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Indoor Air Pollution and Human Perception in Public Buildings in Tianjin, China

Yuexia Sun[a], Pan Wang[a], Qingnan Zhang[a], Hongting Ma[a,*], Jing Hou[a], Xiangrui Kong[a]

[a] *Tianjin Key Laboratory of Indoor Air Environmental Quality Control, School of Environmental Science and Engineering, Tianjin University, Tianjin, 300072, China*

Abstract

In recent years public health problems caused by indoor air pollution, such as Sick Building Syndrome (SBS), have been drawing strong public concerns. This study aims at investigating the indoor environment quality (IEQ) and people's perception in public buildings in Tianjin, China. Indoor environment parameters including air temperature, relative humidity, air speed, TVOC, formaldehyde and CO_2 were monitored at two office buildings and two shopping malls, which located in Tianjin region. The measurement was done during January 2014-December 2014. Occupants' perception on indoor air quality (IAQ), thermal environment, and SBS symptoms were surveyed by questionnaire. Approximately 31.5% and 2.5% of the samples in two offices exceeded the Chinese National Indoor Air Quality Standard for formaldehyde (0.08 mg/m^3), as well as 19.9% and 55.3% of samples in two shopping malls. High formaldehyde concentration, especially in the mall, should be of health effect concern. It was indicated that indoor air quality (IAQ) may lead to SBS symptoms in public building in Tianjin.

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Keywords: Indoor air quality; Public buildings; Human perception; Formaldehyde; TVOC

1. Introduction

Indoor concentrations of many pollutants are often higher than those typically encountered outside which would cause significant harmful health effects due to a long time period that people staying indoors. Klepeis et al. reported

* Corresponding author. Tel.: 022-27890131; fax: 022-7933501.
E-mail address: mht116@tju.edu.cn

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that people (in USA) may spend an average of 87% of their time in enclosed buildings and approximately 6% of their time in enclosed vehicles [1]. Skolnick reported that a population living in the tight energy efficient buildings were infected upper respiratory diseases at rates 46% to 50% higher than a compared group living in better ventilated houses [2]. Fanger claimed that the incidence of allergic and asthmatic diseases has doubled in developed countries over the past two decades [3]. Bornehag et al. believed that the worsening of indoor air quality (IAQ) is a primary reason for the increment in these diseases. IAQ has declined because of comprehensive energy conservation campaigns. High-energy prices have motivated people to tighten their buildings and reduce the rate of ventilation, so that the air renewal in many premises is at historically low level [4].

Good indoor air quality (IAQ) in public buildings provides a comfortable and healthy environment for the occupants to work, learn, study, etc. Therefore, it is important to ascertain the IAQ status in the public buildings. However, the indoor air quality in public buildings remain largely unknown, especially in China. This study, therefore, was designed to investigate the indoor air environment and human perceptions in office buildings and shopping malls in Tianjin region.

2. Methods

This study selected four buildings used after 2005 in Tianjin region, among which were two office buildings and two shopping malls. The information on building ID, building type and its HVAC system are shown in Table 1.

Table 1. Information on building code, building type and HVAC system

Building ID	Building type	HVAC system
A	Office building	Air fan-coil system; Purification plant located in fan coil terminal; Membrane humidifier located in fresh air unit
B	Office building	VRF air conditioning system without purification or humidifying device
C	Shopping mall	Centralized air system without humidifying device; Fiber medium efficient filter located in the supply air duct
D	Shopping mall	Centralized air system without humidifying device; Fiber medium efficient filter located in the return air duct

Since January 2014, the field test on these four buildings was performed every two months for one year. Therefore each building was measured for 6 times within one year to monitor the conditions in different seasons. Within every two-month round, office buildings and shopping malls were investigated for two days continuously, two weekdays for offices, one week day and one weekend for shopping malls. The test time in office buildings started from 9 am to 5 pm, during which parameters in all measurement locations were monitored for 5 times. The test time in shopping malls started from 10 am to 9 pm, during which parameters in all measurement locations were monitored for 7 rounds.

The height of the measurement locations was 0.7 m - 1.5 m above floor, where was the human breathing zone. Six parameters (formaldehyde, TVOC, carbon dioxide, temperature and humidity, air speed) in each location were measured. Measurement instruments were calibrated prior to the test. The ranges and accuracy of instruments used in this study are summarized in Table 2.

Table 2. Detection range and accuracy of the instrument for measurement

Indoor pollutant/parameter	Range	Accuracy
Temperature	-30℃ - +60.0℃	±0.6℃
Relative humidity (RH)	0-99%	±3% RH (25℃， 20-90% RH), ±5% RH for others
Carbon dioxide (CO_2)	0-2000 ppm	±50 ppm

Air speed	0-10 m/s	±0.1 m/s
Total volatile organic compounds (TVOC)	0-20 ppm	0.01 ppm
Formaldehyde (HCHO)	0-10 ppm	0.01 ppm

Questionnaires were used to survey occupants' perception on IAQ, thermal environment, light and acoustic environment, as shown in Table 3. Background information and SBS symptoms of occupants were also collected by questionnaire. At least 60 surveys were done in each building.

Table 3. Contents of questionnaire survey

Items	Main contents
Background information	gender, age, job category
Environmental perception	perception on odor, thermal environment, acoustic environment, light environment, IAQ, etc
Health outcomes and others	SBS symptoms, etc

3. Results and discussions

3.1. The thermal environment

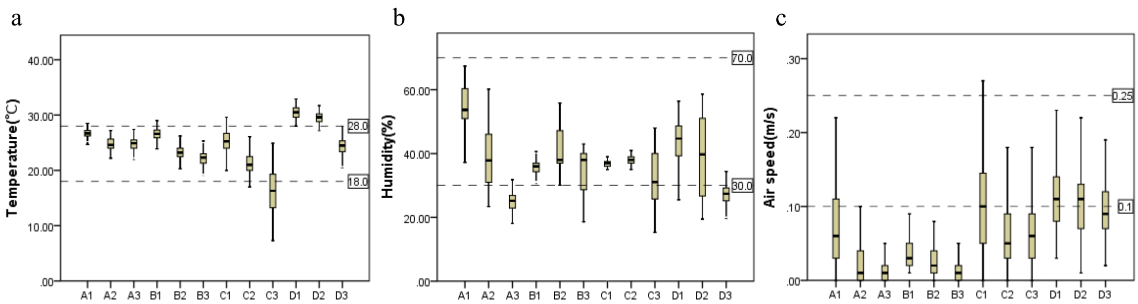

Fig. 1. (a) Temperature in investigated buildings; (b) Relative humidity in investigated buildings; (c) Air speed in investigated buildings.

(Character A, B, C, D represents four buildings. Subscript indicates seasons: 1-summer, 2-transition season, 3-winter. The dash line indicates the national code for specific parameters.)

As shown in Fig. 1, indoor air temperature varied in different seasons. Summer had the highest indoor air temperature, followed by the transition season, the lowest in winter. The indoor average temperature in office buildings throughout the year was between 23.6℃ and 26.6℃, while these in shopping malls varied greatly in different seasons. Especially in shopping mall D, the indoor average temperature in summer was 30.4℃, which was above the national code for indoor temperature. In shopping mall D, 10% of surveyed occupants reported "very hot" and 30% "hot". The relative humidity in four buildings were generally low in winter, especially in building A and D, where the indoor average relative humidity in winter were 25.0% and 27.2%, which were below the national code for indoor relative humidity.

The average air speed during the whole year was relatively low. It was 0.04 m/s in office buildings and 0.10 m/s in shopping malls. The Chinese national code for indoor air temperature, relative humidity and air speed are 18℃-28℃, 30%-70% and 0.1 m/s-0.25 m/s, respectively [5]. In most conditions, indoor air temperature and relative humidity in four buildings were within the standard. However, the average indoor air speed in these four building was lower than the standard with the minimum air speed was zero.

3.2. Indoor air quality

The distribution of formaldehyde, TVOC, CO_2 concentrations in different seasons is shown in Fig. 2. The average values of formaldehyde, TVOC, CO_2 in four buildings are shown in Table 4.

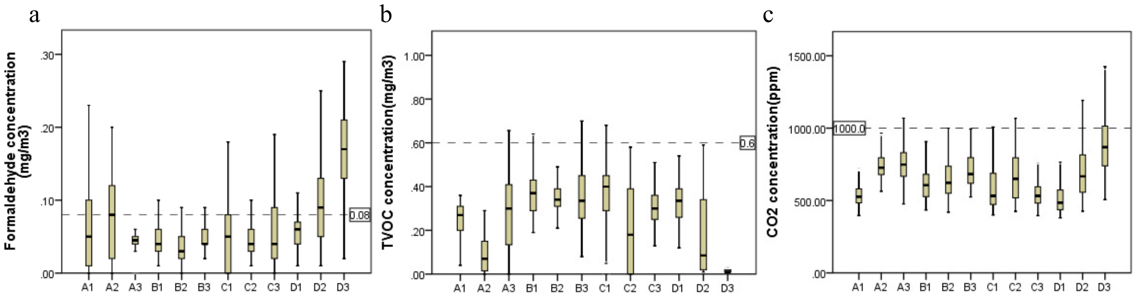

Fig. 2. (a) Formaldehyde in investigated buildings; (b) TVOC in investigated buildings; (c) CO2 in investigated buildings.

(Character A, B, C, D represents four buildings. Subscript indicates seasons: 1-summer, 2-transition season, 3-winter. The dash line indicates the national code for specific parameters)

Table 4. CO2, HCHO, TVOC concentrations in four buildings

Building ID	Ave. CO_2 (ppm)	Ave. HCHO (mg/m^3)	Ave. TVOC (mg/m^3)	CO_2 above 1000 ppm	HCHO above 0.08 mg/m^3	TVOC above 0.6 mg/m^3
Office building A	681	0.06	0.20	1.8%	31.5%	0.3%
Office building B	661	0.04	0.36	0.9%	2.5%	0.9%
Shopping mall C	600	0.06	0.29	1.1%	19.9%	1.7%
Shopping mall D	717	0.16	0.20	13.2%	55.3%	0.1%

Fig. 2 shows the high formaldehyde concentration in these four buildings was very prevailing especially in building A and D. It was found that with the increment of occupant's density and the use of office equipment (such as printers, photocopy machines), the concentration of formaldehyde increased (data not shown). In shopping malls, concentrations of formaldehyde and TVOC were higher in the zone for household appliances and furniture. In addition, CO_2 concentration was higher in restaurant areas inside shopping malls. Therefore it may be practical to install CO_2/formaldehyde-controlled VAV system in specific areas in shopping malls.

3.3. Questionnaire survey

Table 5 shows the evaluation on indoor environment quality in four buildings by occupants. The overall evaluation on indoor environment quality in offices was better than in shopping malls. People in shopping malls were especially dissatisfied with the thermal and acoustic environment.

Table 5. Indoor environment quality evaluated by occupants

Indoor environment	Building type	Evaluation grade（%）				
		Very bad	Bad	General	Well	Very well
Thermal environment	Office	0	13	67	13	8
	Shopping mall	9	43	45	3	1
Acoustic environment	Office	2	9	57	24	8

	Shopping mall	15	42	35	7	1
Light environment	Office	0	7	59	25	9
	Shopping mall	9	32	47	10	1
Indoor air quality	Office	0	14	60	18	9
	Shopping mall	14	42	33	9	1
Overall evaluation	Office	0	7	63	21	9
	Shopping mall	10	35	43	9	2

SBS symptoms reported by occupants are summarized in Table 6. The often reported symptoms were fatigue, heavy head, headache, breathe difficulty, chest tight etc. Health problems reported by occupants were more serious in shopping malls than in offices. When leaving the working environment, 51.7% of office building staff thought the symptoms were remitted, while it was 43.2% in shopping malls.

Table 6. SBS symptoms reported by occupants

Symptoms	Building type	Never → Often（%）				
		1	2	3	4	5
Fatigue	Office	21	39	27	8	4
	Shopping mall	17	33	16	21	13
Heavy head	Office	35	37	20	7	17
	Shopping mall	16	35	28	10	10
Headache	Office	39	38	18	3	17
	Shopping mall	27	30	20	11	11
Breathing difficulty	Office	45	34	18	3	0
	Shopping mall	22	38	17	10	12
Chest tight	Office	48	31	19	3	0
	Shopping mall	26	31	19	17	8
Sore throat	Office	34	33	23	7	3
	Shopping mall	20	29	27	15	9
Dry eyes	Office	28	38	23	8	4
	Shopping mall	23	24	33	14	7
Blocked nose	Office	40	38	17	4	1
	Shopping mall	25	28	30	13	4
Running nose	Office	42	42	14	2	1
	Shopping mall	32	32	27	8	2
Watery eyes	Office	50	32	13	3	1
	Shopping mall	36	30	21	10	4
Common cold symptoms	Office	41	32	23	3	1
	Shopping mall	32	30	18	16	4
Wheeze	Office	52	33	13	2	1
	Shopping mall	34	32	15	14	5
Tinnitus	Office	56	28	13	3	1
	Shopping mall	33	31	20	13	3

Nausea	Office	57	27	12	4	0
	Shopping mall	37	30	23	9	2
Dry skin	Office	34	37	20	8	1
	Shopping mall	31	27	23	18	2
Neck/joint pain	Office	34	29	21	10	6
	Shopping mall	27	24	21	16	12

4. Conclusions

A study on indoor environment quality in four public buildings in Tianjin was conducted. Some problems or situations with risk for the good IEQ were identified, such as: (1) high CO_2 concentration in the dining-room in shopping malls during the period of dining as a result of insufficient ventilation; (2) high formaldehyde concentrations in offices and shopping malls; (3) lack of regular hygiene and maintenance of HVAC systems (as shown by the questionnaire survey); (4) serious SBS symptoms reported by occupants especially in shopping malls. These findings provide certain guidance in improvement of IEQ conditions in public buildings.

Acknowledgements

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