Indoor air quality and sick building syndrome of office buildings in Taiwan

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ABSTRACT
Our study conducted serial measurements of indoor air quality and sick building syndrome (SBS) of employees in eight air-conditioned office buildings to examine the association between indoor air pollution and the reporting symptoms of SBS. Airborne microbes, carbon dioxide (CO_2), particulate matter (PM_{10}), formaldehyde, and total volatile organic compounds (TVOC) were measured in every test space within the buildings. Frequency of reporting symptoms and other environmental variables were documented by self-administrated questionnaires.

Our results show that many building characteristics such as with carpets on the floors, having new decoration nearby, presence of passive smoking exposure and other perceptive factors appear to be associated with higher odds ratio (OR) of selected SBS symptoms. In addition, higher indoor TVOC and CO_2 are also related to an increased occurrence of symptoms such as irritation of mucus and skin, neurotoxic symptoms and other non-specific symptoms (OR = 2.80–4.43). Our study suggests that building-decoration-related VOCs and high CO_2 levels appear to be the dominant factors attributable to the reporting of SBS by employees in Taiwan's office buildings.

INDEX TERMS
Indoor air quality; Sick building syndromes; Office buildings; VOCs; CO_2

INTRODUCTION
Sick building syndrome (SBS) is a constellation of symptoms that have no clear aetiology and may be related to exposure present in a particulate building environment. Office workers often report sick building syndromes especially in modern large air-conditioned buildings. Serial studies have explored the causal relationship between various environmental factors and symptoms reported. To date, SBS have been agreed as a multifactorial problem associated with a combination of microbial, chemical, physical and psychological mechanisms (Berglund and Gunnarsson, 2000; Brasche *et al.*, 2001; Mizoue *et al.*, 2001; Bholah and Subratty, 2002). Yet, little consistency in findings and evidences could be drawn from a rich body of literatures in this regard. The issues are even more complicated for large office buildings.

Meanwhile, air-conditioned large office buildings have become the most common working place during the past decades in Taiwan. However, only limit investigations and data have addressed comprehensively the issue of general indoor air quality and frequency of SBS reported in these office buildings. Association between building environmental factors and related SBS symptoms is even more lacking. Our study was designed to conducted series of comprehensive building investigations including environmental measures and questionnaire-based survey of SBS in air-conditioned office buildings, to characterize the contribution of individual factor to the observed SBS symptoms, and to estimate the potential health impact on the population involved.

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METHODS

Eight large air-conditioned office buildings were randomly selected from the records of Taiwan's official building registration, and were asked for participation of their occupants after prior walk-through investigation. All these buildings were located at metropolitan cities of northern, central and southern Taiwan, respectively. A self-administrated questionnaire was answered by participants to document the frequency of reporting symptoms and other environmental factors, family history and personal characteristics. Questions of health complaints included (1) irritated symptoms such as itchy eyes, throat and dry or itchy skin; (2) symptoms of central nerve system such as headache, fatigue, trouble concentrating, fainting, nausea; (3) respiratory symptoms such as chest tightness, running nose, sneeze, cough and wheezing; and (4) non-specific symptoms. All these were investigated by the questionnaire. The definition of reporting SBS symptoms is for those frequencies of symptom that only occurred at work, and would recovery at home or during weekends.

Various indoor air pollutants including total volatile organic compounds (TVOCs), formaldehyde, carbon dioxide, particulate matters and airborne microbes were measured at various testing spaces during the sampling week. Except the measurement of airborne microbes, all the indicated pollutants were measured using real-time monitors to document 8-h exposure levels in each testing space. Daily 8-h average concentrations for each pollutant were estimated to represent the exposure levels of employee in each test space. Duplicate samples of airborne fungi and bacteria were collected using Burkard sampler with Malt Extract Agar plates (MEA) and Tryptic Soy Agar (TSA) at a flow rate of 10 LPM (Su *et al.*, 2001). Airborne fungi and bacteria were collected three times a day as scheduled, at the beginning of the working day, at noon and in the, and continued for five working days a week in every investigated building. These measurements were conducted everyday and continued for five working days per week in every investigated building. After incubation, the yields of colonies were then corrected by using positive hole conversion table, constructed based on statistical distribution model, before the calculation of final concentrations, colony forming unit per cubic metre (CFU/m^3).

Odds ratio was calculated to present the ratio of risk associated with symptom occurrence by building characteristic, and the concentrations of measured indoor air pollutants. The software of EXCEL was for data management, and statistical analyses were conducted with STATVIEW Version 4.53.

RESULTS

Three hundred and twelve participants from eight office buildings have returned their questionnaires, and 300 occupants, 179 females and 121 males, completed the questionnaire (Table 1). Higher percentage of females workers in building A (69.15%), compared to other buildings. Higher frequency of reporting symptoms was also found in building A; mostly are irritated symptoms, symptoms of central nervous system and respiratory symptoms.

The average concentrations of each pollutant were calculated to present the exposure levels for each office building (Table 1). Higher TVOC concentrations were found in building A and C (3.31 and 11.74 ppm) n cpmparison to3 ppm recommended by Singapore (Singapore, 1996). We also identified a high level of formaldehyde concentrations, between 0.12 and 0.85 ppm, from those office buildings in Taiwan. Those levels are higher than the recommendation levels that have been set in several countries such as Australia, Canada and Hong Kong, ranging from 0.05 to 0.1 ppm (Standards Australia, 1991; Health Canada, 1995; Hong Kong, 1999). It was also found that most of our investigated buildings were with total bacteria and total fungi concentrations higher than 1000 CFU/m^3, an often-quoted guideline in earlier research (ACGIH, 1989).

Table 1 Participant demographics and average concentrations of various indoor air pollutants in each test building

	A	B	C	D	E	F	G	H
Building age (years)	8	9	2	3	4	5	10	10
Numbers of subjects (n)	107	22	24	29	34	30	41	13
Male	33	11	12	14	14	13	21	3
Female	74	11	12	15	20	17	20	10
Frequency of reported symptoms (%)								
Irritated symptoms	39.25	9.10	12.5	10.34	8.82	20.00	12.20	15.38
Symptoms of central nervous system	30.84	9.10	4.17	3.45	11.76	13.33	9.76	15.38
Respiratory symptoms	21.50	0.00	8.33	6.90	8.82	6.67	4.88	0.00
Average concentration of indoor air pollutants								
Carbon dioxide (ppm)	757.92	691.67	461.89	581.02	611.52	806.67	516.88	687.50
TVOC (ppm)	3.31	2.24	11.74	2.30	2.30	2.30	1.15	1.89
Formaldehyde (ppm)	0.13	0.18	0.85	0.22	0.12	0.18	0.12	0.20
PM10 ($\mu g/m^3$)	31.71	79.91	40.00	110.00	95.36	31.33	184.11	161.69
Total fungi (CFU/m^3)	426	277	3136	5192	1003	1962	2882	4646
Total bacteria (CFU/m^3)	983	1226	1134	2400	1163	1843	1680	1623

Table 2 shows the estimated odds ratio (OR) for different symptoms associated with various building characteristics and indoor air pollutants. It was found that the likelihood of reporting SBS symptoms, OR = 1.74–2.64, appeared to be greater for occupants of buildings with carpets on the floors, having new decoration nearby, and the presence of passive smoke exposure. Water damage and visible mould growth in the buildings seemed to exert only slight effect on reporting SBS symptoms. If the occupants reported the recollection of noticeable environmental changes, such as feeling too cold, too hot, too dry, too strong airflow, too stuffy air and smell of chemicals and unpleasant odours, occurring in the workplace during the past 4 weeks, higher frequency of reporting selected SBS symptoms would be observed (OR= 2.35–10.43). Higher levels of indoor TVOC and CO_2 were related to an increased occurrence of various symptoms such as irritation of mucous and skin, symptoms of central nervous system and respiratory symptoms (OR = 2.80–4.43). However, similar association was not seen with indoor exposure of formaldehyde, PM_{10} and airborne microbes.

Table 2 Odds ratio for different symptoms associated with various building characteristics and indoor air pollutants

Building characteristics/ concentrations of indoor air pollutants	Odds ratio		
	Irritated symptoms	Symptoms of central nervous system	Respiratory symptoms
Carpets	2.64	2.21	2.07
New decoration nearby	1.86	2.63	2.62
Water damage	0.61	1.71	0
Visible mould growth	1.71	0.90	0.76
Passive smoking	1.85	1.74	1.85
Events that happened during past 4 weeks			
Strong air flow	10.43	10.30	4.86
Stuffy air	3.80	2.39	3.19
Too hot	3.92	2.40	3.07
Too cold	4.36	3.17	2.35
Too dry	7.53	5.97	6.20
Chemicals or odours	3.73	4.94	4.90
Carbon dioxide (ppm)	2.90	4.85	2.80
TVOC (ppm)	3.79	3.16	4.43
Formaldehyde (ppm)	0.38	0.22	0.38
PM_{10} ($\mu g/m^3$)	0.24	0.30	0.22
Total fungi (CFU/m^3)	0.29	0.27	0.30
Total bacteria (CFU/m^3)	0.21	0.21	0.19

DISCUSSION

The environmental measurements of indoor air quality from our study show that the exposure levels of TVOC, formaldehyde and airborne microbes are generally higher than guidelines and recommendation levels adopted in many other countries. Potential sources for formaldehyde and volatile organic compounds, such as paint, adhesives, vinyl floor, ceiling, wall coverings, carpets, insulation material, composite wood products and some equipment, are widely available inside most office buildings in Taiwan. In addition, our previous study has estimated excessive increase of both cancer risk and chronic non-carcinogenic effects in non-industrial office environments of high formaldehyde levels (in press). These high exposure levels might associate with over-decoration and large quantity of furniture and equipment without any emission regulation and labelling system in Taiwan.

Overall high levels of airborne microbes were found in these office buildings when compared to any recommendation proposed by many countries. Moreover, our previous studies have also demonstrated that the high exposure levels of airborne microbes were repeatedly observed in domestic environments in our region (Wu *et al.*, 2000; Su *et al.*, 2001). These relative high levels of airborne microbes exposure may be attributable to the subtropical climate in Taiwan. The apparent high levels of microbial contaminations in these air-conditioned office building further highlight the importance of controlling indoor biocontaminations and preventing their health implications in Taiwan.

The frequency of reported SBS symptoms ranged from 9.10 to 39.25%, similar to the prevalence in other countries. Building characteristic, such as with carpets on the floors, and with new decoration and passive smoke exposure inside buildings, were associated with increasing complaints of irritated symptoms, central nervous system problems, and respiratory symptoms. This observation was supported by the environmental data where high levels of

TVOC were also measured in those sites with the above characteristics. In addition to the current observation with higher reporting SBS, we would propose the need for a long-term investigation between the above exposure and chronicle diseases.

The dampness factors, water damage and visible mould growth in office buildings, and airborne microbial concentrations did not seem to result in an observation of increased reporting of SBS symptoms. Such a finding is not consistent with previous studies indicating association between indoor dampness and microbial contamination with higher prevalence of SBS symptoms (Bholah and Subratty, 2002). One plausible rationale is that the overall microbial concentrations in Taiwan are so high that variation of concentration distribution is too small to differentiate the related effect.

Higher levels of carbon dioxide have also contributed to the increased reporting of symptoms, especially for those of central nervous system. The results suggest that population density and ventilation rate, two major determining parameters for indoor carbon dioxide concentrations, also played an important role on reporting SBS. Moreover, when those occupants perceive the indoor conditions being uncomfortable, such as improper airflow pattern, unpleasant thermal condition, or odours, the frequency of reporting most SBS symptoms would seem also to increase. This indicates that those perceptive variables might be proper predictable indicators for early diagnosing indoor environmental problems and remediation actions.

CONCLUSIONS AND IMPLICATIONS

Our results indicate that high levels of indoor VOCs and carbon dioxide might be two important risk factors for increasing reporting of various SBS symptoms for occupants in Taiwan's large office buildings. Our findings suggest the regulation of building material emissions and adequate control strategy for operating ventilation system should be highlighted in field management. Moreover, further research is needed to explore the associations between high levels of microbial exposure and their health implications in our region.

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