Research Article

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Health Risks from Indoor PM10 and Effects of Sick Building Syndrome in Office Workers

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Abstract

This study aimed to determine the index of health risk from indoor PM10 exposure so as to characterize the association between indoor PM10 and the prevalence effects of Sick Building Syndrome (SBS) and significant confounding factors among office workers in an academic institute in Thailand. This cross-sectional study was conducted from January to March 2020 and involved 96 workers in 33 offices. Particle air sampling equipment, and a self-administered questionnaire which was developed by the researchers, were used as the tools to acquire the concentration level of building PM10 and assess SBS symptoms, respectively. Results showed that 12 rooms in total had concentrations of PM10 that exceeded the average analysis value of 38.1±14.0 $\mu g/m^3$. The prevalence of SBS effects with regards to general symptoms, mucosal symptoms, skin symptoms, and eye-related symptoms were 75.0%, 57.4%, 45.5%, and 54.9%, respectively. For health risk assessments, the Hazard Quotient (HQ) regarding exposure to PM10 was found to be at moderate health hazard levels. Chi-square test results of two case studies, under and over average analysis value, examined for dry eye symptoms (DES) revealed significant associations with PM10 concentration ($p<0.05$). Moreover, using binary logistic regression analysis, a working period (more than 8 hours daily) significantly increased the risk (adjusted odds ratio, AOR) of DES to 3.86 (95% CI: 1.01-14.72). These findings could assist administrators in controlling work duration (limit to fewer than 8 hours daily) to decrease the occurrence of DES symptoms in officers and to reinforce the occupational health and safety regulations.

Keywords: Health risk assessment, Hazard quotient, Indoor PM10, Sick building syndrome, Office workers

Introduction

Based on the current situation of world pollution, air pollutants generate serious health issues that impact quality of life and lead to diseases including respiratory and cardiovascular problems[1]. Air pollutants consist of particulate matter (PM), carbon monoxide (CO), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2). They affect human health both outdoors and indoors[2]. During the past 30 years, Indoor Air Quality (IAQ) has been challenged. There is evidence of its impact on people living in modern societies, who spend more than 90% of their life indoors[3]. Improving the quality of life and work environments brings consequential benefits to wellness and performance. Hence, indoor air pollution has continuously become more severe. IAQ is a multi-disciplinary phenomenon which can be determined by many mechanisms of chemical, biological, and physical contamination[4]. Some contaminants interact with people through the dermal layer and their clothing. Therefore, providing good IAQ in building environments can help to minimize any health effects[5, 6]. The most important parameter of IAQ is airborne particulate matter (PM), because it is inhalable with adverse impacts on human health and is easily monitored[7-9]. PM is a mixture of solid particles and liquid droplets suspended in the air. Sources of PM in indoor air include cleaning processes, walking and playing activities, furnishings, and IT equipment[10]. It varies widely in size defined by a diameter of 10 microns or less (PM10) and 2.5 microns or less (PM2.5). Therefore, PM2.5 comprises a portion of PM10[9].

Evidence-based symptoms are generally enhanced in some buildings and all disappear after people leave the building, which has been found during the last 40 years in many countries including Europe and the USA[11]. The term "Building Related Illness" (BRI) is used to describe the occurrence of diagnosable illnesses which can be attributed directly to airborne building contaminants[12]. Although BRI presents a fairly homogeneous clinical picture and known etiology, nonspecific BRI deals with work-related symptoms, which include dermal irritation and irritation of the mucous membranes of the eye, nose, throat, etc. BRI has been investigated and is called "Sick Building Syndrome" or SBS[11,13-17]. SBS is widely used to describe the situations that workers experience when they acquire acute health and comfort effects linked to the time spent in buildings, and it has been attributed to demographic, psychosocial and environmental factors[18]. In terms of the physical environment, higher concentration of indoor air pollutants are a potential cause of SBS symptoms[14]. Recent studies have been conducted in a variety of settings including households and schools among the sensitive groups of children and elderly. These studies have identified the diversity of air pollutants in buildings that result in SBS, including carbon dioxide (CO_2), CO, PM, and volatile organic compounds (VOCs)[19-23]. In terms of PM, notably, PM2.5 can get deep into the lungs and into the bloodstream and creates overt symptoms when exposure occurs over many years. On the other hand, building PM10 can affect respiratory systems and cause acute health symptoms once inhaled[24]. Hence, PM10 has been widely mentioned in academic and research societies due to its frequency and occurrence in several locations[1,25-27].

Although SBS effects have been directly connected to building occupant health status, few studies have conducted analyses among groups of academic office workers. Moreover, the problem of SBS exists, and there are few studies of PM10 and SBS within academic institutes in Thailand, so it is necessary to conduct this research. Hence, this work aimed to investigate health risk and the effects of indoor PM10 in academic office buildings concerning the prevalence of SBS symptoms. The results could help organizations create mitigating measures to reduce the potential risk of SBS among their workers.

Materials and methods

Ethical statement

This study protocol followed the principles of the Declaration of Helsinki and was approved by the Ethics Committee for Research Involving Human Subjects, Faculty of Public Health, Mahidol University (COA. No. MUPH 2019-153) before collecting field data. Subjects gave written consent after being informed of the objectives of the study and its procedures.

Cross-sectional survey

To determine the association of indoor PM10 and SBS problems, a self-administered questionnaire and particle air sampling equipment were used as tools to collect information. The study was conducted in 2020 from January to March among office staff working in an academic institution in Thailand. The 96 participants were enrolled from 33 offices. The inclusion criterion to select the population was working in an administrative office with more than 6 months' work experience.

Participants reported their demographic information, lifestyle behaviors, and their health status by questionnaire. It was validated by experts who evaluated whether the questions effectively captured the topic under investigation. The questionnaire also referred to SBS symptoms as detailed below, and corresponded to the previous studies[18,28]: (1) general symptoms including dizziness, headache, fatigue, and inability to concentrate; (2) mucous membrane symptoms including eye irritation, nasal irritation, dry throat, rhinorrhea, work-related chest tightness, shortness of breath, and cough; (3) skin symptoms including dry facial skin, itchiness and rash and dry hands; and (4) eye-related symptoms including dry eye, tearing, eye pruritus, and conjunctivitis. For each question, answers were provided using a binary outcome scale for each symptom (Yes or No).

Collection equipment and procedures

PM less than 10 micrometers in size was the studied object. The collection method was the air sampling method in accordance with the National Institute for Occupational Safety and Health (NIOSH) guidelines. NIOSH collection method number 0600 (Issue 3) was applied to specify the sampling procedure of respiratory PM10. The aluminum cyclone sampler with tarred 5-μm PVC membrane was firstly calibrated using a bubble meter and then sampled following the above-mentioned method. The PM10 monitoring equipment applied in this study is presented in Figure 1. Measurements were made within an 8-hour specified timeframe[29]. Sampling points were verified by the minimum number per total floor area. One sampling point per 500 m^2 was applied in this study following the guideline for less than 3,000 m^2 in total floor area. During field data collection, sampling points were sited at least 0.5 m from corners, walls, and windows[30]. The concentration of PM10 was calculated using Eq. (1).

$$C = \frac{(W_2 - W_1) - (B_2 - B_1)}{V} \times 10^3 \qquad \text{Eq. (1)}$$

Where C is the concentration of PM10 (mg/m^3); W_2 and W_1 are the post-sampling weight of sample-containing filter and tare weight of filter before sampling (mg), respectively; B_2 and B_1 are mean post-sampling weight and mean tare weight of blank filters (mg), respectively; and V is air volume sampling (L) at a flow rate of 1.7 L/min.

Figure 1 Collection equipment for respiratory PM10

Health risk assessment

Human health risk assessment is the evaluation process for the probability of adverse health effects from exposure to a contaminated environment. It includes four basic steps as follows[31,32]. First, hazard identification: PM10 hazard in office buildings was identified. Second, regarding dose-response assessment: the risk from inhalation of non-carcinogens was discussed. Reference concentrations (RfC) were sought from relevant studies. Then, exposure assessment: the exposure was assessed by determining how much PM10 affected human health, and chronic daily intake (CDI) was evaluated using Eq. (2). Where C is the concentration of PM10. IR is the average adult inhalation rate of 0.66 m^3/hr (16 m^3/day)[33]. ET, EF, ED, BW, AT, and their unit measurement are detailed as exposure time (hours/day), exposure frequency (days/year), exposure duration (years), body weight (kilograms), and average time affected (365 days), respectively. Moreover, (4) risk characterization: this comprised of HQ calculated following Eq. (3). To estimate the senses of control, HQ < 1 refers to the non-hazard level, 0.1 to 1.0 refers to low risk level, 1.1 to 10 refers to moderate hazard level, and HQ > 10 refers to high risk level[34].

$$CDI = \frac{C \times IR \times ET \times EF \times ED}{BW \times AT} \quad \text{Eq. (2)}$$

$$HQ = \frac{CDI}{RfC} \quad \text{Eq. (3)}$$

Statistical analysis

Firstly, frequency statistics were used to analyze the prevalent symptoms of SBS and PM10 exposure. The correlation coefficients among pairs of PM10 pollutants (exceeding or below average values) were investigated using Chi-square analysis. A *p*-value less than 0.05 revealed significance in all statistical analyses. To investigate the association of health symptoms with physical environments and lifestyle behaviors, a binary logistic regression model with adjustment for sex, age, use of correct refractive errors equipment, history of non-communicable diseases, environmental tobacco smoke, and working duration were evaluated. All statistical analyses were performed at a significance level of 95% Confidence Interval (CI) using Statistical Product and Service Solution (SPSS, Version 18.0, SPSS Ltd., USA).

Results

Ninety-six individuals responded to the survey. The sample included more females (83.3%) than males (16.7%). The average age was 43.7±9.0 years. Among them, males were most prevalent in the 36-40 year and 41-45 year age groups. Most respondents (92.7%) reported being in the non-environmental tobacco smoke group. On the other hand, about 7.3% of them reported receiving second-hand smoke. For non-communicable disease status, 15 of 96 participants reported health problems concerning hypertension (66.7%), cardiovascular disease (6.6%), and diabetes (26.7%). Average daily working hours and weekly working hours were 8.0±0.7 and 40.7±3.9 hours, respectively. BMI ranges were analyzed revealing that 64.6% of subjects had a BMI ≥23.0 kg/m^2 [35]. The demographic characteristics of the sample are presented in Table 1.

Table 1 Survey participants' demographic data (n=96)

Characteristic	n	%
Sex		
Male	16	16.7
Female	80	83.3
Age (years)	32	33.3
≤ 40	32	33.3
> 40	64	66.7
Mean ± SD	43.7 ± 9.0	
Environmental tobacco smoke		
None	89	92.7
Second-hand smoke	7	7.3

Table 1 Survey participants' demographic data (n=96) (cont.)

Characteristic	n	%
NCD status		
Hypertension (HT)	10	66.7
Cardiovascular disease (CVD)	1	6.6
Diabetes	4	26.7
Daily working hours		
≤ 8 hours	85	88.5
> 8 hours	11	11.5
Mean ± SD	8.0 ± 0.7	
Weekly working hours		
≤ 40 hours	82	85.4
> 40 hours	14	14.5
Mean ± SD	40.7 ± 3.9	

SD, standard deviation

Characteristics of the working environment were examined in all offices using an area sampling method including PM10, temperature, humidity, and ventilation. Figure 2 presents PM10 concentration in each office. The average concentration of PM10 in office buildings was 38.1±14.0 μg/m^3. Temperature was found to range from 23 to 28 °C and averaged 24.9±1.2 °C. For ventilation, air change rate was at a standard level for general offices (2.0 m^3/m^2-hr). Humidity levels were between 40 and 60%.

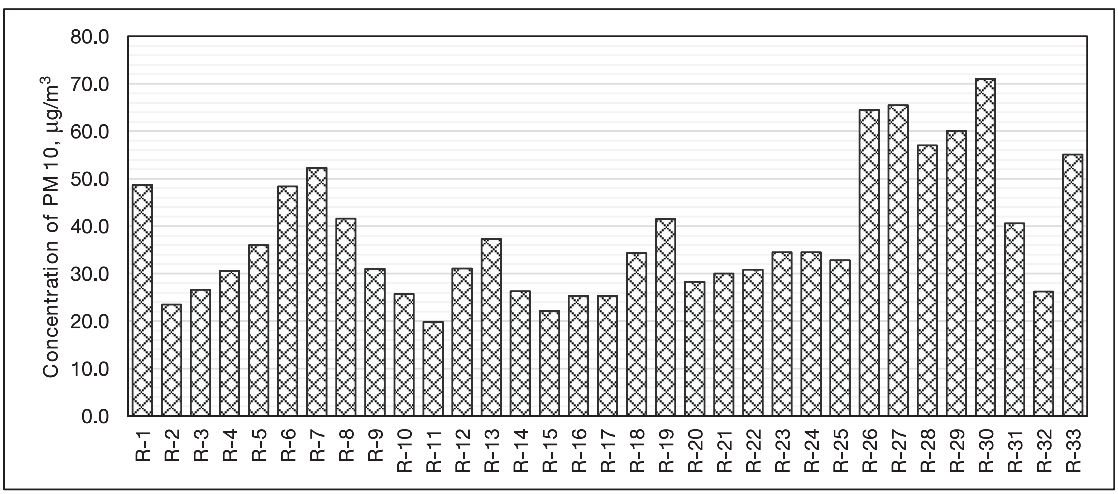

Figure 2 Average PM10 concentration in 33 offices

Applying four steps of health risk assessment, the RfC of PM10 (0.011 mg/kg/capita)[36] was used to estimate health risk. Data used in this calculation are tabulated in Table 2. The averaged result of CDI for PM10 was 0.052 ± 0.035 mg/kg/day, respectively. The mean HQ for indoor PM10 was 4.7 ± 3.2 among all participants, which was more than one, thereby indicating an unacceptable risk for human health. The values were in the moderate hazard level (1.1 ≤ HQ ≤ 10).

For SBS effects, prevalence of general symptoms, mucous membrane symptoms, skin symptoms, and eye-related symptoms were reportedly 75.0, 57.4, 45.5 and 54.9%, respectively. Figure 3(a) shows the occurrence of mucous membrane symptoms. Cough and dry throat were found to exhibit the highest frequency of 83.1 and 77.1%, respectively. Nasal irritation was third highest (70.8%). Dry hands and dry facial skin had the highest prevalence for the skin symptoms as shown in Figure 3(b). For those general symptoms (Figure 3(c)), the most frequent were 83.3% for dizziness and 80.2% for fatigue. With regards to eye-related symptoms, the prevalence of eye pruritus and dry eye were relatively high (62.5 and 60.4%, respectively) as shown in (Figure 3(d)).

Table 2 Variables for health risk determination

Variable	Range of values (Min-Max)	Unit
Concentration of PM10	28.4-81.7	$\mu g/m^3$
Exposure time (ET)	6.0-10. 0	Hours/day
Exposure frequency (EF)	265.0-318.0	Days/year
Exposure duration (ED)	3.0-20.0	Years
Body weight (BW)	39.0-110.0	Kilograms

In this study, the Chi-square test was used to study the associations between SBS and PM10 concentration. We classified the PM10 concentration in two groups, i.e. higher and lower than average analysis value. Results for all symptoms are listed in Table 3. No significant association was found between PM10 concentration in office buildings and mucous membrane, skin, and general symptoms ($p>0.05$). However, only concentrations of PM10 that exceeded the average levels were significantly associated with increased occurrence of DES ($p<0.05$).

Other factors which may be associated with DES included sex, use of correct refractive errors equipment, history of NCD, and daily working hours. These confounding factors were further analyzed by binary logistic regression as shown in Table 4. In this study, DES was not significantly associated with sex, age, use of correct refractive errors equipment and history of NCD. Of these factors, only working hours (less or more than 8 hours daily) played an important role in increasing the prevalence of DES symptoms; AOR 3.86 (95% CI: 1.01-14.72).

Discussion

In 12 of the 33 offices with above-average PM10 concentration, one of the major causes in all were open windows and proximity to a major road with heavy traffic. Moreover, we found that these offices had natural ventilation during rush hours, based on the organizations' save-energy policy. Levels peaked in room no. 30, which was situated on the ground floor. These findings correspond with related studies of indoor air quality, which found that it is affected by outdoor air intrusion into the indoor environment[26,37-40]. On the other hand, other offices revealed lower concentrations and values that were acceptable. However, in terms of control and toxicology, any substance has its own toxicity regarding the length of the exposure period, and participants are still subject to negative effects in terms of both acute and chronic conditions including respiratory diseases, heart disease, cancer, and severely debilitating or fatal illness[7]. Accordingly, the average HQ value was in the moderate hazard level, but some of the results showed few cases with HQ higher than 10 due to a high level of particle concentrations in workers' rooms. Notably, the present results indicated a significant risk from inhalation exposure

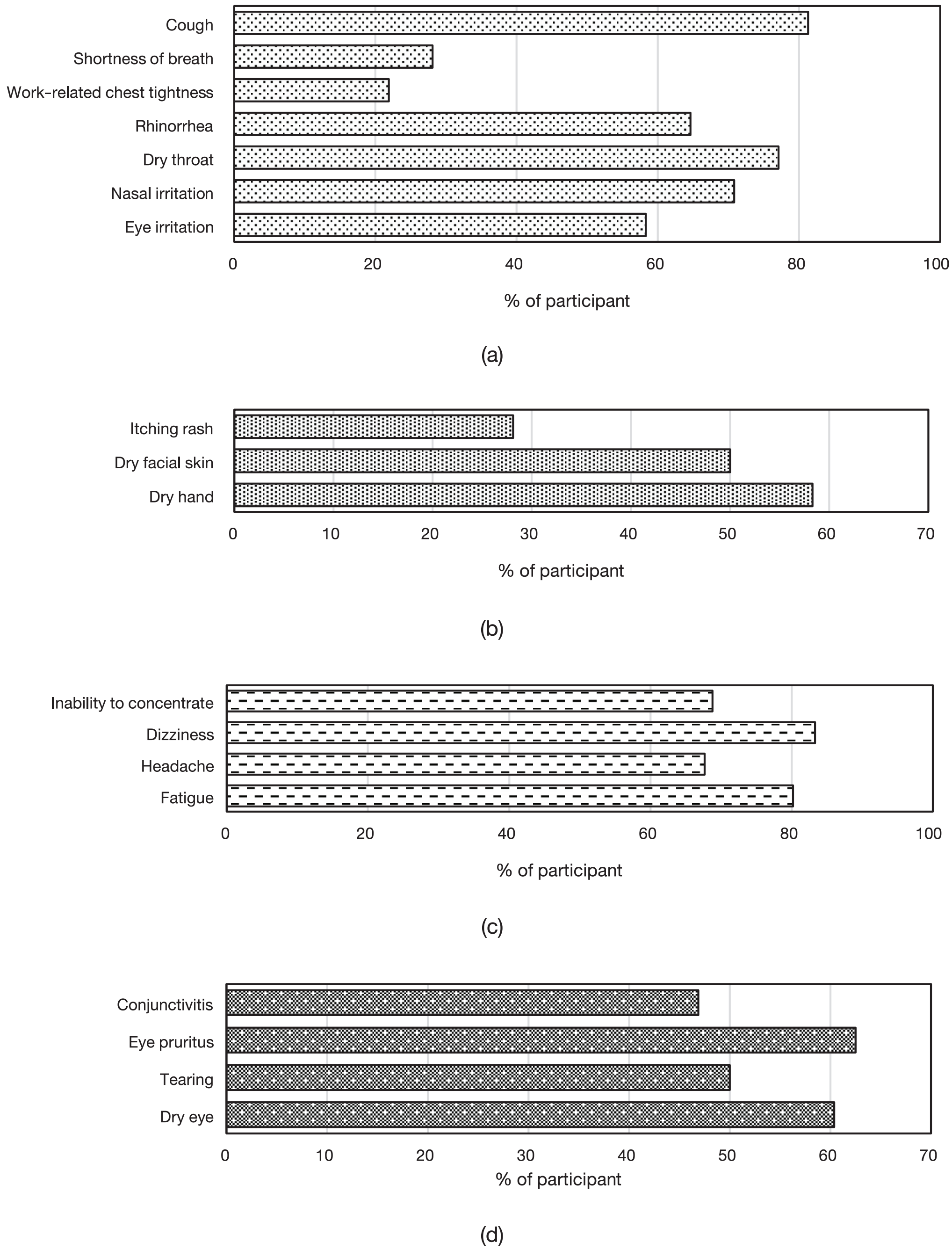

Figure 3 Prevalence of sick building syndrome (SBS) symptoms among the workers (a) Mucous membrane; (b) Skin; (c) General; and (d) Eye-related symptoms

Table 3 Presence of sick building syndrome (SBS) and its association in two PM10 concentration groups

Types of SBS	PM10 concentration				p^a
	Below average (n = 47)		Exceeded average (n = 35)		
	n	%	n	%	
Mucous membrane symptoms					
Eye irritation	19	40.4	14	40.0	0.969
Nasal irritation	11	23.4	13	37.1	0.208
Dry throat	9	19.1	10	28.6	0.356
Rhinorrhea	13	27.7	15	42.9	0.183
Work-related chest tightness	38	80.9	27	77.1	0.522
Shortness of breath	32	68.1	26	74.3	0.684
Cough	6	12.8	8	22.9	0.259
Skin symptoms					
Dry facial skin	19	40.4	20	57.1	0.173
Itchy rash	30	63.8	28	80.0	0.173
Dry hands	17	36.2	12	34.3	0.788
General symptoms					
Fatigue	8	17.0	5	14.3	0.698
Headache	13	27.7	12	34.3	0.577
Dizziness	8	17.0	4	11.4	0.451
Inability to concentrate	13	27.7	11	31.4	0.773
Eye-related symptoms					
Dry eye	22	46.8	9	25.7	0.045
Tearing	21	44.7	17	48.6	0.818
Eye pruritus	20	42.6	12	34.3	0.393
Conjunctivitis	25	53.2	16	45.7	0.430

[a]*p* by Chi-square test

Table 4 Dominant risk factors for dry eye symptoms (DES) using logistic regression analysis

Risk factor	Simple binary logistic regression		Multiple binary logistic regression	
	OR (95% CI)	*p*	AOR (95% CI)	*p*
Sex	1.229 (0.415 – 3.639)	0.709	0.816 (0.238 – 2.798)	0.747
Age (years)	0.636 (0.269 – 1.505)	0.303	0.666 (0.250 – 1.774)	0.416
Use of correct refractive errors equipment	0.230 (0.027 – 1.990)	0.182	0.206 (0.022 – 1.921)	0.165
History of NCD	0.624 (0.151 – 2.582)	0.516	0.608 (0.141 – 2.622)	0.504
Daily working hours	3.600 (1.00 – 12.955)	0.050	3.864 (1.014 – 14.722)	0.048

AOR, Adjusted Odds Ratio; CI, Confidence Interval of these indoor air pollutants. Improving office procedures should be recommended, for example, controlling PM sources, upgrading ventilation, strictly applying preventive maintenance plans for air filters, and using air cleaners[41].

Numerous studies have shown that being male/female and other personal factors are risk factors for SBS[42-44]. However, in this study, SBS symptoms were not significantly different between sexes, which was not consistent with other studies. Due to the similar working conditions and job characteristics for both males and females, this result was consistent with the hypothesis of Brasche et al[45]. As mentioned previously, dry hands and dry facial skin were the most prevalent skin symptoms. In contrast with the study of Sun et al[14] in 2018, the incidence of dry hand was relatively low. A major difference in those results came from the selected study site (household and office workers) which had a variety of activities and emission sources.

DES symptoms corresponded to the concentration of indoor PM10. This implies that building occupants who worked in offices for more than 8 hours daily, where the PM10 concentration exceeded the standard, had a 3.86 times greater risk for DES. This finding was consistent with related studies[46-48], where PM10 was significantly associated with blurred vision, burning eyes, red eyes, and watery eyes[48]. Moreover, the eye symptoms were also related to a positive relationship with the increased levels of PM in Hawaii, USA[49]. In addition, indoor air pollution increases SBS symptoms, especially eye-related symptoms. As a result, the following mitigation measures are proposed: daily working hours for faculty and staff building occupants should not exceed 8 continuous hours as an occupational health and safety regulation.

There were some limitations in this study. The study design was only able to determine significant risk factors and cannot draw cause and effect relationships between the variables. Moreover, data on outdoor air and climate as potential impact factors should be collected, due to their potential influence on symptoms. Another limitation of the study was its small sample size. Thus, more large-scale office studies in tropical countries are recommended in the future.

Conclusion

Indoor PM10 concentrations in building offices were investigated. The result shows an average value of 38.1±14.0 $\mu g/m^3$. Twelve of 33 offices in the study site exceeded the average value due to being located near an open window and proximity to a major road with heavy traffic. The results also indicate that HQ for PM10 was at moderate health hazard level (4.7±3.2). The prevalence of general-, mucosal-, skin-, and eye-symptoms among the affected academic office workers were 75.0, 57.4, 45.5 and 54.9%. DES was significantly associated with different PM10 concentrations ($p = 0.045$). Moreover, the confounding factor of working hours (more than 8 hours daily) comprised a major risk factor for DES ($p<0.05$); building occupants working in offices with PM10 concentration higher than standard for more than 8 hours per day had a 3.86 times higher risk of DES than occupants of offices with lower PM10 concentrations. These results could help organizations to create mitigating measures to minimize risk of SBS among workers, by limiting the working period to less than 8 hours daily.

Author Contributions

TT, NO, CP, TN: Conceptualization; TT, NO, CP, TC, TN: Data collection and analysis; TN: Project administration; TT, NO, CP, TC: Methodology; TT, NO, CP: Writing - Original draft; TN: Writing - reviewing and editing.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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