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Evaluation of Indoor Air Quality and Health Related Parameters in Office Buildings with or without Indoor Plants

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A case study was conducted to evaluate the quality of indoor air and the health-related parameters of indoor occupants with the consideration of indoor-plant placement in the office buildings in Seoul, Korea from October, 2006 to July, 2007. The office buildings with more than seven floors were categorized into two groups. One group was composed of six newly-built buildings established in 2005 to 2006 and the other group was composed of six aged buildings established in 1990 to 1992. An office room on the 3rd floor was chosen as the place with indoor plants and on the 4th floor as the place without indoor plants. The quality of indoor air was estimated using the concentrations of air-borne fine particles including formaldehyde and other volatile organic compounds (VOCs)—benzene, toluene, ethylene, and xylene (BTEX). The physical condition of indoor occupants was evaluated based on certain health-related parameters such as the symptom degree of sick building syndrome (SBS) and the scale of symptom checklist (90) revised (SCL-90-R). The concentration of formaldehyde was decreased not by the individual application of ventilation or indoor-plant placement but by the combined application of the two factors as evidenced by reductions from 80.8 to 66.4 μg·m^{-3} in the newly-built building and from 23.3 to 18.6 μg·m^{-3} in the aged building. The concentrations of BTEX varied with indoor conditions. In office rooms with high concentrations of BTEX, these concentrations were obviously reduced by the individual application of ventilation but hardly reduced by the individual application of indoor-plant placement. The indoor occupants of the newly-built buildings perceived little improvement in the symptom degree of SBS by the individual application of ventilation (changing from 19 to 15 points) or indoor-plant placement (changing from 26 to 25). In contrast, the indoor occupants of the aged buildings felt a good improvement in the symptom degree of SBS by the combined application of ventilation and indoor-plant placement, reducing from 23 to 14 points. Observing the mental health of indoor occupants using SCL-90-R, the various results did not show a clear tendency. It could be tentatively postulated that the individual application of ventilation or indoor-plant placement in the office room failed to make sufficient improvement in the mental health of indoor occupants.

Key Words: BTEX, IAQ, Indoor-plant placement, SCL-90-R, SBS.

Introduction

Urbanites spend the greater part of their daily lives in an office room (Seifert et al., 1992), so the inner conditions of the office room should be considered one of the most influential factors on human health. Previous researchers have pointed out that indoor air of good quality offers indoor occupants substantial benefits (Fanger, 2006) while poor quality air causes adverse effects such as asthma, dizziness, physical fatigue, and some allergic diseases in the eyes, nose, and throat (Brasche et al., 1999; Carpenter, 1998; Carrer et al., 1999; EPA, 1987, 1991; Seo et al., 2006).

According to many previous results, the indoor air is known to be easily contaminated by air-borne fine particles (Sullivan et al., 2001; Wolkoff, 2003). These particles are aromatic hydrocarbons, chiefly formaldehyde and BTEX (benzene, toluene, ethylene, and xylene). Preceding studies indicated that these particles

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are chiefly responsible for the symptoms of sick building syndrome (SBS) among indoor occupants (Brasche, 1999; Carpenter, 1998; Carrer et al., 1999) and noted that abundant pollution sources emit these particles including particle board, plywood, carpet, cosmetics, and tobacco smoke (Spengler and Sexton, 1983). For that reason, Guo et al. (2003) suggested that good quality indoor air should be maintained by the methods of controlling pollution sources, designing ventilation systems to expel contaminated air, and applying air cleaning systems. However, those practices are costly, inefficient, and require maintenance (Lim et al., 2006).

Modern urbanites demand various functions of plants (Bennett and Hill, 1973; Gilbert, 1968, 1971; Rao, 1979; Raza et al., 1991). One such function can be air purification. It is widely accepted that plants can alleviate not only mental stress but also physical fatigue of human beings in an environmentally-friendly way (Asaumi et al., 1995; Bell et al., 2001; Hartig et al., 1991; Herzog et al., 1997; Kaplan, 2001; Kondo and Toriyama, 1989; Lohr and Pearson-Mims, 1996; Park et al., 2008; Shibata and Suzuki, 2001). Additionally, it has frequently been reported that indoor plants decease the symptom degree of SBS among indoor occupants (Godish and Guindon, 1989; Kim et al., 2010). Subsequent studies confirmed that plants could decompose those air-borne fine particles (Coward et al., 1996; Giese et al., 1994; Lim et al., 2009; Lohr and Pearson-Mims, 1996; Park and Seong, 2007).

After reviewing the former studies on air purification in indoor spaces and the health improvement of indoor occupants by plants, the present case study was conducted to find out the relationship between indoor air quality (IAQ) and certain health-related parameters with the consideration of indoor-plant placement.

Materials and Methods

An evaluation of the quality of indoor air and certain health-related parameters of indoor occupants was conducted with the consideration of indoor-plant placement in office buildings in Seoul, Korea from October, 2006 to July, 2007. The detailed methods of experimental practices are as follows.

Organization of office buildings and placement of indoor plants

The present case study examined 12 office buildings with more than six floors in Seoul, Korea. These office buildings were categorized into two groups; six newly-built buildings established in 2005 to 2006 and six aged buildings established in 1990 to 1992. Each office building provided two office rooms with floor areas of more than 100 m^2 on the 3rd and the 4th floor. The office room on the 3rd floor chosen as the place with indoor plants and that on the 4th floor was the place without indoor plants. All office rooms had no ventilation system except windows, which occupied more than a half of the surface of the wall. The office room occupants tried to maintain steady indoor conditions by opening their windows in summer and closing in winter without the help of air conditioners.

The placement of indoor plants was conducted by placing a large potted plant in every 10-m^2 area in the early days of October, 2006, and every office room also had 12 additional small pots of plants. The large indoor plants were kentia palm, lady palm, rubber plants, and corn palm and small plants were dumb cane and rubber plants. The National Institute of Horticultural and Herbal Science in Korea provided information on the appropriate kinds and positioning of indoor plants for air purification (Fig. 1).

Evaluation on indoor air quality

The measurement items for IAQ evaluation were the concentrations of formaldehyde and BTEX in indoor air. As the office rooms for the present case study managed their indoor condition as an airtight state in winter and ventilation state in summer, the evaluation was conducted in winter (January) for airtight state and in summer (July) for ventilation state in 2007.

Air sampling was carried out at a height of 1.5 m above floor level at three locations with three replications in each office room in airtight condition using a low-volume vacuum pump (MP-Σ, Shibata, Japan). After indoor air was captured into a 2,4-dinitrophenylhydrazine (DNPH) cartridge and ozone scrubber (Supelco, USA) using the low-volume vacuum pump at a flow rate of 0.2 $L\cdot min^{-1}$ for 60 min, the amount of formaldehyde in the captured air was analyzed using high-performance liquid chromatography (HPLC) (Alliance 2690 & 2787, Waters, USA) equipped with a 0.32-mm id and 1-µm thickness by 60-m long HP-1 capillary column (Agilent Tec., USA). Another low-volume vacuum pump absorbed indoor air into Perkin Elmer Tenax-TA adsorbent tubes (1/4" × 20 cm, Supelco, USA) at a flow rate of 0.1 $L\cdot min^{-1}$ for 60 min. BTEX in the adsorbent tube was desorbed using a coupling thermal desorption system (TDS) (Aerotrap 6016, Tekmar, USA) and quantitatively analyzed using a gas chromatography/mass selective detector (GC/MSD) (G-14-N, Shimadzu, Japan) and flame ionization detector (FID). The probabilities of calibration curves were managed at 0.5% level for formaldehyde and BTEX. The extraction efficiencies were 90 to 110% for formaldehyde and 80 to 115% for BTEX.

Evaluation on human health

To evaluate human physical condition and mental health with the consideration of indoor-plant placement, one group of the newly-built buildings supplied a six-floor office building established in 2007 with 33 indoor occupants in two 105-m^2-area office rooms on the 3rd and the 4th floor and the other group of the aged buildings supplied a seven-floor office building established in 1992 with 38 indoor occupants in two 135-m^2-area office

Fig. 1. Features of indoor-plant placement in office buildings.

rooms on the 3rd and the 4th floor.

In the two office buildings, the office rooms on the 3rd floor were the places with indoor plants and those on the 4th floor were the places without indoor plants. There were 16 indoor occupants of the office room on the 3rd floor with 22 indoor plants (10 large pots and 12 small pots) and 17 indoor occupants of the office room on the 4th floor without indoor plants in the newly built building and there were 19 indoor occupants of the office room on the 3rd floor with 25 indoor plants (13 large pots and 12 small pots) and 19 indoor occupants of the office room on the 4th floor without indoor plants in the aged building. The indoor occupants provided personal information such as sex, age, and duration of occupation in a day (Tables 1 and 2).

All the indoor occupants took a form of questionnaire to evaluate the symptom degree of SBS three times: just after indoor-plant placement and during the periods of airtight (January) and ventilation (July) conditions in 2007. The questionnaire had 12 items about physical conditions such as flush, asthma, and other allergic symptoms in the eye, nose, and throat. Indoor occupants answered on each item with one of four degrees: no symptom (0 points), light symptoms (1 point), moderate symptoms (2 points), and severe symptoms (3 points). The scores of the 12 items were combined as a total score to compare the symptom degree of SBS. The score range of SBS symptom degree was distributed from 0 to 36 points. The examination for diagnosing SBS symptom was conducted with the advice of the medical college of Yonsei University.

A diagnosis of mental health for indoor occupants was conducted twice with a standard form of questionnaire, symptom checklist (90) revised (SCL-90-R) (Derogatis, 1997); once at each measurement time, i.e. the periods of airtight (January) and ventilation (July) conditions in 2007. SCL-90-R had 83 regular items dealing with the nine symptoms of mental health such as somatization (SOM) (12 items), obsessive-compulsive (O-C) (10 items), interpersonal sensitivity (I-S) (9 items), depression (DEP) (13 items), anxiety (ANX) (10 items), hostility (HOS) (6 items), phobic anxiety (PHOB) (7 items), paranoid ideation (PAR) (6 items), and psychoticism (PSY) (10 items). The additional seven items of SCL-90-R were excluded in the present case study. Indoor occupants answered on each item with one of five degrees: no symptom (1 point) to severe symptom (5 points) within 12 to 15 min. All the degree scores for

Table 1. General conditions of office buildings and indoor occupants.

Observation object	Index	Classification	Newly-built building	Aged building
Office building	Year of completion		2007	1992
	Floor		6	7
	Indoor area/office room (m^2)		105	135
Indoor occupants	Number of participants		33	38
	Sex	Male	12	24
		Female	21	14
	Age	20s	17	20
		30s	15	14
		Above 40s	1	3
	Working hours in a day	< 7–8 h	1	—
		< 8–9 h	7	8
		< 9–10 h	11	4
		> 10 h	14	26
	Indoor plant	Placement	16	19
		Non-placement	17	19

Table 2. List of indoor plants in office buildings.

Observation site	Indoor plant		Number (size)
	Common name	Scientific name	
Newly-built building	Total number of indoor plants		22 plants
	Kentia palm	*Howea forsterana*	2 (large)
	Lady palm	*Rhapis excels*	2 (large)
	Rubber plant	*Ficus elastic co. robusta*	3 (large)
	Corn plant	*Dracaera fragrans*	3 (large)
	Dumb cane	*Dieffenbachia camilla*	6 (small)
	Rubber plant	*Ficus elastica*	6 (small)
Aged building	Total number of indoor plants		25 plants
	Kentia palm	*Howea forsterana*	3 (large)
	Lady palm	*Rhapis excels*	2 (large)
	Rubber plant	*Ficus elastic co. robusta*	4 (large)
	Corn plant	*Dracaera fragrans*	4 (large)
	Dumb cane	*Dieffenbachia camilla*	6 (small)
	Rubber plant	*Ficus elastica*	6 (small)

each symptom were summed and calibrated as a percentage for even comparison between the symptoms, so the score range for each symptom was 0 to 100%. The symptom score was applied to assess whether the indoor occupants were in potential danger or had abnormality of a certain symptom by more than 60 to 70 points.

Results

The office room in newly-built buildings had more formaldehyde in indoor air, with a minimum value of 66.4 $\mu g \cdot m^{-3}$, than those in aged buildings with a maximum value of 28.8 $\mu g \cdot m^{-3}$ during the observation period. In the newly-built buildings, individual application of ventilation or indoor-plant placement made little difference or a slight increase in the concentration of formaldehyde, recorded as 73.3 $\mu g \cdot m^{-3}$ during the period of ventilation without indoor plants and 92.2 $\mu g \cdot m^{-3}$ in the period of airtight condition without indoor plants. The combined application of ventilation and indoor-plant placement brought about a significant decrease in the concentration of formaldehyde, decreasing from 80.8 to 66.4 $\mu g \cdot m^{-3}$. In the aged building, the concentration of formaldehyde was decreased by indoor-plant placement regardless of ventilation, showing 16.5 $\mu g \cdot m^{-3}$ in the period of airtight conditions and 18.6 $\mu g \cdot m^{-3}$ in the period of ventilation (Table 3).

The observation of BTEX concentrations revealed that the concentration of toluene was higher at the office rooms in newly-built buildings but those of other chemical substances were higher in aged buildings. In the case of high concentrations of chemical substances, the individual application of ventilation made significant decreases, from 7.20 to 1.71 $\mu g \cdot m^{-3}$ for benzene and from 275 to 119 $\mu g{\cdot}m^{-3}$ for toluene. The additional application of indoor-plant placement made little improvement in the decreases, showing 1.96 $\mu g{\cdot}m^{-3}$ for benzene and 106 $\mu g{\cdot}m^{-3}$ for toluene as compared with individual application of ventilation. The individual application of indoor-plant placement failed to significantly decrease the concentrations of BTEX (Table 3).

The overall view on the total score of SBS symptoms showed that the indoor occupants in aged buildings perceived a greater degree of SBS symptoms than those in newly-built buildings. The Kruskal-Wallis test verified that the individual application of ventilation failed to show a regular tendency in SBS symptom score but the combined application of ventilation and indoor-plant placement caused a significant decrease in that score. In the aged buildings, the total score of SBS symptoms was hardly decreased by the individual application of ventilation but significantly decreased by the application of indoor-plant placement with or without ventilation (Fig. 2).

Mental health evaluation using SCL-90-R revealed that no one had symptoms above 60 points, the critical point of potential danger or abnormality in mental health. In the newly-built buildings, the individual application of indoor-plant placement decreased the symptom scale for more items than the individual application of ventilation. The additional application of indoor-plant placement further decreased the symptom scales, with some exceptions. In the aged buildings, the application of ventilation and indoor-plant placement failed to bring

Table 3. Changes of the concentrations of formaldehyde and BTEX in office buildings according to indoor plants.

Observation site	Indoor plant	Measurement time	Form-aldehyde	Benzene	Toluene	Ethyl-benzene	Xylene
					($\mu g{\cdot}m^{-3}$)		
Newly-built building	Without	January	80.8	1.12	275	3.21	5.38
		July	73.3	1.72	119	1.36	3.67
		P value[z]	NS	NS	*	NS	NS
	With	January	99.2	2.41	518	1.62	8.03
		July	66.4	1.54	106	1.08	1.64
		P value	**	NS	**	NS	*
Aged building	Without	January	23.2	7.20	67	3.44	14.81
		July	28.8	1.72	53	2.17	6.17
		P value	NS	*	NS	NS	NS
	With	January	16.5	8.00	62	6.43	36.48
		July	18.6	1.96	78	2.19	6.72
		P value	NS	**	NS	*	**
LSD 0.05			29.9	3.82	218	2.34	13.21
LSD 0.01			36.6	6.72	400	4.92	24.25

[z] NS: non-significance, * significance at $P=0.05$, ** significance at $P=0.01$ by Wilcoxon's rank sum test.

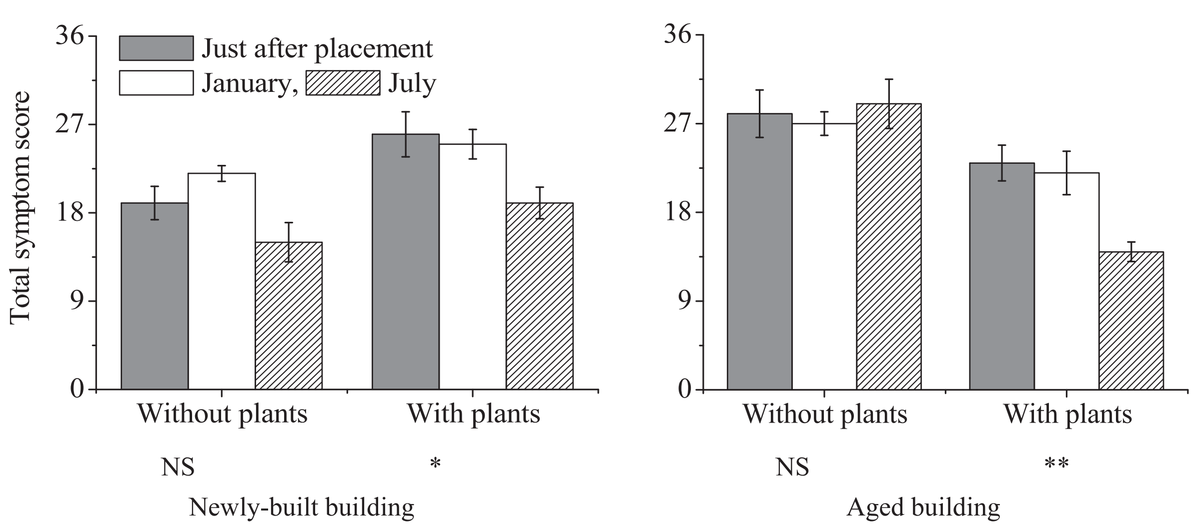

Fig. 2. Symptom evaluation of sick building syndrome (SBS) as a total score according to indoor-plant placement. Vertical bars represent ±SE of the means (n = 17, 16, and 19 from left to right).
NS: Non-significance, * significance at $P=0.05$, ** significance at $P=0.01$ by Kruskal-Wallis test.

Table 4. Evaluation of mental health by symptom checklist (90) revised according to indoor plant placement.

Site	Indoor plant	Measure time	Symptom (Number of items)								
			SOM[z] (12)	O-C (10)	I-S (9)	DEP (13)	ANX (10)	HOS (6)	PHOB (7)	PAR (6)	PSY (10)
Newly-built building	Without	January	47	50	45	47	47	45	47	44	46
		July	47	43	48	49	43	46	46	44	46
		P value[y]	NS	**	NS	NS	*	NS	NS	NS	NS
	With	January	50	46	44	43	44	44	46	45	45
		July	49	40	41	42	43	44	46	46	46
		P value	NS	*	NS	NS	NS	NS	NS	NS	NS
Aged building	Without	January	49	42	44	40	45	43	47	42	46
		July	54	46	46	46	46	46	49	45	47
		P value	**	NS	NS	*	NS	NS	NS	NS	NS
	With	January	47	43	43	43	43	46	46	41	44
		July	48	44	44	45	44	45	46	43	46
		P value	NS	NS	NS	NS	NS	NS	NS	NS	NS
LSD 0.05			9.8	12.6	5.0	9.6	5.0	3.8	3.9	4.9	1.8
LSD 0.01			17.9	23.1	9.2	17.7	9.2	7.1	7.2	8.9	3.4

[z] SOM: somatization; O-C: obsessive-compulsive; I-S: interpersonal sensitivity; DEP: depression; ANX: anxiety; HOS: hostility; PHOB: phobic anxiety; PAR: paranoid ideation; PSY: psychoticism.
[y] NS: non-significance, * significance at $P = 0.05$, ** significance at $P = 0.01$ by Wilcoxon's rank sum test.

about any noticeable results in symptom scale decreases regardless of individual or combined application (Table 4).

Discussion

While many previous studies reported that indoor air contamination could be alleviated by the application of ventilation (Guo et al., 2003) or indoor-plant placement (Coward et al., 1996; Giese et al., 1994; Lohr and Pearson-Mims, 1996; Park and Seong, 2007), the present study demonstrated that the concentration of formaldehyde in indoor air was hardly decreased by the individual application of ventilation or indoor-plant placement. Spengler and Sexton (1983) indicated that abundant pollution sources emit air-borne fine particles in indoor space, and Park and Seong (2007) reported that indoor plants did not maintain a steady efficiency in decomposing those particles because of their physiological life cycle (Table 3).

In observing the decomposition of BTEX, the individual application of ventilation or indoor-plant placement achieved good efficiency against high concentrations but performed poorly with low concentrations. Additionally, abnormally high concentrations were observed for some chemical substances such as 518 $\mu g \cdot m^{-3}$ for toluene in the newly-built buildings with indoor plants and 36.48 $\mu g \cdot m^{-3}$ for xylene in the aged building with indoor plants. These chemical substances were reported to be emitted from various pollution sources indoors (Spengler and Sexton, 1983) and to be decomposed or accumulated within plants according to their physiological life cycle (Park and Seong, 2007; Wolverton, 1996) (Table 3).

Many former studies have agreed that SBS is mainly caused by certain air-borne fine particles like formaldehyde and BTEX (Brasche et al., 1999; Carpenter, 1998; Carrer et al., 1999; EPA, 1987, 1991; Godish, 1990) which are known to be constantly emitted from various pollution sources indoors (Spengler and Sexton, 1983). In the present study, the symptom degree of SBS was compared with the consideration of IAQ by indoor-plant placement (Kim et al., 2010). As shown in Table 3, the office rooms in newly-built buildings exhibited a poor decrease in the concentrations of some chemical substances like formaldehyde and toluene by the individual application of ventilation or indoor-plant placement but better decreases in the concentrations of other particles by the individual application of ventilation or indoor-plant placement. From these results, it seems that the application of ventilation slightly improved the symptom degree of SBS. This was accelerated by the supplementary application of indoor-plant placement under conditions of moderate concentration of air-borne fine particles, but the application of indoor-plant placement brought about poor improvement in the symptom degree of SBS under conditions of high concentrations of the particles (Fig. 2).

Although the individual application of ventilation showed increased scores of SCL-90-R in some items, the individual application of indoor-plant placement hardly affected most items. Subsequent studies found that the application of indoor-plant placement could alleviate the mental stress as well as the visual fatigue of indoor occupants (Asaumi et al., 1995; Kondo and Toriyama, 1989; Park et al., 2008; Shibata and Suzuki, 2001). Like previous reports (Asaumi et al., 1995; Bell et al., 2001; Hartig et al., 1991; Herzog et al., 1997; Kaplan, 2001; Lim et al., 2009; Kondo and Toriyama, 1989; Lohr and Pearson-Mims, 1996; Shibata and Suzuki, 2001), the application of indoor-plant placement could be one of the most appropriate and environmentally-friendly methods to alleviate mental stress (Table 4).

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