detection limit (detection limit of 0.1 ppm)

Table 3. Indoor Pearson correlation matrix of air quality parameters measured for two open-air restaurants: RBR (open-air Restaurant beside a Road) and RNR (open-air Restaurant near a Road); bolded values are correlated

Parameters	CO	Wind speed	Temperature	Relative humidity	No. of people	No. of vehicle	PM10
CO	1	-0.1	0.29	-0.18	-0.07	-0.16	-0.13
Wind speed		1	0.45	-0.22	-0.44	-0.48	-0.45*
Temperature			1	-0.71	-0.75	-0.75	-0.45*
Relative humidity				1	0.87	0.73	-0.11
No. of people					1	0.89	0.15
No. of vehicle						1	0.26
PM10							1

* statistically significant, p-value < 0.05

The World Health Organisation's (WHO) 2005 limit is 50 μg/m^3 for 24 hr for PM10 and 26 ppm for 1 hr for CO. Based on this stricter limit, the PM10 concentration in the open-air restaurants was unhealthy. The indoor CO concentrations were higher than the outdoor concentrations, but this result was not statistically significant (Welch's t test; p-value = 0.1093).

We found no relationship between the number of occupants and the PM10 and CO concentrations for any site or between number of vehicles counted on the road and PM10 and CO concentrations for any site, indoors and outdoors.

Only the indoor ambient parameters, such as wind speed and temperature, affect the PM10 concentrations (refer to Table 3). Wind speed and temperature were inversely correlated with PM10 concentrations for the indoor sites (p-value = 0.0420 and 0.0427, respectively). The CO concentration was not affected by ambient indoor or outdoor parameters.

For open-air restaurants, the indoor and outdoor temperatures, wind speeds and relative humidities can be considered identical (refer Figure 4). Both the indoor and outdoor temperatures were related to the relative humidity and wind speed, but the relative humidity was not related to the wind speed (refer Table 3 and Table 4). The number of occupants within the restaurant was positively correlated with relative humidity, but it was negatively correlated with temperature and wind speed.

Table 4. Outdoor Pearson correlation matrix of air quality parameters measured for two open-air restaurants: RBR (open-air Restaurant beside a Road) and RNR (open-air Restaurant near a Road); bolded values are correlated; note that no correlations are statistically significant

Parameters	CO	Wind speed	Temperature	Relative humidity	No. of people	No. of vehicle	PM10
CO	1	-0.33	-0.33	0.23	0.2	0.23	0.28
Wind speed		1	0.35	-0.22	-0.29	-0.26	-0.38
Temperature			1	-0.83	-0.64	-0.64	-0.22
Relative humidity				1	0.64	0.67	-0.15
No. of people					1	0.93	0.35
No. of vehicle						1	0.29
PM10							1

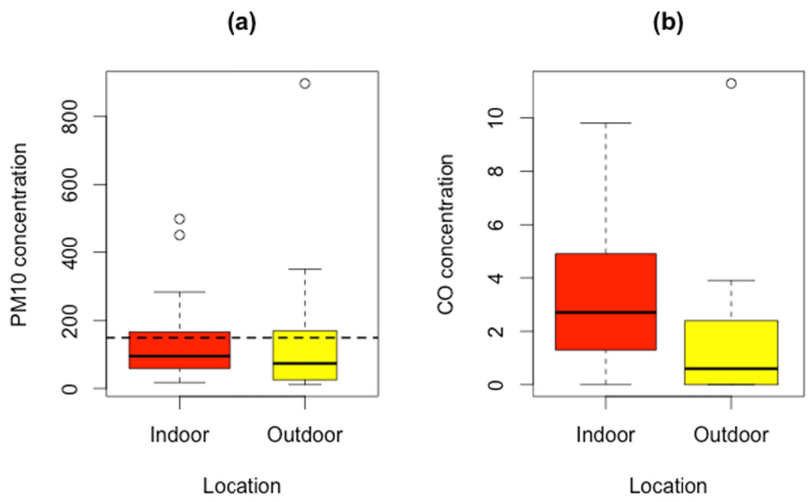


Figure 3. Indoor and outdoor concentrations of (a) PM10 in μg/m^3 (indoor: n = 45; outdoor: n = 18) and (b) CO in ppm (indoor: n = 21; outdoor: n = 18) of the three open-air restaurants; in (a), dashed line is 150 μg/m^3; width of box-plot is proportional to n

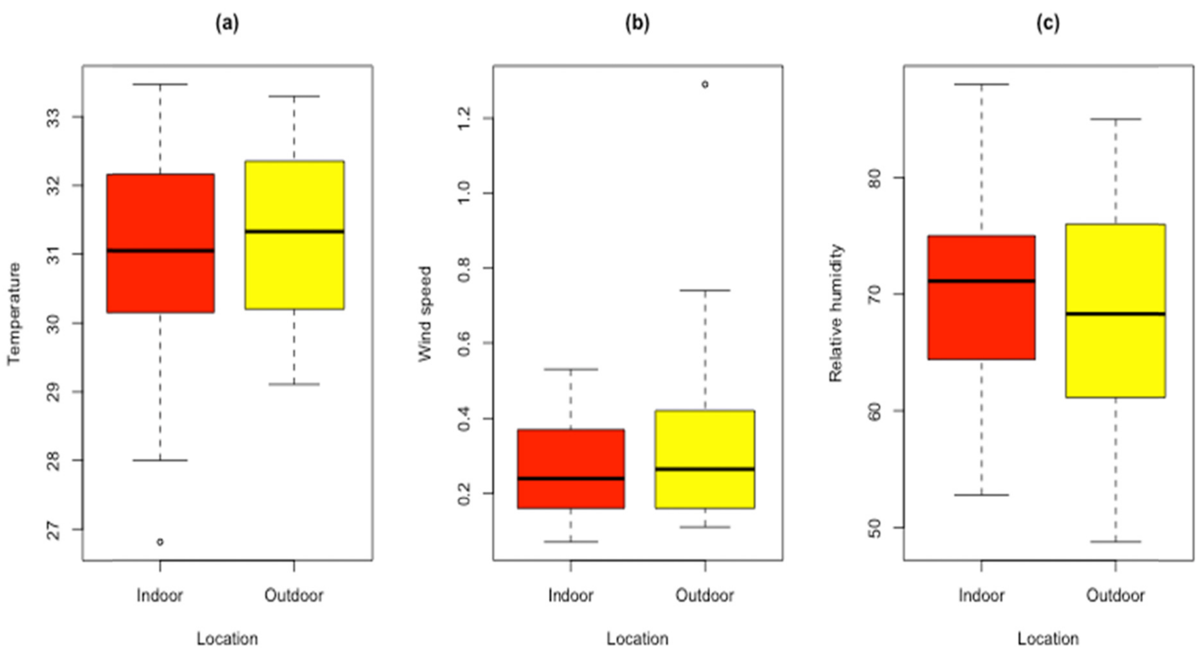


Figure 4. Indoor and outdoor (a) temperature (°C), (b) wind speed (m/s) and (c) relative humidity (%) (indoor: n = 21; outdoor = 18) of two (RBR and RNR) open-air restaurants; width of box plot is proportional to n; temperature, only RBR and RNR are included between because they can be directly compared; wind speed and relative humidity are similar indoors and outdoors

Qualitative observation at RF showed that smoking, ventilation and outside construction activity affect the indoor air quality in open-air restaurants. Relative to other times of day, the PM10 concentrations were high in the morning due to cigarette smoke in this restaurant. Ventilation was low because fans were also turned off at this time. We discovered a correlation between the number of smokers and PM10 ($R = 0.60$), although its linear regression line is not statistically significant (highest p-value < 0.1). Through qualitative observation of the nearby construction site, we found that loading and unloading and transportation of construction material using heavy vehicles corresponded to higher PM10 concentrations in the restaurant.

At RF, we found a strong positive relationship between PM10 and total colony count (Figure 5; R = 0.90; p-value = 8.56E-13). There were no significant relationships discovered between CFU and temperature or the number of occupants. The majority of bacteria present in open-air restaurants were Gram-positive, particularly cocci, which include diplococci, micrococci, staphylococci and streptococci (refer to Table 5). Gram-positive bacilli comprised a low percentage of the total bacteria count (1.2% to 1.8%). The total percentage of pathogenic gram-negative bacteria found in the restaurant was 0.6% to 1.8% (refer to Table 5 and Figure 6), with the higher range corresponding to greater restaurant occupancy. Only one Gram-negative genera was identified as a member of the family Enterobacteriaceae, which contains E.Coli and Salmonella (Northcutt et al., 2004), associated with food poisoning (Hirsh & Martin, 1983).

Table 5. Percentages (%) of Gram-positive genera, Gram-negative genera and fungi at restaurant RF at different times of day

Bacteria/Fungi	08:00 LST	11:00 LST	18:00 LST
Gram positive genera	29.5	27.7	27.1
Rods	-	1.2	1.8
Bacili	-	1.2	1.8
Cocci	29.5	26.5	25.3
Diplococci	2.4	1.8	-
Micrococci	13.9	12.1	11.5
Staphylococci	4.2	5.4	4.8
Streptococci	9.0	7.2	9.0
Gram negative genera	0.6	1.8	1.8
Enterobacteriaceae	0.6	1.8	1.8
Fungi	5.4	4.8	1.2

- Bacteria not present

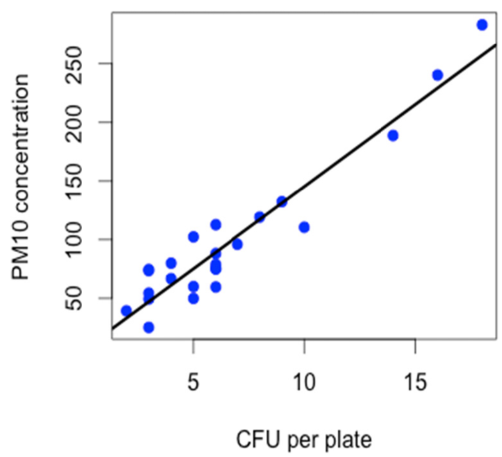


Figure 5. PM10 concentration (μg/m^3) and CFU per plate; solid black line is regression line (R = 0.90; p-value = 8.56E-13)

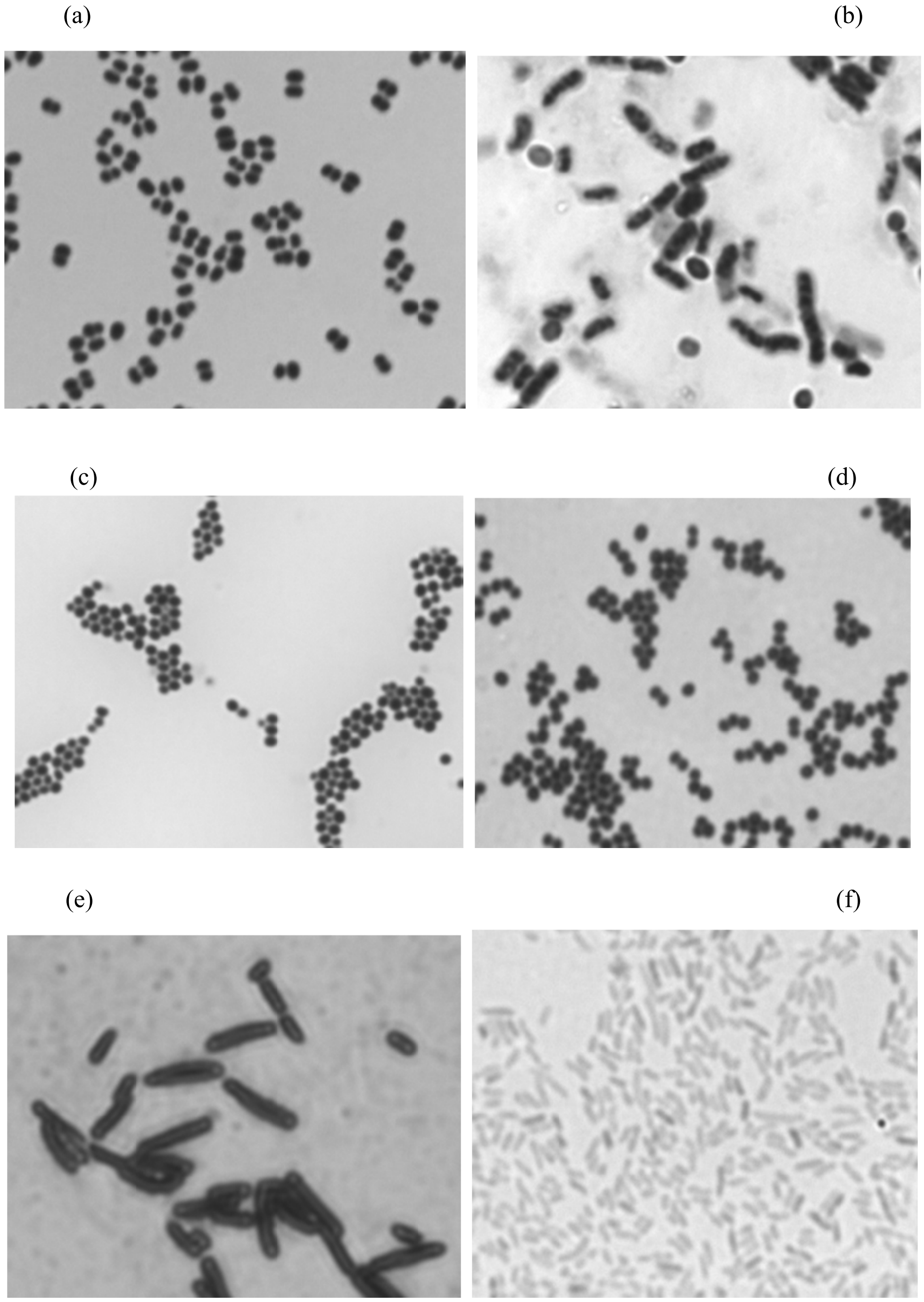


Figure 6. Bacteria found in the open-air restaurant RF: Gram positive genera: (a) Diplococci, (b) Streptococci, (c) Staphylococci, (d) Micrococci and (e) Bacilli; Gram negative genera: (f) Enterobacteriaceae

4. Discussion

We found that the general indoor air quality of open-air restaurants was moderate, exceeding standards established by the Department of Occupational Safety and Health (DOSH) and the Malaysian Department of Environment (DOE) only for the 75th percentile (3rd quartile) of measurements made (Figure 3 (a)). The contaminant concentration ranges in open-air restaurants were found to be similar to those in indoor, closed restaurants (Baek et al., 1997), and air quality was consistent among the surveyed restaurants regardless of their proximity to major streets. Previously reported PM10 concentrations in indoor environments, including wet markets (Guo et al., 2004), hotels and shopping malls, had large ranges (Asadi et al., 2011), as shown in Table 1.

This study used averaging times of 15 min and 30 min; therefore, the results are not directly comparable to national and international standards, which use 8-hr and 24-hr averaging times. However, these are the only available standards that can be used to assess air quality; thus, they are applied here. Numerous studies still adopt this comparison (Baek et al., 1997; Lee et al., 2002; Lee et al., 2001). The exposure time of occupants to PM and CO in the restaurants is less than 8 hr or 24 hr; therefore, the measured values can be considered as peak values within the larger averaging time set.

Restaurants have higher indoor air pollutant concentrations compared with homes or offices. However, the open design of the restaurant promotes air circulation, and thus indoor and outdoor concentrations of PM10 and CO are often similar. However, CO concentrations can be slightly elevated indoors due to local sources, such as gas stoves (Figure 3 (b)). A study on the indoor air quality of restaurants showed that heating and cooking (using kerosene/gas stoves) activities and inadequate ventilation worsen indoor air quality (Baek et al., 1997), particularly PM10 and PM2.5 levels (Lee et al., 2001).

In the surveyed restaurants, kerosene/gas stoves and background sources of PM10 could have overwhelmed any contribution from occupants. CO originates from the incomplete combustion of organic material and accumulates in closed environments; thus, no significant relationship is expected between number of occupants and the CO level. The correlation matrix tables (refer to Table 3 (indoor) and Table 4 (outdoor)) show that occupants were not the main source of PM10 in open-air restaurants. Cooking activities may be the predominant source, though coarse particulate matter can also originate from human activities such as walking (Qian et al. 2008), depending on the floor type (Zhang et al., 2008). Because the restaurants' occupants were mainly seated, human activities were not likely a large contributor to the increased PM10 concentrations.

Although cooking can significantly increase PM concentrations (Chao & Wong, 2002), no cooking occurred at RF in the mornings; thus, RF's morning PM10 concentrations were solely from smokers. Smoking is a major contributor to the PM10 concentrations in Hong Kong shopping malls (Li et al., 2001). Other studies have shown that cigarette smoke is a major source of PM (Wallace 1996), but in confined areas with low ventilation rates (McDonald et al., 2003), its dispersion is limited (Saha et al., 2012). In a study assessing the effects of a ban on smoking in restaurants, researchers discovered that the ban greatly reduced fine PM concentrations (Bohac et al., 2010). However, the dataset on number of smokers and PM concentrations is limited because only one to three smokers were present during measurements.

Lunchtime pollutant concentration measurements were high relative to other times of day, such as breakfast and dinner, due to high occupancy. Given the open-air nature of the restaurant, the ventilation rate is more important to dispersion for the restaurants studied than for a closed building. When construction materials are moved, they are exposed to wind, causing resuspension of coarser PM from the materials (Muleski et al., 2005).

The results obtained showed that wind speed and temperature had negative correlations to indoor PM10 concentrations and did not affect CO concentrations. A study has shown that naturally ventilated buildings have higher pollutant levels than air-conditioned buildings (Kukadia & Palmer, 1998) but do not retain external air pollutants for long periods because of their high air-change rates. Studies have also shown that concentrations of larger particulates, such as PM10, are correlated with ambient temperature (Celik & Kadi, 2007; Zaharim et al., 2007). Ventilation systems, outdoor air pollutant penetration factors, particulate deposition and resuspension rates and background air pollutants affect indoor air quality (Fromme et al., 2007). In most Asian countries, where buildings have no ventilation systems, indoor air pollution is higher than outdoor air pollution, particularly for buildings located near roads and/or construction sites (Montgomery & Kalman, 1989; Chao & Wong, 2002) because outdoor air pollutant sources can affect indoor air quality in addition to indoor sources, such as cooking, cleaning and smoking activities.

Total colony count was likely correlated with PM10 because the large surface area of course particles facilitates microorganism attachment. The bacteria sampling method employed is based on the theory of sedimentation and can therefore be biased towards larger particles. One limitation of this method is that only a fraction of the total bio-aerosols collected may be culture-able. Allergens have been detected on indoor soot particle surfaces (Ormstad et al., 1998). High concentrations of PM10 indicates that microorganisms are transported faster and in larger quantities per unit area. High bacteria counts could be caused by high occupancy, lack of proper sanitation and inadequate ventilation rates (Lee et al., 2002). The effect of temperature on airborne biological contaminants is minimal relative to ventilation and human activities indoors (Balasubraman et al., 2011).

Other studies have shown that Gram-positive bacteria are dominant in both indoor and outdoor environments (Aydogdu et al., 2010). Cocci were found to be prevalent in 100 large U.S. office buildings (Tsai & Macher, 2005). Gram-positive micrococci, staphylococci and streptococci are commonly found on human skin and mucus membranes. These organisms disperse and spread through direct skin-to-skin contact and are expelled through respiration (Chikere et al., 2008). The presence of cocci in the air of the restaurants implies overcrowding combined with inadequate ventilation (Awad, 2007). Gram-positive bacilli are associated with outdoor sources, such as soil emissions, water, dust, air, faeces, vegetation, wounds and abscesses (Aydogdu et al., 2010). They are found indoors as a result of transport by wind-blown particulates (Yassin and Almouqatea 2010). Although the majority of these species are considered harmless to human health, certain species can cause infections, especially in individuals with weak immune systems (Mckernan et al., 2008). Enterobacteriaceae are related to E. coli and Salmonella (Northcutt et al., 2004), which are associated with food poisoning (Hirsh & Martin, 1983). Possible sources of these pathogens include improper handling, serving and preparing of food. The potential presence of these species in restaurants is a risk to human health, which could easily increase with the number of occupants.

5. Conclusions

We surveyed three typical open-air Malaysian restaurants and found that the indoor air quality of these establishments was moderate based on the Department of Environment Malaysia and Department of Occupational Safety and Health standards, only exceeding standards in the 75th percentile of measurements. Indoor PM10 is influenced by wind speed and temperature. The CO concentrations were higher indoors than outdoors, but they were not correlated with temperature or wind speed, suggesting that CO originated from within the restaurants. Indoor ambient parameters, including wind speed, temperature and relative humidity, were similar to outdoor parameters. We found a strong positive relationship between PM10 and CFU per plate. The majority of bacteria detected were Gram-positive (84.3%) and non-pathogenic to humans, with minute percentages of Gram-negative bacteria, enterobacteriaceae (4.2%). The presence of airborne bacteria indicated overcrowding and inadequate ventilation within the open-air restaurants. Wind speed is the sole ambient parameter to consider when trying to improve indoor air quality in open-air restaurants.

Acknowledgments

The authors like to thank Universiti Sains Malaysia (USM) for providing the short-term grant (Grant No.: 1001/PTEKIND/6311006) that assisted them to complete this research. The authors acknowledge the assistance given by Vivienne Sim, Nor Atika Marzan and Ummi Amirah Fadhilah Ayub.

References

Asadi, E., Costa, J. J., & Gameiro da Silva, M. (2011). Indoor air quality audit implementation in a hotel building in Portugal. *Building and Environment, 46*(8), 1617-1623. http://dx.doi.org/10.1016/j.buildenv.2011.01.027

Awad, A. H. A. (2007). Airborne dust, bacteria, actinomycetes and fungi at a flourmill. *Aerobiologia, 23*(1), 59-69. http://dx.doi.org/10.1007/s10453-007-9049-z

Aydogdu, H., Asan, A., & Otkun, M. T. (2010). Indoor and outdoor airborne bacteria in child day-care centers in Edirne City (Turkey), seasonal distribution and influence of meteorological factors. *Environmental Monitoring and Assessment, 164*(1-4), 53-66. http://dx.doi.org/10.1007/s10661-009-0874-0

Baek, S.-O., Kim, Y.-S., & Perry, R. (1997). Indoor air quality in homes, offices and restaurants in Korean urban areas—indoor/outdoor relationships. *Atmospheric Environment, 31*(4), 529-544. http://dx.doi.org/10.1016/s1352-2310(96)00215-4

Balasubraman, R., Nainar, P., & Rajasekar, A. (2011). Airborne bacteria, fungi, and endotoxin levels in residential microenvironments: A case study. *Aerobiologia*, 1-16.

Benson, H. J. (2001). *Microbiological Applications: Laboratory Manual in General Microbiology* (8th ed.). Boston: McGraw-Hill.

Bohac, D. L., Hewett, M. J., Kapphahn, K. I., Grimsrud, D. T., Apte, M. G., & Gundel, L. A. (2010). Change in indoor particle levels after a smoking ban in Minnesota bars and restaurants. *American Journal of Preventive Medicine, 39*(6, Supplement 1), S3-S9. http://dx.doi.org/10.1016/j.amepre.2010.09.012

Cambra-López, M., Winkel, A., Mosquera, J., Ognik, N. W. M., & Aarnik, A. J. A. (2012). *Comparison between light scattering and gravimetric devices for sampling PM10 mass concentration in livestock houses*. Paper presented at the Ninth International Livestock Environment Symposium, Valencia, Spain, July 8–12, 2012.

Celik, M. B., & Kadi, I. (2007). The relation between meteorological factors and pollutants concentrations in Karabuk city. G.U. *Journal of Science, 20*(4), 87-95.

Chao, C. Y., & Wong, K. K. (2002). Residential indoor PM10 and PM2.5 in Hong Kong and the elemental composition. *Atmospheric Environment, 36*(2), 265-277.

Chikere, C. B., Omoni, V. T., & Chikere, B. O. (2008). Distribution of potential nosocomial pathogens in a hospital environment. *African Journal of Biotechnology, 7*(20), 3535-3539.

El-Fadel, M., & Massoud, M. (2000). Particulate matter in urban areas: health-based economic assessment. *Science of the Total Environment, 257*(2-3), 133-146. http://dx.doi.org/10.1016/S0048-9697(00)00503-9

Fabian, M. P., Miller, S. L., Reponen, T., & Hernandez, M. T. (2005). Ambient bioaerosol indices for indoor air quality assessments of flood reclamation. *Journal of Aerosol Science, 36*(5-6), 763-783. http://dx.doi.org/10.1016/j.jaerosci.2004.11.018

Fromme, H., Twardella, D., Dietrich, S., Heitmann, D., Schierl, R., Liebl, B., et al. (2007). Particulate matter in the indoor air of classrooms—exploratory results from Munich and surrounding area. *Atmospheric Environment, 41*(4), 854-866. http://dx.doi.org/10.1016/j.atmosenv.2006.08.053

Guo, H., Lee, S. C., & Chan, L. Y. (2004). Indoor air quality investigation at air-conditioned and non-air-conditioned markets in Hong Kong. *Science of the Total Environment, 323*(1-3), 87-98. http://dx.doi.org/10.1016/j.scitotenv.2003.09.031

Hirsh, D. C., & Martin, L. D. (1983). Detection of Salmonella Spp in milk by using Felix-01 bacteriophage high-pressure liquid-chromatography. *Applied and Environmental Microbiology, 46*(5), 1243-1245.

Kukadia, V., & Palmer, J. (1998). The effect of external atmospheric pollution on indoor air quality: A pilot study. *Energy and Buildings, 27*(3), 223-230. http://dx.doi.org/10.1016/S0378-7788(97)00044-3

Lee, S. C., & Chang, M. (2000). Indoor and outdoor air quality investigation at schools in Hong Kong. *Chemosphere, 41*(1-2), 109-113. http://dx.doi.org/10.1016/S0045-6535(99)00396-3

Lee, S. C., Li, W.-M., & Yin Chan, L. (2001). Indoor air quality at restaurants with different styles of cooking in metropolitan Hong Kong. *Science of the Total Environment, 279*(1-3), 181-193. http://dx.doi.org/10.1016/s0048-9697(01)00765-3

Lee, S.-C., Guo, H., Li, W.-M., & Chan, L.-Y. (2002). Inter-comparison of air pollutant concentrations in different indoor environments in Hong Kong. *Atmospheric Environment, 36*(12), 1929-1940. http://dx.doi.org/10.1016/s1352-2310(02)00176-0

Li, W.-M., Lee, S. C., & Chan, L. Y. (2001). Indoor air quality at nine shopping malls in Hong Kong. *Science of the Total Environment, 273*(1-3), 27-40. http://dx.doi.org/10.1016/s0048-9697(00)00833-0

McDonald, J. D., Zielinska, B., Sagebiel, J. C., McDaniel, M. R., & Mousset-Jones, P. (2003). Source apportionment of airborne fine particulate matter in an underground mine. *Journal of the Air & Waste Management Association, 53*(4), 386-395. http://dx.doi.org/10.1080/10473289.2003.10466178

Mckernan, L. T., Wallingford, K. M., Hein, M. J., Burge, H., Rogers, C. A., & Herrick, R. (2008). Monitoring microbial populations on wide-body commercial passenger aircraft. *Annals of Occupational Hygiene, 52*(2), 139-149. http://dx.doi.org/10.1093/annhyg/mem068

Montgomery, D. D., & Kalman, D. A. (1989). Indoor/Outdoor air quality: Reference pollutant concentrations in complaint-free residences. *Applied Industrial Hygiene, 4*(1), 17-20. http://dx.doi.org/10.1080/08828032.1989.10389885

Muleski, G. E., Cowherd, C., & Kinsey, J. S. (2005). Particulate emissions from construction activities. *Journal of the Air & Waste Management Association, 55*(6), 772-783. http://dx.doi.org/10.1080/10473289.2005.10464669

Northcutt, J. K., Jones, D. R., & Musgrove, M. T. (2004). Airborne microorganisms during the commercial production and processing of Japanese quail. *Poultry Science, 83*(10), 1812-1812.

Ormstad, H., Johansen, B. V., & Gaarder, P. I. (1998). Airborne house dust particles and diesel exhaust particles as allergen carriers. *Clinical and Experimental Allergy, 28*(6), 702-708. http://dx.doi.org/10.1046/j.1365-2222.1998.00302.x

Qian, J., Ferro, A. R., & Fowler, K. R. (2008). Estimating the resuspension rate and residence time of indoor particles. *Journal of the Air & Waste Management Association, 58*(4), 502-516. http://dx.doi.org/10.3155/1047-3289.58.4.502

R Development Core Team. (2012). *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing.

Rajasekar, A., & Balasubramanian, R. (2011). Assessment of airborne bacteria and fungi in food courts. *Building and Environment, 46*(10), 2081-2087. http://dx.doi.org/10.1016/j.buildenv.2011.04.021

Reanprayoon, P., & Yoonaiwong, W. (2012). Airborne concentrations of bacteria and fungi in Thailand border market. *Aerobiologia, 28*(1), 49-60. http://dx.doi.org/10.1007/s10453-011-9210-6

Saha, S., Guha, A., & Roy, S. (2012). Experimental and computational investigation of indoor air quality inside several community kitchens in a large campus. *Building and Environment, 52*, 177-190. http://dx.doi.org/10.1016/j.buildenv.2011.10.015

Tsai, F. C., & Macher, J. M. (2005). Concentrations of airborne culturable bacteria in 100 large US office buildings from the BASE study. *Indoor Air, 15*, 71-81. http;//dx.doi.org/10.1111/j.1600-0668.2005.00346.x

Wallace, L. (1996). Indoor particles: A review. *Journal of the Air & Waste Management Association, 46*(2), 98-126.

Wan Mahiyuddin, W. R., Sahani, M., Aripin, R., Latif, M. T., Thach, T.-Q., & Wong, C.-M. (2013). Short-term effects of daily air pollution on mortality. *Atmospheric Environment, 65*(0), 69-79. http://dx.doi.org/10.1016/j.atmosenv.2012.10.019

Yassin, M. F., & Almouqatea, S. (2010). Assessment of airborne bacteria and fungi in an indoor and outdoor environment. *International Journal of Environmental Science and Technology, 7*(3), 535-544. http://dx.doi.org/10.1007/BF03326162

Zaharim, A., Shaharuddin, M., Nor, M. J. M., Karim, O. A., & Sopian, K. (2007). Relationships between airborne particulate matter and meteorological variables using non-decimated wavelet transform. *European Journal of Scientific Research, 27*(2), 308-312.

Zhang, X. Y., Ahmadi, G., Qian, J., & Ferro, A. (2008). Particle detachment, resuspension and transport due to human walking in indoor environments. *Journal of Adhesion Science and Technology, 22*(5-6), 591-621. http://dx.doi.org/10.1163/156856108x305624

Zhao, B., & Wu, J. (2007). Particle deposition in indoor environments: Analysis of influencing factors. *Journal of Hazardous Materials, 147*(1-2), 439-448. http://dx.doi.org/10.1016/j.jhazmat.2007.01.032