Human and Ecological Risk Assessment: An International Journal

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/bher20

An evaluation of occupant health and indoor environmental quality in university workspaces

Mina Moayedi & Hamed Kamelnia

To cite this article: Mina Moayedi & Hamed Kamelnia (2022): An evaluation of occupant health and indoor environmental quality in university workspaces, Human and Ecological Risk Assessment: An International Journal, DOI: 10.1080/10807039.2022.2146573

To link to this article: https://doi.org/10.1080/10807039.2022.2146573

Published online: 17 Nov 2022.

HUMAN AND ECOLOGICAL RISK ASSESSMENT: AN INTERNATIONAL JOURNAL
https://doi.org/10.1080/10807039.2022.2146573

An evaluation of occupant health and indoor environmental quality in university workspaces

Mina Moayedi[a] and Hamed Kamelnia[a,b]

[a]Department of Architecture and Urbanism, Ferdowsi University of Mashhad, Mashhad, Iran; [b]Healthy Building Laboratory, Ferdowsi University of Mashhad, Mashhad, Iran

ABSTRACT
Indoor environmental quality is an important parameter in determining the occupant's health status in the office environment. To show the important connection between human health and environmental quality, this study was carried out to investigate the relationship between Indoor Air Quality (IAQ), the prevalence of health symptoms, selected personal factors, and office characteristics among university office workers. Six parameters of IAQ, including air temperature, relative air humidity, formaldehyde, particulate matter, carbon monoxide, and carbon dioxide, were measured by a direct reading instrument. We found eye irritation, dryness, and itching were the most common health symptoms, and the prevalence of weekly dermal, mucosal, psychological, and general symptoms were 60.9%, 75.4%, 60.8%, and 64.7%, respectively. Age, and working experience were associated with general symptoms, while gender was related to dermal symptoms. Furthermore, we observed that the prevalence of health symptoms in 15–30 years old office rooms was significantly higher than others, and health symptoms among employees with 11–20 years of working experience were higher than other age groups. Strategies like using a proper ventilation system, air cleaners, maintaining social distance, humidity, and temperature control can help to improve indoor air quality and protect us from the risk of airborne transmitted diseases.

Abbreviations: IEQ: Indoor Environmental Quality; IAQ: Indoor Air Quality; PM: Particulate Matter; CO: Carbon monoxide; CO2: Carbon dioxide; HCHO: formaldehyde; VOC: Volatile Organic Compounds; RH: Relative air Humidity; SBS: Sick Building Syndrome; WHO: World Health Organization

ARTICLE HISTORY
Received 9 February 2022
Revised manuscript
Accepted 8 November 2022

KEYWORDS
Occupant well-being; indoor environmental quality; health; office; indoor air

Introduction

Office employees spend a significant deal of time in buildings where the physical environment comfort affects their performance. In this point of view, the physical environment is one of the important parameters in developing a healthy working environment, especially after the COVID-19 pandemic (Chan and Liu 2018; López et al. 2023). According to former research by the EPA claims, one of the five most significant health risks in a work environment is air pollution (Norhidayah et al. 2013).

CONTACT Hamed Kamelnia kamelnia@um.ac.ir Department of Architecture and Urbanism, Ferdowsi University of Mashhad, Mashhad, Iran.

Human health and well-being have been the main factors for research on indoor air quality. SBS (Sick Building Syndrome) and BRI (Building Related Illness) were first documented in the 1980s (ASHARE Environmental Health Committee 2011; World Health Organization 1984) In 1983, the World Health Organization (WHO) described office-related symptoms as symptoms that are work-related, such as irritation of the skin and mucous membranes, headaches, tiredness, and difficulty in concentrating, that can be severely debilitating as reported by workers in many office environments (Fisk and Rosenfeld 1997; Gou and Siu-Yu Lau 2012; Veenaas et al. 2020; Wolkoff, Azuma, and Carrer 2021; World Health Organization 1984).

It has been proved that a bad working environment is not only accompanied by decreased job satisfaction, low level of productivity, and cognitive performance degradation but also leads to musculoskeletal disorder, burnout, depression, and absenteeism, etc. (Fassoulis & Alexopoulos 2015; Al Horr et al. 2016; Cedeño Laurent et al. 2021).

Indoor Air Quality (IAQ) was firstly investigated in the 1970s (Zhang 2005) and continues until nowadays because it is a fundamental determining factor for the health, well-being, productivity, and comfort of human beings (Geng et al. 2017; Al Horr et al. 2016; Roumi, Zhang, and Stewart 2022; Wyon 2004; Zhang et al. 2017). The COVID-19 pandemic has highlighted the matter of IAQ since the airborne disease is transmitted chiefly through respiratory aerosols (López et al. 2023). The concept of IAQ cannot be easily shown, as it depends on the comfort and health of individuals in this environment. Comparative studies carried out by the United States Environmental Protection Agency (USEPA) ranked IAQ as one of the top five environmental hazards to public health (U.S. Environmental Protection Agency 1996). In the last decades, different factors have been reported for soared exposure levels to air pollutants in the indoor environment, including the construction of more tightly sealed buildings, reduction of ventilation rates (for energy saving), inefficient filtration, and use of synthetic building materials and furnishings, plus the use of chemically formulated personal care products, paints, pesticides, and cleaners (Kelly and Fussell 2019; Lai et al. 2009). As studying all types of indoor air pollutants for general air quality monitoring and assessment is a complex matter (Mui et al. 2008; Wong, Mui, and Hui 2006), it was suggested the measurement and analysis of indoor carbon monoxide (CO), carbon dioxide (CO2) concentration, (Du et al. 2020; López et al. 2023), formaldehyde (HCHO) (Golden 2011; Gunschera et al. 2013; Nielsen, Larsen, and Wolkoff 2013), volatile organic compound (VOC) (Araki et al. 2010; Wolkoff 2013) and particulate matter could be useful for understanding IAQ (Wong et al. 2006). The U.S. EPA (2000) has reported a higher level of air pollutants in indoor air, compared to outdoor air pollutants, by two-five times and sometimes above 100 times (Putra 2015). Furthermore, improper indoor air can reduce the motivation of these individuals. According to the WHO, optimum environmental conditions of a healthy building can result in higher health levels and productivity of occupants (Ali, Chua, and Lim 2015; Qiu, Wang, and Tang 2020).

The COVID-19 pandemic, declared by the World Health Organization, has indicated renewed interests in the assessment of evaluated IEQ, mainly indoor air quality and thermal comfort. Previous IAQ and health studies have been done in different indoor environments but generally among office staff (Al Horr et al. 2016; Zamani & Nafiz

2013). Most of the previous studies have only studied one aspect of IAQ factors in association with health symptoms, including room temperature and humidity (Jo and Sohn 2009; Wolkoff 2018; Wolkoff et al. 2021) ventilation (Sun et al. 2019; Zhai and Metzger 2019), volatile organic compounds (VOC) (ECJRC 1997; Sahlberg et al. 2013; Yang et al. 2020), atopy and FeNO (Lim et al. 2015). Female gender (Fu et al. 2022; Hedge 1984; Lim et al. 2015), and allergy (Sahlberg et al. 2012) were reported to be associated with office-related symptoms.

However, there is a scarcity of studies on associations between indoor health symptoms and environmental factors in universities. Most surveys on the quality of university environments focus on classrooms, public spaces, open spaces, and students-related spaces. While university staff spends most of their time in their workspaces, and these spaces usually do not have the necessary qualities. Other studies confirm that academic staffs are in a great risk of stress-related conditions than many other employees (Sterling et al. 2014). Even a little space per capita is considered; for example, in Iran, per capita is 9 square meters per employee in the university space. Additionally, concerns about the prevalence of Sick Building Syndrome are widely increasing, especially in Asia and Iran (Jafari et al. 2015; Sarkhosh et al. 2021). Therefore, this article investigated associations between indoor air quality and occupant health among office workers. Studying associations between measured indoor exposures and health symptoms was the first aim of this work. The second one was to study the relation of health symptoms and selected office characteristics, working experience, and gender.

Materials and methods

Study population

To achieve the research aim, we conducted a questionnaire survey study targeting occupants of university office buildings. It is a cross-sectional study of 26 workstations at the department offices. Totally, there were 32 offices at the departments in the Ferdowsi University of Mashhad that has been selected as the third university in Iran (1949) and the largest university in the east of the country with the most significant number of international students and all fields with 12 faculties with different characteristics for this research.

The inclusion criterion for the selection of office environments was they should have air-conditioning ventilation system and a similar area. Among all the selected samples, 62.5% were formed by cellular offices and 37.5% by shared offices. Totally, 76 office workers were employed at all the offices. The sample offices had floor areas ranging from 10 to 50 m^2 and were occupied by 1–5 people. The size of the samples was calculated by the Cochran formula; accordingly, 64 office workers were targeted for the study, among whom one was excluded because of pregnancy. The study was approved by the Healthy Building Laboratory (HBL) before the field data collection. All the participants gave informed agreement after being informed on the purpose of the study.

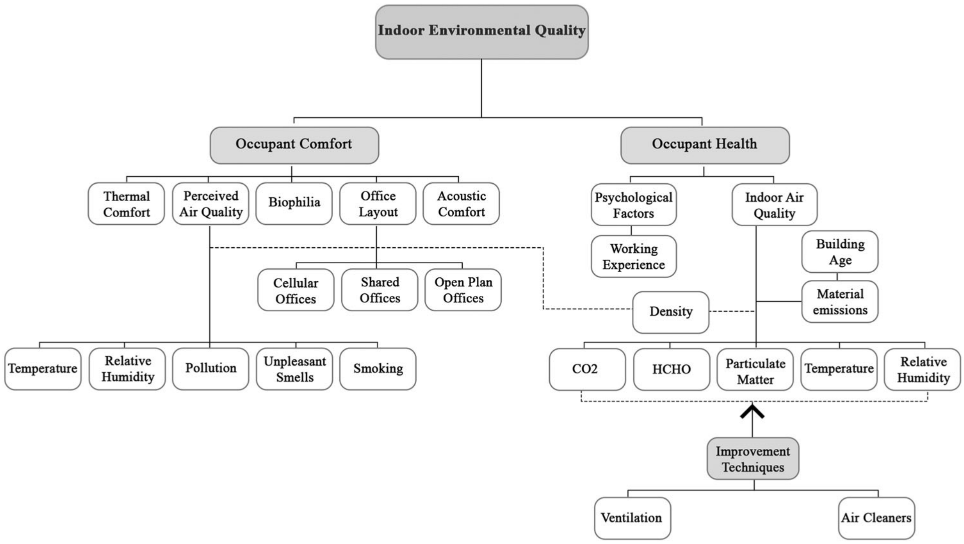

Figure 1. The result model of indoor environmental quality factors.

$$sample\ \ size = \frac{\frac{z^2 \mathrm{pq}}{d^2}}{1 + \frac{1}{N}\left(\frac{z^2 \mathrm{pq}}{d^2} - 1\right)} \sim \ \ 64$$

N = population size
e = Margin of error (percentage in decimal form)
z = z-score

Questionnaire

To study the relationship between IAQ and health symptoms, a post-occupancy evaluation survey was designed to collect demographic information, office characteristics, perceived indoor air quality, and health symptoms. The questions were accommodated from Indoor Air Quality report (European Commission Joint Research Centre) and Work Symptoms Survey, NIOSH (National Institute Occupational Safety and Health 1991) , and previous SBS studies (Lim et al. 2015; Wong et al. 2009a). Among the classification in the conceptual model of the study (Figure 1), this article pursues IEQ considering affecting factors that can enhance the occupant health and comfort.

The questionnaire was divided into four parts. The first part collected a respondent's demographic information like gender, age, marital status, education level, years of work experience and, work hours/day.

The second part included items on office characteristics such as new furniture in the office, the efficiency of the ventilation system, and office wall painted during the past three months.

The occupant's acceptance of the perceived IAQ given by four aspects, namely thermal environment, humidity, air quality, and pollutions, was studied with a Likert-type scale in the third part. For perceived indoor environment quality, there were nine items on too low temperature, too high temperature, dry air, humid air, stuffy bad air, air pollution, unpleasant smell, dust and dirt, and smoking.

Health symptoms consisted of 22 questions categorized into four different groups of symptoms (mucosal, dermal, psychological, and general symptoms). Mucosal symptoms included eye irritation, dryness and itching, blurred vision, runny and stuffy nose, nose irritation and itching, cough and sore throat, throat irritation, and asthma. Dermal symptoms included itching in the skin or the face and dry skin. Psychological symptoms included difficulty in concentration, tension or stress, depression, and aggression. At last, general symptoms included heart palpitations and pain, blood pressure, headache, nausea, dizziness, pain in shoulder, neck or back muscles, fatigue, or lethargy, feeling drowsy and insomnia, and sleep disorder.

Five alternative answers considered in each of the health questions for their frequency of occurrence during the past three months: never, rarely (3–4 times per month), sometimes (8–10 times per month), often (16–20 times per month) and always (every day).

In designing the questions, reference was made to some previous studies (Bluyssen et al. 1996; Lim et al. 2015; Runeson et al. 2006). At the end of the survey, the amounts of sick leaves were asked.

Environmental measurements

Environmental measurements were carried on to describe the physical conditions in the workstations. These factors included measurements of air temperature, relative air humidity (RH), carbon monoxide (CO), carbon dioxide (CO_2), formaldehyde (HCHO), and particulate matter in 6 levels (PM0.3, PM0.5, PM1.0, PM2.5, PM5.0, and PM10). The air quality factors in previous studies are represented in Table 1 which shows the particulate matter mainly included on PM2.5 and PM10. Therefore, in this study, particulate matter was measured in 6 levels.

The samplers were placed in the middle of the office space at worker's breathing zone level in a sitting position (a vertical height of approximately 1–1.5 m) above the floor level and about 1 m from the staff (Lim et al. 2015; Mandin et al. 2017). Data collection took about 50–60 minutes to complete, and it has been done two times in a day (defined as 8:00–17:00, in the morning and the afternoon) in two different semesters (winter and summer).

There were six important parameters in this study. The Portable CO2 Meter HS-2 was used for the CO2, temperature, and humidity detection. The HCHO, CO, and particulate matter (PM0.3, PM0.5, PM1.0, PM2.5, PM5.0, and PM10) were recorded by using the particle counter dust measuring device PCE-PCO 1. To ensure the quality of the data taken by the instruments, all the instruments were calibrated before the measurement started.

Additional physical descriptors were simultaneously derived from the office plans, photographs, and measurements, including potential exterior view, indoor plants, ventilation system, lighting system, materials, and building age.

Statistical analysis

Associations of the prevalence of health symptoms concerning office exposures (office characteristics and IAQ measurement) were analyzed by Spearman's rank correlation

Table 1. Overview of the air quality parameters in studies.

References	Year	Parameters
(Hedge et al., 1989)	1989	CO, CO2, NO2, HCHO, VOC
(Jones, 1999)	1999	HCHO, CO2, CO, NO2
(Pope III et al., 2002)	2002	PM2.5, PM10, CO, NO2, SO2
(USEPA, 2004)	2004	PM10, PM2.5, CO
(Wong et al., 2006)	2006	TVOC, CO, CO2, RH, T, NO2, HCHO
(Rios et al., 2009)	2009	VOC, PM, RH, T
(Araki et al., 2010)	2010	MVOC, HCHO
(Tsai et al., 2012)	2012	CO2, PM2.5, RH, T
(Karakatsani et al., 2012)	2012	PM2.5, PM10, NO2, O3, RH, T
(Wolkoff, 2013)	2013	VOC, HCHO
(Zamani & Nafiz, 2013)	2013	CO2, CO, TVOC, PM10, PM2.5
(CPCB, 2014)	2014	PM10, PM2.5, CO
(Putra, 2015)	2015	PM2.5, PM10
(Lim et al., 2015)	2015	CO, CO2, RH, T
(Li, Wen, and Zhang 2017)	2017	PM2.5
(Sun et al. 2019)	2019	TVOC, HCHO, PM2.5, RH, T
(Nezis et al. 2019)	2019	PM10, PM2.5, PM1.0
(Chen et al. 2020)	2020	HCHO, TVOC
(Mentese et al. 2020)	2020	CO2, PM, TVOC, RH, T
(Hou et al. 2021)	2021	CO2, RH, T
(Yin et al. 2022)	2022	PM2.5, CO2
(Jung et al. 2022)	2022	CO, CO2, HCHO, TVOC, O3, NO2

test. Then, Spearman's rank correlation test was used to analyze the associations between perceived IAQ, health symptoms, and absenteeism among the office workers. Associations of the prevalence of health symptoms between the groups were analyzed by the Chi-square test. Moreover, comparisons between the prevalence of health symptoms with building age and among employee working experience were analyzed by multilevel logistic regression. Also, personal factors of office workers in association with health symptoms were compared using the Chi-square test and independent t-test. Finally, an odds ratio (OR) with 95% confidence interval (95% CI) was calculated.

To examine the internal consistency of the items in the questionnaire, a preliminary investigation was done, and a reliability check using Cronbach's alpha produced a value of 0.791. This result showed that the degree to which the items in the questionnaire correlated with each other was significant (Fassoulis & Alexopoulos 2015).

$$\rho_T = \frac{k^2 \overline{\sigma_{ij}}}{\sigma_X^2} = 0.791$$

ρ_T = tau-equivalent reliability

k = number of items

σ_{ij} = covariance between Xi and Xj

σ_X^2 = item variances and inter-item co-variances

All the data analysis was conducted using Statistical Package for the Social Sciences (SPSS) 25.0, using two-tailed tests at a 0.05 significance level.

Results

Socio-demographic information

Table 2 summarizes descriptive information of the employees who participated in the study. According to Table 2, 71.9% of the respondents were females, and the mean age

Table 2. Demographic characteristics of the studied employees (N = 64).

Variables		N (%)
Gender	Male	18 (28.1)
	Female	46 (71.9)
Age (years)	≤30	4 (6.3)
	31–40	22 (34.4)
	41–50	34 (53.1)
	>50	4 (6.3)
Marital status	Single	6 (9.4)
	Married	58 (90.6)
Education level	Under diploma/Diploma	6 (9.4)
	Bachelor's degree	40 (62.5)
	Master's degree	18 (28.1)
Working experience (years)	0–10	10 (15.6)
	11–20	34 (53.1)
	21–30	20 (31.3)
Work hours/day	Mean ± SD	7.71 ± 0.87
	Min–Max	5–11

was 43.2 ± 0.71 years (ranging between 41 and 50 years). More than half of the respondents had work experience between 11 and 20 years. A large majority of the respondents had a university education (90.6%). Moreover, 90.6% of the study population were married, and the mean work hours per day among the respondents was 7.71 ± 0.87 years.

Prevalence of health syndrome

Among the respondents who participated in this study, eye irritation, dryness, and itching were the most common health symptoms, followed by musculoskeletal pain, blurred vision, and fatigue, or lethargy. Table 3 shows associations between health symptoms and indoor air quality factors among the office workers. There were eight parameters that showed significant associations between the prevalence of health symptoms and the indoor air pollutants in office spaces; HCHO, CO2, PM0.3, PM0.5, PM1.0, PM2.5, PM0.5, and PM10. Based on the result, HCHO was associated with nose irritation and itching. CO2 was associated with eye irritation, dryness, itching, and asthma. The particulate matter had a significant association with the mucosal, dermal, psychological, and general symptoms. Prevalence of heart palpitations and pain and as well as cough and sore throat, has the most association with particulate matter. Also, the percentage of occupants that reported different types of allergies was under 10%.

Perceived indoor air quality

Among the 26 studied offices, 40.6% of office rooms had centralized air conditioning systems, 34.4% had split, and centralized conditioning systems, and 25% had centralized air conditioning systems. Moreover, gypsum, glass, wooden, and stone tiles were the most used materials. The relationship between health symptoms and perceived indoor air quality among the office workers is shown in Table 4. These factors are occupant environmental perception of temperature, humidity, pollution in the air and smell. A Spearman correlation coefficient measured the degree of association between the two variables. The participants reporting too low and too high temperature as well as smelly,

Table 3. Spearman correlation of associations between health symptoms and indoor air quality factors among the office workers.

Health symptoms	HCHO	CO2	PM0.3	PM0.5	PM1.0	PM2.5	PM5.0	PM10
Mucosal								
Eye irritation, dryness and itching	0.143	0.424* (0.016)[1]	0.252	0.248	0.057	0.244	0.277	0.349
Blurred vision	−0.022	0.106	0.223	0.303	0.082	0.122	0.118	0.329
Runny and stuffy nose	−0.205	0.158	0.496** −0.004	0.412* −0.019	0.422* −0.016	0.25	0.34	0.428* −0.015
Nose irritation and itching	−0.365* −0.04	0.05	0.513** −0.003	0.468** −0.007	0.381* −0.031	0.179	0.352* −0.048	0.412* −0.019
Cough and sore throat	−0.244	0.039	0.551** −0.001	0.454** −0.009	0.612** 0	0.406* −0.021	0.487** −0.005	0.407* −0.021
Throat irritation	0.006	0.307	0.532** −0.002	0.405* −0.021	0.362* −0.042	0.168	0.17	0.113
Asthma	0.071	0.364* −0.041	0.481** −0.005	0.308	0.413* −0.019	0.249	0.218	0.189
Dermal								
Itchy skin	−0.075	0.26	0.442* −0.011	0.156	0.161	−0.002	−0.024	−0.159
Dry skin	0.193	0.141	0.408* −0.02	0.122	0.001	−0.018	−0.103	−0.085
Psychological								
Difficulty in concentration	−0.295	−0.101	0.566** −0.001	0.491** −0.004	0.394* −0.026	0.135	0.258	0.309
Tension or stress	−0.108	0.233	0.429* −0.014	0.335	0.282	0.241	0.256	0.368* −0.038
Depression	−0.084	0.168	0.222	0.15	0.164	0.246	0.23	0.109
Aggression	−0.155	0.026	0.189	0.202	0.21	0.329	0.417	0.39
General								
Headache	−0.285	−0.015	0.493** −0.004	0.454** −0.009	0.252	0.128	0.24	0.274
Nausea	−0.129	0.055	0.336	0.369	0.401	0.342	0.466	0.497
Dizziness	−0.199	−0.015	0.28	0.101	0.099	−0.117	0.002	−0.019
Heart palpitations and pain	−0.148	0.052	0.648** 0	0.549** −0.001	0.583** 0	0.422* −0.016	0.531** −0.002	0.586** 0
Blood pressure	−0.197	−0.066	0.410* −0.02	0.404* −0.022	0.319	0.227	0.288	0.414* −0.018
Musculoskeletal pain	−0.033	−0.081	0.361	0.224	0.075	−0.024	0.125	0.163
Fatigue or lethargy	−0.053	−0.201	0.396* −0.025	0.26	0.257	−0.039	0.073	0.119
Feeling drowsy	−0.066	0.05	0.414* −0.019	0.433* −0.013	0.504** −0.003	0.427* −0.015	0.416* −0.018	0.434* −0.013
Insomnia and sleep disorder	−0.326	−0.026	0.472** −0.006	0.434* −0.013	0.354* −0.047	0.297	0.378* −0.033	0.457** −0.009

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).
[1]p-value.

dirty, humid, or dry air were more likely to have health symptoms. Additionally, the respondents reporting indoor air pollution in office spaces were more likely to report health symptoms. The occupant's acceptance of the perceived indoor air quality showed that too low temperature and dry air in the office was related with the mucosal, dermal, psychological, and general symptoms. Other studies showed that the perception of "dry air" in office environments keeps up to be a major complaint (Bluyssen et al. 2016; Wolkoff 2018). Besides, too high temperature, humid air, air pollution, and unpleasant smell were associated with the mucosal, psychological and general symptoms. Temperature variability in the workspace can decrease concentration and increase

Table 4. Spearman correlation of associations between health symptoms and perceived indoor air quality among the office workers.

Health symptoms	Too low temperature	Too high temperature	Dry air	Humid air	Stuffy bad air	Air pollution	Unpleasant smell	Dust and dirt	Smoking
Mucosal									
Eye irritation, dryness and itching						0.386*			
Blurred vision						0.409*			
Runny and stuffy nose	0.472**	0.593**	0.373**			0.476	0.500**	0.603**	
Nose irritation and itching	0.478**	0.584**	0.354*	0.641*			0.359*	0.564**	
Cough and sore throat			0.414*	0.368*	0.407*	0.658**		0.377*	
Asthma					0.353*	0.486**			
Dermal									
Dry skin	0.456**		0.457**						
Psychological									
Difficulty in concentration	0.405*	0.492**		0.597**					
Tension or stress	0.349*	0.472**	0.390*	0.421*		0.372*	0.536**		
Aggression						0.405*	0.420*		
General									
Headache	0.496**	0.401*		0.606**		0.437*		0.382*	
Nausea				0.357*		0.374*	0.494**	0.456**	0.441*
Dizziness	0.427*	0.466**	0.482**	0.459**					
Heart palpitations and pain			0.360*	0.552**		0.404*	0.402*	0.446*	
Blood pressure									
Musculoskeletal pain	0.429*	0.424*							
Fatigue or lethargy		0.463**		0.412*		0.524**			
Insomnia and sleep disorder							0.363*	0.451**	0.367*
absenteeism		0.425*						0.409*	0.420*

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

drowsiness, stress, and affect sleep quality (Engineer et al. 2021). Moreover, epidemiological studies indicated that an increase in temperature was associated with dry eye symptoms (Zhong et al. 2018). Dust and dirt were also observed to associate with the mucosal and general symptoms. Stuffy bad air was associated with the mucosal symptoms, while smoking was associated with the general symptoms. Recent research found that working in the office with a face mask results in higher concentrations of carbon dioxide exposure that may lead to physical symptoms like drowsiness, skin irritation, and loss of attention (Licina and Yildirim 2021). However, the respondents who felt too high temperature, dust, and dirt, and cigarette smoke in the air were also more likely to have sick leaves and absenteeism.

Relationship between building age, working experience, and prevalence of health syndrome

Comparisons of indoor air quality in relation to health symptoms in less than 5 years old, 5–10 years old, 10–15 years old, 15–30 years old, and 30 years old (or more) office rooms are presented in Table 5. Indoor HCHO and CO2 in the 15–30 years old office rooms were significantly higher than the other office spaces. The concentration of particulate matter was considerably higher in the office rooms with the age of 30 years or

Table 5. Multilevel logistic regression analysis of associations between health symptoms and building age among the office workers.

		Building age 0–5 years Coefficient (sig.)	Building age 10–15 years Coefficient (sig.)	Building age 15–30 years Coefficient (sig.)	Building age >30 years Coefficient (sig.)
CO2	Eye irritation, dryness and itching	0.791 (0.111)	0.791 (0.111)	0.194 (0.547)	0.283 (0.429)
	Asthma	0.791 (0.111)	−0.725 (0.165)	−0.086 (0.790)	0.759* (0.11)
HCHO	Nose irritation and itching	0.000 (1.000)	−0.186 (0.764)	−0.747** (0.005)	−0.110 (0.762)
PM0.3	Runny and stuffy nose	0.761 (0.135)	−0.363 (0.548)	0.560 (0.058)	.
	Nose irritation and itching	0.761 (0.135)	−0.186 (0.764)	0.560 (0.058)	.
	Cough and sore throat	0.186 (0.764)	0.745 (0.148)	0.699* (0.011)	.
	Throat irritation	0.295 (0.630)	0.791 (0.111)	0.754** (0.005)	.
	Asthma	0.295 (0.630)	0.725 (0.165)	0.636* (0.026)	.
	Itchy skin	0.186 (0.764)	0.725 (0.165)	0.659* (0.020)	.
	Dry skin	0.825 (0.086)	0.559 (0.327)	0.446 (0.146)	.
	Difficulty in concentration	0.761 (0.135)	0.395 (0.510)	0.496 (0.101)	.
	Tension or stress	0.648 (0.237)	−0.791 (0.111)	0.691* (0.013)	.
	Headache	0.913* (0.030)	0.612 (0.272)	0.239 (0.454)	.
	Heart palpitations and pain	0.825 (0.086)	0.186 (0.764)	0.728** (0.007)	.
	Blood pressure	0.825 (0.086)	−0.395 (0.510)	0.683* (0.014)	.
	Fatigue or lethargy	0.583 (0.302)	0.791 (0.111)	0.342 (0.277)	.
	Feeling drowsy	0.559 (0.327)	0.181 (0.770)	0.731** (0.007)	.
	Insomnia and sleep disorder	0.648 (0.237)	−0.791 (0.111)	0.773** (0.003)	.
PM0.5	Runny and stuffy nose	0.456 (0.440)	−0.363 (0.548)	0.552 (0.063)	−0.218 (0.545)
	Nose irritation and itching	0.456 (0.440)	−0.186 (0.764)	0.552 (0.063)	0.130 (0.720)
	Cough and sore throat	0.000 (1.000)	0.745 (0.148)	0.688* (0.013)	−0.130 (0.720)
	Throat irritation	0.530 (0.358)	0.791 (0.111)	0.753** (0.005)	−0.488 (0.153)
	Difficulty in concentration	0.456 (0.440)	0.395 (0.510)	0.487 (0.108)	0.261 (0.467)
	Headache	0.913* (0.030)	0.612 (0.272)	0.215 (0.502)	.
	Heart palpitations and pain	0.530 (0.358)	0.186 (0.764)	0.722** (0.008)	−0.429 (0.217)
	Blood pressure	0.559 (0.327)	−0.375 (0.534)	0.672* (0.017)	0.070 (0.848)
	Feeling drowsy	0.559 (0.327)	0.181 (0.770)	0.712** (0.009)	0.163 (0.652)
	Insomnia and sleep disorder	0.354 (0.559)	−0.791 (0.111)	0.767** (0.004)	0.276 (0.440)
PM1.0	Runny and stuffy nose	0.167 (0.789)	−0.363 (0.548)	0.580* (0.048)	0.218 (0.545)
	Nose irritation and itching	0.167 (0.789)	−0.186 (0.764)	0.580* (0.048)	−0.130 (0.720)
	Cough and sore throat	−0.408 (0.495)	0.745 (0.148)	0.908** (0.000)	0.217 (0.546)
	Throat irritation	0.323 (0.596)	0.791 (0.111)	0.682* (0.015)	−0.407 (0.244)
	Asthma	0.323 (0.596)	0.725 (0.165)	0.682* (0.015)	0.000 (1.000)
	Difficulty in concentration	0.167 (0.789)	0.395 (0.510)	0.583* (0.047)	−0.03 (0.905)
	Heart palpitations and pain	0.323 (0.596)	0.186 (0.764)	0.688* (0.013)	0.429 (0.217)
	Feeling drowsy	0.408 (0.495)	0.181 (0.770)	0.666* (0.018)	0.408 (0.242)
	Insomnia and sleep disorder	0.000 (1.000)	−0.791 (0.111)	0.814** (0.001)	0.118 (0.745)
PM2.5	Cough and sore throat	−0.395 (0.510)	0.304 (0.619)	0.731** (0.007)	0.077 (0.832)
	Heart palpitations and pain	0.125 (0.841)	0.152 (0.807)	0.440 (0.153)	0.423 (0.224)
	Feeling drowsy	0.395 (0.510)	0.000 (1.000)	0.594* (0.042)	0.302 (0.397)
PM5.0	Nose irritation and itching	−0.408 (0.495)	−0.250 (0.685)	0.815** (0.001)	−0.065 (0.857)
	Cough and sore throat	−0.250 (0.685)	0.667 (0.219)	0.845** (0.001)	−0.065 (0.857)
	Heart palpitations and pain	−0.395 (0.510)	0.250 (0.685)	0.780** (0.003)	0.000 (1.000)
	Feeling drowsy	0.250 (0.685)	0.081 (0.897)	0.695** (0.012)	0.249 (0.484)
	Insomnia and sleep disorder	−0.395 (0.510)	0.354 (0.559)	0.796** (0.002)	0.172 (0.635)
PM10	Runny and stuffy nose	0.167 (0.789)	−0.444 (0.454)	0.827** (0.001)	0.000 (1.000)
	Nose irritation and itching	0.167 (0.789)	−0.152 (0.807)	0.827** (0.001)	0.000 (1.000)
	Cough and sore throat	−0.408 (0.495)	0.304 (0.619)	0.661* (0.019)	0.051 (0.888)
	Tension or stress	0.000 (1.000)	0.000 (1.000)	0.746** (0.005)	−0.178 (0.623)
	Heart palpitations and pain	0.323 (0.596)	0.152 (0.807)	0.859** (0.000)	0.000 (1.000)
	Blood pressure	0.323 (0.596)	0.323 (0.596)	0.606* (0.037)	0.073 (0.841)
	Feeling drowsy	0.408 (0.495)	0.000 (1.000)	0.505 (0.094)	0.338 (0.340)
	Insomnia and sleep disorder	0.000 (1.000)	0.645 (0.239)	0.782** (0.003)	0.233 (0.516)

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

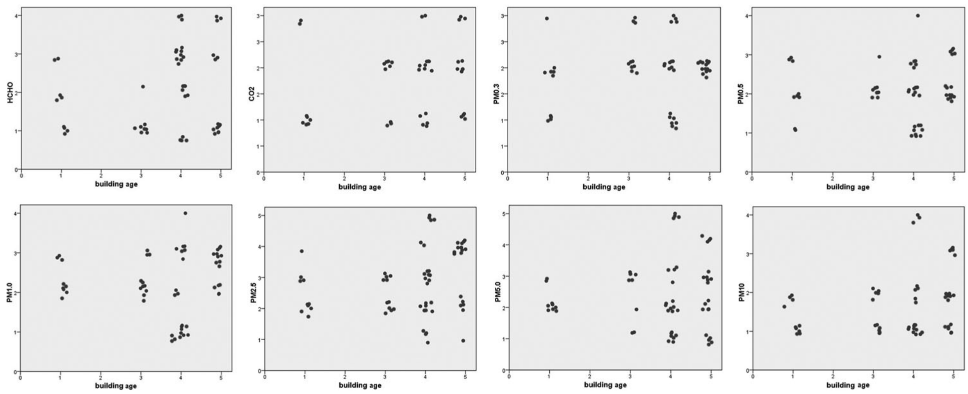

Figure 2. Relationship between building age and IAQ parameters.

more (Figure 2). Associations between the prevalence of health symptoms and building age as a continuous parameter were analyzed with a multilevel logistic regression test. Building age was associated with the prevalence of health symptoms.

In general, the prevalence of health symptoms in 0–5 years old office rooms was significant, in the range 10–15 years decreased and in the office room with 15–30 years significantly increased. However, a small association was found in office rooms above 30 years in this regard.

Comparisons between the IAQ parameters and the prevalence of health symptoms with working experience are shown in Table 6. Based on the result, multilevel logistic regression analysis indicated that there was a meaningful variation in the prevalence of health syndrome among the three age groups, such that the health symptoms score in the 11–20 years age group was higher than that in the other two groups (i.e., 0–10 years and 21–30 years).

As a next step, associations between the mucosal, dermal, psychological, and general symptoms with personal factors, office characteristics, and indoor office measurements were investigated (Table 7). Accordingly, the general symptoms were associated with age ($p = 0.035$) and working experience ($p = 0.049$), while the dermal symptoms were associated with gender ($p = 0.048$). Moreover, the office materials were associated with the general symptoms ($p = 0.012$). However, none of the temperature, relative air humidity, and HCHO factors were significantly associated with health symptoms. In addition, CO2 was observed to be associated with mucosal symptoms ($p = 0.042$). PM0.3 was associated with the mucosal, dermal, psychological, and general symptoms, while PM0.5, PM1.0, PM2.5, PM5.0, and PM10 were associated with the general symptoms.

Discussion

In this study, work-related symptoms were prevalent among the university staff, particularly eye, nose, and throat symptoms, musculoskeletal pain, headache, and fatigue. Similar results were observed in other studies. In a study by Runeson et al. among the Swedish workforce, general symptoms including headache, fatigue, and sensation of getting cold were most common, followed by mucosal symptoms (Runeson et al. 2006).

Table 6. Multilevel logistic regression analysis of associations between health symptoms and employee working experience among the office workers.

		Working experience 0–10 years Coefficient (sig.)	Working experience 11–20 years Coefficient (sig.)	Working experience 21–30 years Coefficient (sig.)
CO2	Eye irritation, dryness and itching	−0.304 (0.619)	0.334 (0190)	0.670* (0.034)
	Asthma	−0.02739	0.463 (0.061)	0.372 (0.290)
HCHO	Nose irritation and itching	−0.968** (0.007)	−0.647** (0.005)	0.507 (0.135)
PM0.3	Runny and stuffy nose	0.645 (0.239)	0.616** (0.009)	0.163 (0.653)
	Nose irritation and itching	0.645 (0.239)	0.581* (0.015)	0.261 (0.466)
	Cough and sore throat	0.913* (0.030)	0.640** (0.006)	0.237 (0.510)
	Throat irritation	0.761 (0.135)	0.637** (0.006)	0.312 (0.380)
	Asthma	0.152 (0.807)	0.604* (0.010)	0.285 (0.424)
	Itchy skin	1.000** (0.000)	0.553* (0.021)	0.026 (0.943)
	Dry skin	0.913* (0.030)	0.378 (0.135)	0.150 (0.680)
	Difficulty in concentration	0.645 (0.239)	0.611** (0.009)	0.435 (0.209)
	Tension or stress	0.913* (0.030)	0.492* (0.045)	−0.023 (0.951)
	Headache	0.444 (0.454)	0.787** (0.000)	0.047 (0.897)
	Heart palpitations and pain	0.408 (0.495)	0.627** (0.007)	0.542 (0.106)
	Blood pressure	.	0.448 (0.072)	0.300 (0.400)
	Fatigue or lethargy	0.000 (1.000)	0.331 (0.194)	0.450 (0.192)
	Feeling drowsy	0.761 (0.135)	0.540* (0.025)	0.198 (0.584)
	Insomnia and sleep disorder	1.000** (0.000)	0.510* (0.037)	0.074 (0.838)
PM0.5	Runny and stuffy nose	0.645 (0.239)	0.437 (0.080)	0.231 (0.520)
	Nose irritation and itching	0.645 (0.239)	0.477 (0.053)	0.335 (0.345)
	Cough and sore throat	0.913* (0.030)	0.439 (0.078)	0.263 (0.462)
	Throat irritation	0.761 (0.135)	0.378 (0.135)	0.360 (0.308)
	Difficulty in concentration	0.645 (0.239)	0.503* (0.039)	0.430 (0.215)
	Headache	0.444 (0.454)	0.707** (0.001)	−0.064 (0.862)
	Heart palpitations and pain	0.408 (0.495)	0.445 (0.073)	0.565 (0.089)
	Blood pressure	.	0.365 (0.149)	0.311 (0.381)
	Feeling drowsy	0.761 (0.135)	0.445 (0.073)	0.196 (0.588)
	Insomnia and sleep disorder	1.000** (0.000)	0.459 (0.064)	0.154 (0.671)
PM1.0	Runny and stuffy nose	0.354 (0.559)	0.377 (0.136)	0.670* (0.034)
	Nose irritation and itching	0.530 (0.358)	0.263 (0.308)	0.595 (0.069)
	Cough and Sore throat	1.000** (0.000)	0.569* (0.017)	0.469 (0.172)
	Throat irritation	0.917* (0.029)	0.189 (0.467)	0.394 (0.259)
	Asthma	0.250 (0.685)	0.321 (0.209)	0.565 (0.089)
	Difficulty in concentration	0.707 (0.182)	0.355 (0.162)	0.336 (0.343)
	Heart palpitations and pain	0.559 (0.327)	0.444 (0.074)	0.851** (0.002)
	Feeling drowsy	0.917* (0.029)	0.521* (0.032)	0.369 (0.294)
	Insomnia and sleep disorder	0.913* (0.030)	0.300 (0.243)	0.242 (0.500)
PM2.5	Cough and sore throat	0.892* (0.042)	0.281 (0.275)	0.378 (0.281)
	Heart palpitations and pain	0.363 (0.548)	0.333 (0.191)	0.704* (0.023)
	Feeling drowsy	0.973* (0.005)	0.444 (0.074)	0.107 (0.769)
PM5.0	Nose irritation and itching	0.500 (0.391)	0.265 (0.304)	0.369 (0.295)
	Cough and sore throat	0.884* (0.047)	0.364 (0.151)	0.592 (0.071)
		0.791 (0.111)	0.467 (0.059)	0.423 (0.233)

(*continued*)

Table 6. Continued.

		Working experience 0–10 years Coefficient (sig.)	Working experience 11–20 years Coefficient (sig.)	Working experience 21–30 years Coefficient (sig.)
	Heart palpitations and pain			
	Feeling drowsy	0.884* (0.047)	0.434 (0.082)	−0.094 (0.796)
	Insomnia and sleep disorder	0.645 (0.239)	0.294 (0.253)	0.624 (0.054)
PM10	Runny and stuffy nose	0.395 (0.510)	0.458 (0.064)	0.479 (0.161)
	Nose irritation and itching	0.791 (0.111)	0.392 (0.120)	0.352 (0.319)
	Cough and sore throat	0.559 (0.327)	0.435 (0.081)	0.297 (0.405)
	Tension or stress	0.559 (0.327)	0.285 (0.268)	0.326 (0.358)
	Heart palpitations and pain	1.000** (0.000)	0.559* (0.020)	0.624 (0.054)
	Blood pressure	.	0.392 (0.120)	0.348 (0.325)
	Feeling drowsy	0.559 (0.327)	0.551* (0.022)	0.005 (0.990)
	Insomnia and sleep disorder	0.408 (0.495)	0.435 (0.081)	0.559 (0.093)

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

Sarkhosh et al. reported that drowsiness, fatigue, periodic headaches, weakness, muscle pain, and skin dryness were common symptoms among office workers (Sarkhosh et al. 2021). Tsantaki et al. (2022) found that General symptoms (41%) were the most prevalent symptoms followed by Mucosal (20%), and Dermal (8%) with the lowest prevalence among university staff. In a study by Rios et al. on office employees in Brazil, eye and upper airway symptoms, as well as headache and fatigue, were commonly found (27.1–58.5%) in these individuals (Rios et al. 2009). The weekly general (23.0%) and mucosal (16.0%) symptoms were reported as common among office workers in a Malaysian university (Lim et al. 2015). Moreover, we found that the prevalence of the general symptoms was associated with age ($p = 0.035$).

Gender variations were observed only for the dermal symptoms. Other studies agreed to report a higher prevalence of health symptoms among women (Fu et al. 2022; Hu et al. 2022; Jung et al. 2022; Lim et al. 2015; Lu et al. 2016). In previous researches, it was suggested that in air-conditioned offices, employees' gender particularly affects health responses, with women more typically reporting symptoms (Hedge et al. 1989). The reasons for gender differences for SBS are not quite known. Stenberg & Wall (1995) claimed a general excess of psychosomatic symptoms between women had been recommended as one reason as sex differential in life situations, social roles, working conditions, and indoor air quality factors (Stenberg and Wall 1995).

Most of the measurement data, such as air temperature, CO, and HCHO levels, were within acceptable area and limits of indoor air quality guidelines (World Health Organization 2010); however, there were some office rooms that had CO2 and particulate matter higher than the standard level. In our study, HCHO, CO2, and particulate matter were associated with health symptoms.

Measured formaldehyde concentrations in the office environments are generally too low to cause sensory irritation in eyes and airways, dizziness, and headaches (Jo and Sohn 2009; Li et al. 2016; Sakellaris et al. 2021; Salonen et al. 2009; Wolkoff 2013). However, the sensory effect of formaldehyde and similar strong irritants may be

Table 7. Multilevel logistic regression analysis of associations between health symptoms and personal and environmental factors among office workers.

	Mucosal symptoms		Dermal symptoms		Psychological symptoms		General symptoms	
	OR (95% CI)	p-value	OR (95% CI)	p-value	OR (95% CI)	p-value	OR (95% CI)	p-value
Age	0.53 (0.46–0.64)	0.255	0.08 (0.05–0.53)	0.903	0.31 (0.38–0.52)	0.579	**0.66 (0.39–0.77)**	**0.035****
Gender	0.43 (0.17–0.21)	0.580	**0.21 (0.14–0.23)**	**0.048***	0.36 (0.21–0.41)	0.416	0.25 (0.04–0.27)	0.995
Working experience	0.41 (0.34–0.49)	0.672	0.21 (0.18–0.49)	0.498	0.40 (0.07–0.52)	0.284	**0.56 (0.07–0.93)**	**0.049***
Building age	0.53 (0.16–1.44)	0.272	0.18 (0.17–0.59)	0.591	0.32 (0.27–0.91)	0.523	0.43 (0.23–0.72)	0.819
Office materials	0.26 (0.49–1.93)	0.965	0.26 (0.21–1.13)	0.349	0.23 (0.02–0.88)	0.815	**0.75 (0.29–1.56)**	**0.012***
New furniture in office	0.53 (0.26–0.56)	0.256	0.37 (0.16–0.38)	0.113	0.36 (0.03–0.38)	0.403	0.47 (0.15–0.56)	0.700
Temperature	0.44 (0.13–0.67)	0.548	0.27 (0.54–0.36)	0.323	0.25 (0.07–0.29)	0.757	0.48 (0.20–0.50)	0.667
Relative air humidity	0.48 (0.01–0.66)	0.437	0.05 (0.00–0.12)	0.953	0.23 (0.04–0.24)	0.817	0.66 (0.13–0.73)	0.099
CO2	**0.65 (0.07–0.94)**	**0.042***	0.17 (0.12–0.45)	0.628	0.36 (0.06–0.52)	0.422	0.43 (0.29–0.51)	0.805
HCHO	0.60 (0.20–1.54)	0.109	0.32 (0.06–0.93)	0.196	0.26 (0.19–0.57)	0.722	0.50 (0.39–1.64)	0.577
PM0.3	**0.67 (0.07–0.56)**	**0.024***	**0.49 (0.04–1.22)**	**0.016***	**0.59 (0.23–0.87)**	**0.016***	**0.80 (0.01–1.25)**	**0.002****
PM0.5	0.59 (0.03–0.65)	0.127	0.19 (0.12–0.51)	0.573	0.50 (0.06–1.05)	0.086	**0.72 (0.02–0.90)**	**0.029***
PM1.0	0.62 (0.09–0.84)	0.069	0.26 (0.11–0.70)	0.340	0.41 (0.17–0.52)	0.270	**0.77 (0.37–1.39)**	**0.006****
PM2.5	0.37 (0.35–1.25)	0.794	0.01 (0.00–0.54)	0.995	0.39 (0.17–0.75)	0.316	**0.76 (0.15–1.41)**	**0.008****
PM5.0	0.50 (0.13–1.43)	0.340	0.12 (0.11–0.58)	0.801	0.42 (0.19–0.74)	0.234	**0.72 (0.11–1.37)**	**0.027***
PM10	0.48 (0.23–1.16)	0.426	0.16 (0.05–0.35)	0.664	0.47 (0.00–1.12)	0.125	**0.71 (0.44–1.11)**	**0.037***

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

worsened in a combined way by other occupational, environmental, and individual risk factors as expressed by Wolkoff, Karcher, and Mayer (2012). Particleboard, insulation, furnishings, resins, furniture, and carpeting are emission resources of formaldehyde (Chen et al. 2020; Frey 2014; Sidheswaran et al. 2013; U.S. Environmental Protection Agency 1996). Formaldehyde was associated with nose irritation and itching in this study. Using efficient ventilation and low-emitting materials can effectively control formaldehyde concentration (Surawattanasakul et al. 2022).

Carbon dioxide was associated with eye irritation, dryness and itching, and asthma in this study. Other research suggested that health symptoms associated with CO2 included headache, tiredness, eye symptoms, nose symptoms, respiratory tract symptoms, and total symptom results (Erdmann et al. 2002; Tsai, Lin, and Chan 2012). In the office environment, the primary source of CO2 is respiration from the building's occupants (Apte, Fisk, and Daisey 2000; Hou et al. 2021; Mentese et al. 2020). Metabolic activity, combustion and motor vehicles in garages are emission resources of CO2 (Jones 1999; Yang et al. 2022). In a study by Seppanen, Fisk, and Mendell (1999), about one-half of 22 studies of SBS symptoms in office work environments showed that increased indoor CO2 levels were positively related to a significant increase in the prevalence of one or even more SBS symptoms. In other studies, CO2 concentrations were associated with increased prevalence of certain mucous membrane and SBS symptoms (Erdmann et al. 2002) as well as with eye irritation and nonspecific and upper respiratory symptoms (Tsai et al. 2012), and headache, fatigue, sleepiness, and affected cognitive performance and decision making ability (Shriram, Ramamurthy, and Ramakrishnan 2019; Zhang et al. 2017) A study by (de Oliveira, Rupp, and Ghisi 2021) demonstrated that a mixed-mode ventilation system is a good strategy for air quality satisfaction and energy savings to reduce CO2 concentrations.

Ambient Particulate Matter (PM) either characterized as coarse particle for the diameter of particles less than 10 μm (PM10) or fine particle for the diameter of particles less than 2.5 μm (PM2.5) (Putra 2015; Yin et al. 2022) are considered as the main cause of sensory irritation (Fierro 2001; Karakatsani et al. 2012; Li, Wen, and Zhang 2017). Coarse particles (PM10-2.5) can irritate the eyes, nose, throat, and upper respiratory tract. Fine particles (PM2.5-0.3) are smaller and can infiltrate deep into the lungs and, in some cases, can enter the bloodstream (Li et al. 2017). In this study, particulate matter in 6 levels (PM0.3, PM0.5, PM1.0, PM2.5, PM5.0, and PM10) were studied and found to be associated with eyes, nose, throat, and skin symptoms as well as with general and psychological symptoms. Heart palpitations and pain were the most common symptoms in relation to particulate matter. This finding is in agreement with the results of other studies about indoor PM exposure. Sun et al. reported that ultrafine particles were important risk factors for dermal symptoms (Sun et al. 2019). Karakatsani et al. (2012) found positive associations between PM10-2.5 and respiratory symptoms. Indoor PM exposure can be caused cardiovascular, cerebrovascular, and respiratory diseases (Nezis et al. 2019; Yang et al. 2022). In addition, the comparison between PM2.5 and COVID-19 cases, hospital admissions, and deaths has been shown in other studies carried in areas influenced by the pandemic (Agarwal et al. 2021).

We found that the prevalence of some health symptoms, in particular nose, throat, and head symptoms that could be related to such environmental factors as air quality,

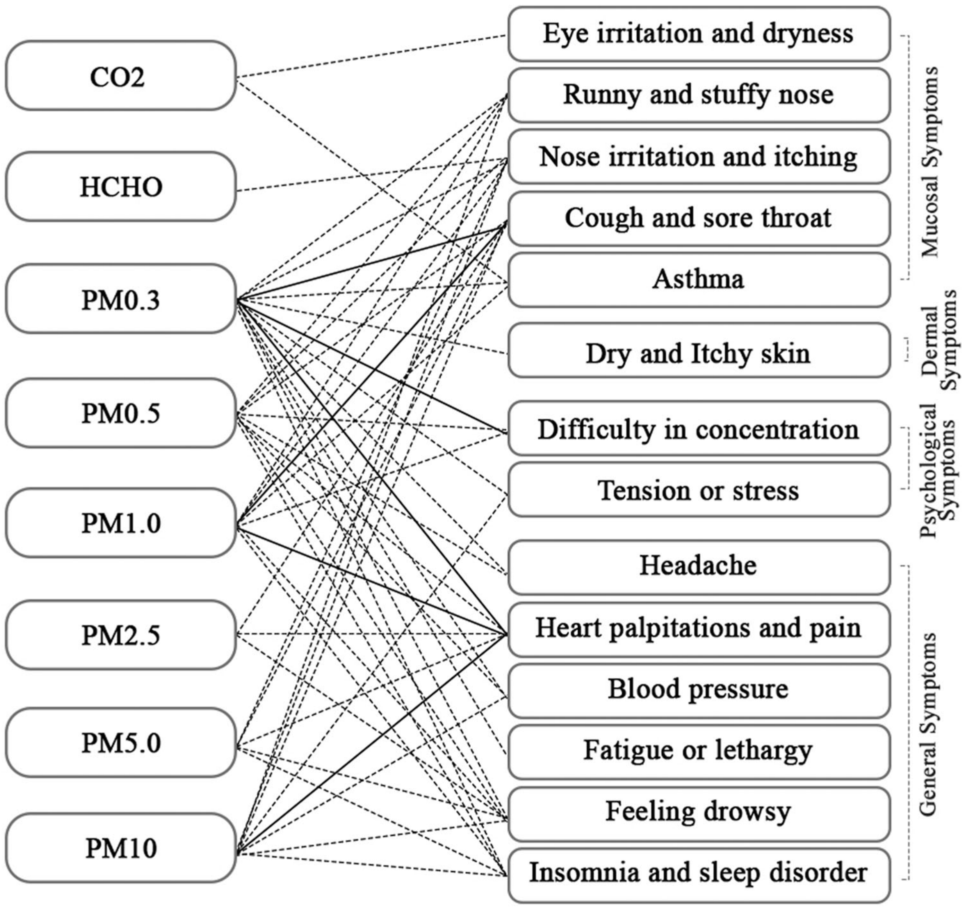

Figure 3. Model of associations between health symptoms and indoor air quality factors.

affected how the respondents rated the IAQ of their workspace (Figure 3). The participants with nose, throat, and head symptoms gave a significantly lower IAQ rating than those without such symptoms. Similar results were gained in other studies (Tähtinen et al. 2020; Wargocki et al. 1999; Wong et al. 2009b). Wong et al. found that nose and head symptoms were associated with perceived air quality and density in apartment buildings in Hong Kong (Wong et al. 2009b). It has been suggested that a high ventilation flow rate could decrease the risk of nose and dermal symptoms (Lu et al. 2016) .

Comparisons of the prevalence of health symptoms in relation with building age indicated that the prevalence was initially low, during the time increased, and it reached its peak in office rooms with 15–30 years. In other studies, it was found that older buildings tended to have significantly more maintenance and health problems (Wong et al. 2009b), which may be related to building materials. According to Sundell (1999), Secondary emissions from building materials denote the emission of pollutants that is caused mainly by actions on the materials. Factors that have an effect on materials may be moisture and alkali in the building structure, high surface temperatures, or different treatments with chemicals such as floor cleaners, waxing, etc. Secondary emissions may increase in time and may last for a long period (Sundell 2004). Additionally, the time spent indoors is the most influential risk factor that has a chief influence on subjective symptoms (Jung et al. 2022).

In this study, we found a significant relationship between health symptoms and working experience so that the prevalence of health symptoms in the 11–20 years age group was higher than that in the other two groups. A possible justification could be that the body becomes used to the environmental conditions over time. This is in agreement with the finding of other studies about job satisfaction. The results also exhibited a U shape the substantial relationship between age and the mean job satisfaction score so that the mean job satisfaction score in the 31–38 years age group was significantly lower than that in the other two groups (Clark, Oswald, and Warr 1996; Hoboubi et al. 2017). The relationship between health symptoms and working experience may be a quantitative reason to explain job satisfaction changes.

However, there were certain limitations during the research. One limitation is that we did not include the psychological work environment. Previous studies indicated that these factors were associated with health symptoms (Azuma et al. 2015; Bakke et al. 2008; Licina and Yildirim 2021; Runeson et al. 2006; Sadick and Kamardeen 2020). In addition, the influences of some building characteristics, such as areas and window sizes, on the prevalence of health symptoms, can be considered as well. Finally, one of the essential limitations in our study is the cross-sectional study design, which limits the possibility of concluding on causality.

Conclusions

Indoor air quality is an important issue because people spend most of their time in indoor environments. Environmental variables such as temperature, relative humidity, CO2, HCHO, and particulate matter levels were monitored in university workspaces. This study found significant associations between IAQ parameters and the prevalence of health symptoms among university staff. In our study, eye, nose, and throat symptoms were more common among the university staff, and HCHO, CO2, and particulate matter were associated with health symptoms. Elevated levels of particulate matter can be the most important risk factor for work-related symptoms. PM0.3 has a significant association with health symptoms, especially cough and sore throat, heart palpitation and pain and difficulty in concentration. Work-related symptoms were observed to be associated with building age and working experience among the office workers. Secondary emissions from building materials in the older buildings were significant. In addition, wearing a face mask results in higher concentrations of carbon dioxide exposure.

Overall, there are two common strategies in buildings to deal with indoor air quality; increasing the ventilation rate and reducing the indoor source of pollution. Building energy efficiency is impacted by its envelope and reduced by ventilation rates, but for the sake of the occupant well-being, the ventilation rate should be higher to dispel PM. It is recommended to reduce occupant density and using a ventilation system for decontamination of viral load that can help in sustaining healthy indoor air quality. The engineering controls like implementing proper ventilation or air filtration have been recommended as a method of enhancing IAQ. Also, air cleaners are one of the general improvement technologies that is recommended in this study. The study suggested implications for the development of healthy and green building policies. It is hoped that this study will encourage research on similar issues that pertain to health and the human habitat.

Acknowledgment

We appreciate the participation of office workers as respondents in this study, who made this research possible.

Disclosure statement

The authors declare that they have no competing interests.

Funding

This study was supported by the Healthy Building Laboratory of the Ferdowsi University of Mashhad.

References

Agarwal N, Swaroop Meena C, Raj BP, Saini L, Kumar A, Gopalakrishnan N, Kumar A, Balam NB, Alam T, Kapoor NR, et al. 2021. Indoor air quality improvement in COVID-19 pandemic: review. Sustain Cities Soc. 70:102942. doi: 10.1016/j.scs.2021.102942.

Ali AS, Chua SJL, Lim ME-L. 2015. The effect of physical environment comfort on employees' performance in office buildings: a case study of three public universities in Malaysia. Structural Survey. 33(4/5):294–308. doi: 10.1108/SS-02-2015-0012.

Al Horr Y, Arif M, Kaushik A, Mazroei A, Katafygiotou M, Elsarrag E. 2016. Occupant productivity and office indoor environment quality: a review of the literature. Build Environ. 105: 369–389. doi: 10.1016/j.buildenv.2016.06.001.

Apte MG, Fisk WJ, Daisey JM. 2000. Associations between indoor CO2 concentrations and sick building syndrome symptoms in U.S. office buildings: an analysis of the 1994–1996 BASE study data. Indoor Air. 10(4):246–257. doi: 10.1034/j.1600-0668.2000.010004246.x.

Araki A, Kawai T, Eitaki Y, Kanazawa A, Morimoto K, Nakayama K, Shibata E, Tanaka M, Takigawa T, Yoshimura T, et al. 2010. Relationship between selected indoor volatile organic compounds, so-called microbial VOC, and the prevalence of mucous membrane symptoms in single family homes. Sci Total Environ. 408(10):2208–2215. doi: 10.1016/j.scitotenv.2010.02.012.

ASHARE Environmental Health Committee. 2011. Indoor air quality position paper. Atlanta, GA: American Society of Heating, Refrigeration, and Air Conditioning Engineers. doi: 10.1016/1359-4311(96)00030-0.

Azuma K, Ikeda K, Kagi N, Yanagi U, Osawa H. 2015. Prevalence and risk factors associated with nonspecific building-related symptoms in office employees in Japan: Relationships between work environment, indoor air quality, and occupational stress. Indoor Air. 25(5): 499–511. doi: 10.1111/ina.12158.

Bakke JV, Wieslander G, Norbäck D, Moen BE. 2008. Atopy, symptoms and indoor environmental perceptions, tear film stability, nasal patency and lavage biomarkers in university staff. Int Arch Occup Environ Health. 81(7):861–872. doi: 10.1007/s00420-007-0280-2.

Bluyssen PM, Roda C, Mandin C, Fossati S, Carrer P, de Kluizenaar Y, Mihucz VG, de Oliveira Fernandes E, Bartzis J. 2016. Self-reported health and comfort in 'modern' office buildings: first results from the European OFFICAIR study. Indoor Air. 26(2):298–317. doi: 10.1111/ina.12196.

Bluyssen PM, Oliveira Fernandes E, Groes L, Clausen G, Fanger PO, Valbjorn O, Bernhard CA, Roulet CA. 1996. European indoor air quality audit project in 56 office buildings. Indoor Air. 6(4):221–238. doi: 10.1111/j.1600-0668.1996.00002.x.

Chan IYS, Liu AMM. 2018. Effects of neighborhood building density, height, greenspace, and cleanliness on indoor environment and health of building occupants. Build Environ. 145:213–222. doi: 10.1016/j.buildenv.2018.06.028.

Chen F, Zhang H, Chen X, Ren J. 2020. Design method for interior decoration pollution control of buildings: introduction and application. Build Simul. 13(3):637–646. doi: 10.1007/s12273-019-0596-3.

Clark A, Oswald A, Warr P. 1996. Is job satisfaction U-shaped in age? J Occup Psychol. 69(1):57–81. doi: 10.1111/j.2044-8325.1996.tb00600.x.

Du Bowen MC, Tandoc ML, Mack, JA, Siegel. 2020. Indoor CO2 concentrations and cognitive function: a critical review. Indoor Air. 30(6):1067–1082. doi: 10.1111/ina.12706.

ECJRC. 1997. Total Volatile Organic Compounds (TVOC) in indoor air quality investigations. Luxembourg: European Commission.

Engineer A, Gualano RJ, Crocker RL, Smith JL, Maizes V, Weil A, Sternberg EM. 2021. An integrative health framework for wellbeing in the built environment. Build Environ. 205:108253. doi: 10.1016/j.buildenv.2021.108253.

Erdmann CA, Kc. Steiner, MG, Apte. 2002. Indoor carbon dioxide and sick building syndrome symptoms in the base study revisited: analysis of the 100 building dataset. Proceedings of Indoor Air 2002 Conference, Monterey, CA. Vol. 3, p. 443–448.

Fassoulis K, Alexopoulos N. 2015. The workplace as a factor of job satisfaction and productivity: a case study of Administrative Personnel at the University of Athens. J Facilit Manag. 13(4):332–349. doi: 10.1108/JFM-06-2014-0018.

Fierro M. 2001. Particulate matter. Energy Build. 36(10):881–892.

Fisk WJ, Rosenfeld AH. 1997. Estimates of improved productivity and health from better indoor environments. Indoor Air. 7(3):158–172. doi: 10.1111/j.1600-0668.1997.t01-1-00002.x.

Frey SE. 2014. Indoor air quality investigations on particulate matter, carbonyls, and tobacco specific nitrosamines. Arizona State University.

Fu P, Zhao Z, Norback D, Zhang X, Yung KKL. 2022. Associations between indoor environment and lifestyles and sick building syndrome symptoms among adults in Taiyuan and Urumqi of China. Indoor Air. 32(7):1–15. doi: 10.1111/ina.13081.

Geng Y, Ji W, Lin B, Zhu Y. 2017. The impact of thermal environment on occupant IEQ perception and productivity. Build Environ. 121:158–167. doi: 10.1016/j.buildenv.2017.05.022.

Golden R. 2011. Identifying an indoor air exposure limit for formaldehyde considering both irritation and cancer hazards. Crit Rev Toxicol. 41(8):672–721. doi: 10.3109/10408444.2011.573467.

Gou Z, Siu-Yu Lau S. 2012. Sick building syndrome in open-plan offices: workplace design elements and perceived indoor environmental quality. J Facilit Manag. 10(4):256–265. doi: 10.1108/14725961211265729.

Gunschera J, Mentese S, Salthammer T, Andersen JR. 2013. Impact of building materials on indoor formaldehyde levels: effect of ceiling tiles, mineral fiber insulation and gypsum board. Build Environ. 64:138–145. doi: 10.1016/j.buildenv.2013.03.001.

Hedge A. 1984. Ill health among office workers: an examination of the relationship between office design and employee well-being. In: E. Grandjean, Editor. Ergonomics and Health in Modem Offices. London: Taylor & Francis. p. 46–51.

Hedge A, T, D, Sterling E, M, Sterling CW, Collett Theodor D, Steding DA, Sterling V, Nie. 1989. Indoor air quality and health in two office buildings with different ventilation systems. Environment. 15(1–6):115–128.

Hoboubi N, Choobineh AR, Kamari Ghanavati F, Keshavarzi S, Hosseini AA. 2017. The impact of job stress and job satisfaction on workforce productivity in an Iranian petrochemical industry. Saf Health Work. 8(1):67–71. doi: 10.1016/j.shaw.2016.07.002.

Hou J, Sun Y, Dai X, Liu J, Shen X, Tan H, Yin H, Huang K, Gao Y, Lai D, et al. 2021. Associations of indoor carbon dioxide concentrations, air temperature, and humidity with perceived air quality and sick building syndrome symptoms in Chinese homes. Indoor Air. 31(4):1018–1028. doi: 10.1111/ina.12810.

Hu J, He Y, Hao X, Li N, Su Y, Qu H. 2022. Optimal temperature ranges considering gender differences in thermal comfort, work performance, and sick building syndrome: a winter field study in university classrooms. Energy Build. 254:111554. doi: 10.1016/j.enbuild.2021.111554.

Jafari MJ, Khajevandi AA, Mousavi Najarkola SA, Yekaninejad MS, Pourhoseingholi MA, Omidi L, Kalantary S. 2015. Association of sick building syndrome with indoor air parameters. Tanaffos. 14(1):55–62.

Jo WJ, Sohn JY. 2009. The effect of environmental and structural factors on indoor air quality of apartments in Korea. Build Environ. 44(9):1794–1802. doi: 10.1016/j.buildenv.2008.12.003.

Jones AP. 1999. Indoor air quality and health. Atmos Environ. 33(28):4535–4564. doi: 10.1016/S1352-2310(99)00272-1.

Jung D, Choe Y, Shin J, Kim E, Min G, Kim D, Cho M, Lee C, Choi K, Woo BL, et al. 2022. Risk assessment of indoor air quality and its association with subjective symptoms among office workers in Korea. IJERPH. 19(4):2446. doi: 10.3390/ijerph1904

Karakatsani A, Analitis A, Perifanou D, Ayres JG, Harrison RM, Kotronarou A, Kavouras IG, Pekkanen J, Hameri K, Kos GP, et al. 2012. Particulate matter air pollution and respiratory symptoms in individuals having either asthma or chronic obstructive pulmonary disease: a european multicentre panel study. Environ Health. 11:75. doi: 10.1186/1476-069X-11-75.

Kelly FJ, Fussell JC. 2019. Improving indoor air quality, health and performance within environments where people live, travel, learn and work. Atmos Environ. 200:90–109. doi: 10.1016/j.atmosenv.2018.11.058.

Lai ACK, Mui KW, Wong LT, Law LY. 2009. An evaluation model for indoor environmental quality (IEQ) acceptance in residential buildings. Energy Build. 41(9):930–936. doi: 10.1016/j.enbuild.2009.03.016.

Cedeño Laurent JG, MacNaughton P, Jones E, Young AS, Bliss M, Flanigan S, Vallarino J, Chen LJ, Cao X, Allen JG. 2021. Associations between acute exposures to PM(2.5) and carbon dioxide indoors and cognitive function in office workers: a multicountry longitudinal prospective observational study. Environ Res Lett. 16(9):094047. doi: 10.1088/1748-9326/ac1bd8.

Li N, Cui H, Zhu C, Zhang X, Su L. 2016. Grey preference analysis of indoor environmental factors using sub-indexes based on Weber/Fechner's law and predicted mean vote. Indoor Built Environ. 25(8):1197–1208. doi: 10.1177/1420326X15592940.

Li Z, Wen Q, Zhang R. 2017. Sources, health effects and control strategies of indoor fine particulate matter (PM2.5): a review. Sci Total Environ. 586:610–622. doi: 10.1016/j.scitotenv.2017.02.029.

Licina D, Yildirim S. 2021. Occupant satisfaction with indoor environmental quality, sick building syndrome (SBS) symptoms and self-reported productivity before and after relocation into WELL-certified office buildings. Build Environ. 204:108183. doi: 10.1016/j.buildenv.2021.108183.

Lim F-L, Hashim Z, Md Said S, Than LT-L, Hashim JH, Norbäck D. 2015. Sick building syndrome (SBS) among office workers in a Malaysian University – associations with atopy, fractional exhaled nitric oxide (FeNO) and the office environment. Sci Total Environ. 536:353–361. doi: 10.1016/j.scitotenv.2015.06.137.

López LR, Dessì P, Cabrera-Codony A, Rocha-Melogno L, Kraakman B, Naddeo V, Balaguer MD, Puig S. 2023. CO2 in indoor environments: from environmental and health risk to potential renewable carbon source. Sci Total Environ. 856(Pt 2):159088. doi: 10.1016/j.scitotenv.2022.159088.

Lu C, Deng Q, Li Y, Sundell J, Norbäck D. 2016. Outdoor air pollution, meteorological conditions and indoor factors in dwellings in relation to sick building syndrome (SBS) among adults in China. Sci Total Environ. 560–561:186–196. doi: 10.1016/j.scitotenv.2016.04.033.

Mandin C, M, Trantallidi Andrea Cattaneo N, Canha VG, Mihucz T, Szigeti R, Mabilia E, Perreca Andrea Spinazzè S, Fossati Y, De Kluizenaar E, et al. 2017. Assessment of indoor air quality in office buildings across Europe – the OFFICAIR study. Sci Total Environ. 579:169–178. doi: 10.1016/j.scitotenv.2016.10.238.

Mentese S, Mirici NA, Elbir T, Palaz E, Mumcuoğlu DT, Cotuker O, Bakar C, Oymak S, Otkun MT. 2020. A long-term multi-parametric monitoring study: indoor air quality (IAQ) and the sources of the pollutants, prevalence of sick building syndrome (SBS) symptoms, and respiratory health indicators. Atmospheric Pollution Research. 11(12):2270–2281. doi: 10.1016/j.apr.2020.07.016.

Mui KW, Wong LT, Hui PS, Law KY. 2008. Epistemic evaluation of policy influence on workplace indoor air quality of Hong Kong in 1996—2005. Build Serv Eng Res Technol. 29(2):157–164. doi: 10.1177/0143624408089522.

National Institute for Occupational Safety and Health. 1991. Building Air Quality: Guideline For Building Owner and Facility Manager. Washington DC. Publication No. 91–114.

Nezis I, Biskos G, Eleftheriadis K, Kalantzi O-I. 2019. Particulate matter and health effects in offices—a review. Building and Environment. 156:62–73. doi: 10.1016/j.buildenv.2019.03.042.

Nielsen GD, Larsen ST, Wolkoff P. 2013. Recent trend in risk assessment of formaldehyde exposures from indoor air. Arch Toxicol. 87(1):73–98.

Norhidayah A, Chia-Kuang L, Azhar MK, Nurulwahida S. 2013. Indoor air quality and sick building syndrome in three selected buildings. Procedia Engineering. 53(2010):93–98. doi: 10.1016/j.proeng.2013.02.014.

de Oliveira CC, Rupp RF, Ghisi E. 2021. Influence of environmental variables on thermal comfort and air quality perception in office buildings in the humid subtropical climate zone of Brazil. Energy Build. 243:110982. doi: 10.1016/j.enbuild.2021.110982.

Putra JCP. 2015. "Effects of indoor air quality on the occupant's health and productivity in an office building." University Tun Hussein Onn Malaysia.

Qiu Y, Wang Y, Tang Y. 2020. Investigation of indoor air quality in six office buildings in Chengdu, China based on field measurements. Build Simul. 13(5):1009–1020. doi: 10.1007/s12273-020-0663-9.

Rios JLdM, Boechat JL, Gioda A, dos Santos CY, de Aquino Neto FR, Lapa e Silva JR. 2009. Symptoms prevalence among office workers of a sealed versus a non-sealed building: associations to indoor air quality. Environ Int. 35(8):1136–1141. doi: 10.1016/j.envint.2009.07.005.

Roumi S, Zhang F, Stewart RA. 2022. Global research trends on building indoor environmental quality modelling and indexing systems—a scientometric review. Energies. 15(12):1–26. doi: 10.3390/en15124494.

Runeson R, Wahlstedt K, Wieslander G, Norbäck D. 2006. Personal and psychosocial factors and symptoms compatible with sick building syndrome in the Swedish workforce. Indoor Air. 16(6):445–453. doi: 10.1111/j.1600-0668.2006.00438.x.

Sadick A-M, Kamardeen I. 2020. Enhancing employees' performance and well-being with nature exposure embedded office workplace design. J Build Eng. 32:101789. doi: 10.1016/j.jobe.2020.101789.

Sahlberg B, Norbäck D, Wieslander G, Gislason T, Janson C. 2012. Onset of mucosal, dermal, and general symptoms in relation to biomarkers and exposures in the dwelling: a cohort study from 1992 to 2002. Indoor Air. 22(4):331–338. doi: 10.1111/j.1600-0668.2012.00766.x.

Sahlberg B, Gunnbjörnsdottir M, Soon A, Jogi R, Gislason T, Wieslander G, Janson C, Norback D. 2013. Airborne molds and bacteria, microbial volatile organic compounds (MVOC), Plasticizers and Formaldehyde in Dwellings in three North European cities in relation to sick building syndrome (SBS). Sci Total Environ. 444:433–440. doi: 10.1016/j.scitotenv.2012.10.114.

Sakellaris I, D, Saraga C, Mandin Y, de Kluizenaar S, Fossati Andrea Spinazzè Andrea Cattaneo V, Mihucz T, Szigeti E, de Oliveira Fernandes K, Kalimeri R, et al. 2021. Association of subjective health symptoms with indoor air quality in European office buildings: the OFFICAIR project. Indoor Air. 31(2):426–439. doi: 10.1111/ina.12749.

Salonen H, Pasanen AL, Lappalainen S, Riuttala H, Tuomi T, Pasanen P, Back B, Reijula K. 2009. Volatile organic compounds and formaldehyde as explaining factors for sensory irritation in office environments. J Occup Environ Hyg. 6(4):239–247. doi: 10.1080/15459620902735892.

Sarkhosh M, Asghar Najafpoor A, Alidadi H, Shamsara J, Amiri H, Andrea T, Kariminejad F. 2021. Indoor air quality associations with sick building syndrome: an application of decision tree technology. Build Environ. 188:107446. doi: 10.1016/j.buildenv.2020.107446.

Seppanen OA, Fisk WJ, Mendell MJ. 1999. Association of ventilation rates and CO_2 concentrations with health and other responses in commercial and institutional buildings. Indoor Air. 9(4):226–252.

Shriram S, Ramamurthy K, Ramakrishnan S. 2019. Effect of occupant-induced indoor CO_2 concentration and bioeffluents on human physiology using a spirometric test. Build Environ. 149: 58–67. doi: 10.1016/j.buildenv.2018.12.015.

Sidheswaran M, Chen W, Chang A, Miller R, Cohn S, Sullivan D, Fisk WJ, Kumagai K, Destaillats H. 2013. Formaldehyde emissions from ventilation filters under different relative humidity conditions. Environ Sci Technol. 47(10):5336–5343. doi: 10.1021/es400290p.

Stenberg B, Wall S. 1995. Why do women report 'sick building symptoms' more often than men? Soc Sci Med. 40(4):491–502. doi: 10.1016/0277-9536(94)E0104-Z.

Sterling S, Maxey L, Luna H. 2014. The Sustainable University: progress and prospects. 1st Ed. London: Routledge.

Sun Y, Hou J, Cheng R, Sheng Y, Zhang X, Sundell J. 2019. Indoor air quality, ventilation and their associations with sick building syndrome in Chinese Homes. Energy Build. 197:112–119. doi: 10.1016/j.enbuild.2019.05.046.

Sundell J. 1999. Indoor environment and health. Stockholm, Sweden: National Institute of Public Health.

Sundell J. 2004. On the history of indoor air quality and health. Indoor Air. 14:51–58. doi: 10.1111/j.1600-0668.2004.00273.x.

Surawattanasakul V, Sirikul W, Sapbamrer R, Wangsan K, Panumasvivat J, Assavanopakun P, Muangkaew S. 2022. Respiratory symptoms and skin sick building syndrome among office workers at University Hospital, Chiang Mai, Thailand: associations with indoor air quality, AIRMED Project. IJERPH. 19(17):10850. doi: 10.3390/ijerph191710850.

Tähtinen K, Remes J, Karvala K, Salmi K, Lahtinen M, Reijula K. 2020. Perceived indoor air quality and psychosocial work environment in office, school and health care environments in Finland. Int J Occup Med Environ Health. 33(4):479–495. doi: 10.13075/ijomeh.1896.01565.

Tsai D-H, Lin J-S, Chan C-C. 2012. Office workers' sick building syndrome and indoor carbon dioxide concentrations. J Occup Environ Hyg. 9(5):345–351. doi: 10.1080/15459624.2012.675291.

Tsantaki E, Smyrnakis E, Constantinidis TC, Benos A. 2022. Indoor air quality and sick building syndrome in a University setting: a case study in Greece. Int J Environ Health Res. 32(3): 595–615. doi: 10.1080/09603123.2020.1789567.

U.S. Environmental Protection Agency. 1996. Indoor air pollution: an introduction for health professionals. Co-sponsored by: The American Lung Association (ALA), The Environmental Protection Agency (EPA), The Consumer Product Safety Commission (CPSC), and The American Medical Association (AMA), U.S. Government Printing Office Publication. Washington, DC. No. 1994-523-217/81322.

Veenaas C, Ripszam M, Glas B, Liljelind I, Claeson A-S, Haglund P. 2020. Differences in chemical composition of indoor air in rooms associated/not associated with building related symptoms. Sci Total Environ. 720:137444. doi: 10.1016/j.scitotenv.2020.137444.

Wargocki P, Wyon DP, Baik YK, Clausen G, Fanger PO. 1999. Perceived air quality, sick building syndrome (SBS) symptoms and productivity in an office with two different pollution loads. Indoor Air. 9(3):165–179.

Wolkoff P. 2013. Indoor air pollutants in office environments: assessment of comfort, health, and performance. Int J Hyg Environ Health. 216(4):371–394. doi: 10.1016/j.ijheh.2012.08.001.

Wolkoff P. 2018. Indoor air humidity, air quality, and health – an overview. Int J Hyg Environ Health. 221(3):376–390. doi: 10.1016/j.ijheh.2018.01.015.

Wolkoff P, Azuma K, Carrer P. 2021. Health, work performance, and risk of infection in office-like environments: the role of indoor temperature, air humidity, and ventilation. Int J Hyg Environ Health. 233:113709. doi: 10.1016/j.ijheh.2021.113709.

Wolkoff P, Karcher T, Mayer H. 2012. Problems of the 'Outer Eyes' in the office environment: an ergophthalmologic approach. J Occup Environ Med. 54(5):621–631. doi: 10.1097/JOM.0b013e31824d2e04.

Wong LT, Mui KW, Hui PS. 2006. A statistical model for characterizing common air pollutants in air-conditioned offices. Atmos Environ. 40(23):4246–4257. doi: 10.1016/j.atmosenv.2006.04.005.
Wong S-K, Wai-Chung Lai L, Ho DC-W, Chau K-W, Lo-Kuen Lam C, Hung-Fai Ng C. 2009a. Sick building syndrome and perceived indoor environmental quality: a survey of apartment buildings in Hong Kong. Habitat Int. 33(4):463–471. doi: 10.1016/j.habitatint.2009.03.001.
Wong S-K, Wai-Chung Lai L, Ho DC-W, Chau K-W, Lo-Kuen Lam C, Hung-Fai Ng C. 2009b. Sick building syndrome and perceived indoor environmental quality: a survey of apartment buildings in Hong Kong. Habitat Int. 33(4):463–471. doi: 10.1016/j.habitatint.2009.03.001.
World Health Organization. 1984. Book reviews : indoor air pollutants: exposure and health effects. Report on a WHO Copenhagen, 1983. Pp 42. Price: Sw.Fr.4. ISBN 92 890 1244 7. J R Soc Health. 104(2):83–84. doi: 10.1177/146642408410400224.
World Health Organization. 2010. Guidelines for indoor air quality: Selected Pollutants. Copenhagen, Denmark. 0-444. http://www.euro.who.int/pubrequest.
Wyon DP. 2004. The effects of indoor air quality on performance and productivity. Indoor Air. 14:92–101. doi: 10.1111/j.1600-0668.2004.00278.x.
Yang S, Mahecha SD, Moreno SA, Licina D. 2022. Integration of indoor air quality prediction into healthy building design. Sustainability (Switzerland). 14(13):7890. doi: 10.3390/su14137890.
Yang S, Pernot JG, Jörin CH, Niculita-Hirzel H, Perret V, Licina D. 2020. Energy, indoor air quality, occupant behavior, self-reported symptoms and satisfaction in energy-efficient dwellings in Switzerland. Build Environ. 171:106618. doi: 10.1016/j.buildenv.2019.106618.
Yin H, Zhai X, Ning Y, Li Z, Ma Z, Wang X, Li A. 2022. Online monitoring of PM2.5 and CO2 in residential buildings under different ventilation modes in Xi'an City. Build Environ. 207:108453. doi: 10.1016/j.buildenv.2021.108453.
Zamani ME, JJ, Nafiz S. 2013. Indoor air quality and prevalence of sick building syndrome among office workers in two different offices in Selangor. Am J Appl Sci. 10(10):1140–1147. doi: 10.3844/ajassp.2013.1140.1147.
Zhai Z (J), Metzger ID. 2019. Insights on critical parameters and conditions for personalized ventilation. Sustain Cities Soc. 48:101584. doi: 10.1016/j.scs.2019.101584.
Zhang X, Wargocki P, Lian Z, Thyregod C. 2017. Effects of exposure to carbon dioxide and bioeffluents on perceived air quality, self-assessed acute health symptoms, and cognitive performance. Indoor Air. 27(1):47–64. doi: 10.1111/ina.12284.
Zhang Y. 2005. Indoor air quality engineering. Boca Raton, Florida: CRC Press LLC.
Zhong J-Y, Lee Y-C, Hsieh C-J, Tseng C-C, Yiin L-M. 2018. Association between dry eye disease, air pollution and weather changes in Taiwan. IJERPH. 15(10):2269. doi: 10.3390/ijerph15102269.