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Improvement of Indoor Air Quality by Houseplants in New-built Apartment Buildings

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A group of 82 households in a new-built apartment complex in Seoul, Korea participated in an investigation to examine the symptoms of sick building syndrome (SBS) using of houseplants for two observation periods. The present study confirmed the decrease of formaldehyde content in an airtight chamber containing a pot with fatsia plants. Houseplants affected the general air conditions, such as increasing relative humidity and decreasing carbon monoxide and carbon dioxide. The toxic chemical substances responsible for SBS persisted at least one more years but were effectively decreased by ventilation. Houseplants facilitated the quantitative decrease of some of these chemical substances in indoor air. Indoor-dwellers felt the decrease in SBS symptoms with time regardless of houseplants in both observation periods. Houseplants made a slight difference to the symptom degree of SBS in the first observation period but a significant difference in the second observation period; however, houseplants made little difference to the content of toxic chemical substances in indoor air except formaldehyde, although houseplants gave desirable results in the decrease of SBS symptoms.

Key Words: ethylbenzene, formaldehyde, sick building syndrome, toluene, xylene.

Introduction

As modern city-dwellers spend most of their daily lives indoors, they have an interest in indoor air quality (IAQ). In particular, the rapid proliferation of apartment houses has increased public concern about IAQ in new-built buildings (Lim et al., 2006).

Previous researchers regarded IAQ as a major factor of indoor-dwellers' lives in various fields (Fanger, 2006). Nevertheless, it was generally accepted that indoor air in new-built buildings had many toxic chemical substances which were emitted from not only building materials but also newly manufactured furniture. These toxic chemical substances were chiefly formaldehyde and other volatile organic compounds (VOCs), such as benzene, toluene, ethylbenzene, and xylene (BTEX) (Craighead, 1995; Sullivan et al., 2001; Wolkoff, 2002). Many researchers proved that these chemical substances were predominantly responsible for a building-associated disease, sick building syndrome (SBS) (Brasche et al., 1999; Career et al., 1999; Carpenter, 1998). Formaldehyde was reported to be a the potential risk for carcinogenesis (Seo et al., 2006) and BTEX was regarded as causing adverse effects, such as asthma, dizziness, and fatigue, and some allergic diseases of the eyes, nose, and throat (Godish, 1990). According to previous studies, the amount of these toxic chemical substances in indoor air was increased not by long exposure to outdoor air but by continual recirculation of polluted indoor air under airtight conditions. For that reason, indoor-dwellers should frequently ventilate or use low pollutant-emitting building materials to improve indoor conditions; however, these practices are expensive (Lim et al., 2006).

In urbanized societies, some residents give significant attention to houseplants to regulate indoor air conditions as well as their positive effect on mental health as an environmentally friendly method (Bennett and Hill, 1973; Gilbert, 1968, 1971; Hartig et al., 1991; Herzog et al., 1997; Raza et al., 1991; Shibata and Suzuki, 2001). After the National Aeronautics and Space Administration

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(NASA) used houseplants to purify toxic chemical substances in the environment in the 1990s, some researchers confirmed that houseplants purified the air of pollutants (Lohr and Pearson-Mims, 1996; Park and Seong, 2007) and other researchers proved that houseplants absorbed chemical substances from water, air, and soil, and transported them into the rhizosphere, where they decomposed or were converted into energy with the aid of microbes (Giese et al., 1994).

In spite of continual studies of IAQ with the intervention of houseplants, substantial results have not been established with direct consideration of SBS symptoms of indoor-dwellers. For that reason, the present study examined indoor air quality using houseplants by measuring the amount of formaldehyde and BTEX in indoor air. Additionally, indoor-dwellers were examined for SBS symptoms in the presence of houseplants to identify the relation of IAQ to SBS with houseplant intervention.

Materials and Methods

Household arrangement and houseplant placement

An apartment complex in Seoul, Korea created 82 households after completion of its construction in early October, 2005. All households provided detailed information about their indoor conditions, as shown in Table 1. The households were classified into two groups according to houseplant possession. One group of 40 households did not have houseplants and the other group of 42 households had houseplants indoors (Table 1).

The households with plants had large pots of areca palm and rubber plants and small pots of bamboo palm and peace lily in the living room, a pot of pothos in the kitchen, and a large pot of elephant bush and small pot of fatsia and rosemary in the bedroom in early October, 2004 for observation in 2005, and a large pot of Satsuma mandarins and small pots of asplenium, gardenia, and peace lily in the living room, a small pot of pothos in the kitchen, and small pots of rosemary and gardenia in the bedroom in early October, 2005 for measurement in 2006. After the observation in 2005, all plants in these households were removed in late July, 2005 for another observation in 2006 with the same initial conditions. The National Institute of Horticultural & Herbal Science in Korea recommended the kinds of houseplants and their use (Table 2 and Fig. 1).

Formaldehyde decomposition by houseplants

As some former researches demonstrated good results in air-pollutant decomposition with fatsia plants (Hong et al., 2005), a pot of these plants was installed into an airtight chamber to examine its decomposition ability of formaldehyde as a preliminary experiment.

A chamber of about 1 m^3 [0.9 m (W) × 0.9 m (L) × 1.24 m (H)] was made with stainless steel and glass to prevent the natural decrease of formaldehyde. A pot of 3.5 L (19 cm Ø) was filled with bark, sand, and growth media (Sunshine Mix-4, SunGro Horticulture, Canada) at a volume rate of 1 : 1 : 5. The pot was installed into the chamber with or without fatsia plants of 1,627-cm^2 leaf area after a 30-d acclimation period. The inner space of the chamber was managed with light intensity of 70 to 120 $\mu mol \cdot m^{-1} \cdot s^{-1}$, air temperature of 23 ± 3°C, and humidity of 30 to 80%.

After placing the pot inside, gaseous formaldehyde was generated within the chamber up to 2,400 $\mu g \cdot m^{-3}$ using 35% aqueous formalin solution (Katayama Chemical Co., Japan). A low-volume vacuum pump with a stainless steel impeller distributed gaseous formaldehyde evenly within the chamber through 10-min air circulation with a flow rate of 6.0 $L \cdot min^{-1}$ at 60-min intervals during the initial observation period without the generation of other VOCs. After 10-min air circulation, the formaldehyde within the chamber was

Table 1. Conditions of participant households in new-built apartment houses.

Index	Classification	Households without houseplants (n = 40)	Households with houseplants (n = 42)
Area (m^2)	>70	7	11
	>100	29	27
	>130	4	4
Persons in the households	1–3	22	26
	4–6	16	13
	>7	2	3
Air cleaner application	Yes	11	17
	No	29	25
Pet	Yes	0	1
	No	40	41
Newly manufactured furniture (within 6 months)	0	7	5
	1–2	7	10
	3–5	12	11
	6–10	14	16

Table 2. Status of houseplant use in indoor space in new-built apartment house.

Site	Observation in 2005		Observation in 2006	
	Plant	Size	Pant	Size
Living room	Areca palm (*Chrysalidocarpus lutescene*)	Large	Satsuma mandarins (*Citrus unshiu*)	Large
	Rubber plant (*Ficus elastica*)	Large	Asplenium (*Asplenium nidus*)	Small
	Bamboo palm (*Chamaedorea seifrizii* Burret)	Small	Gardenia (*Gardenia jasminoides*)	Small
	Peace lily (*Spathiphyllum spp.*)	Small	Peace lily (*Spathiphyllum spp.*)	Small
Kitchen	Pothos (*Epipremnum aureum*)	Small	Pothos (*Epipremnum aureum*)	Small
Bedroom	Elephant bush (*Portulacaria afra*)	Large	Rosemary (*Rosemarinus officinalis*)	Small
	Fatsia (*Fatsia japonica*)	Small	Gardenia (*Gardenia jasminoides*)	Small
	Rosemary (*Rosemarinus officinalis*)	Small		

Fig. 1. Features of houseplant placement in indoor space in a new-built apartment house.

measured using a data logger (Z300-XP, USA) at 60-min intervals up to 5 h.

Evaluation on indoor air quality

Two methods were used to evaluate IAQ in the present experiment: general observation and detailed measurement. General observation dealt with air temperature, relative humidity, and the content of carbon monoxide and carbon dioxide. The observation was conducted just after houseplant placement in early October, 2004 and after a 90-d airtight period in early January, 2005. Detailed measurements of formaldehyde and BTEX were taken in indoor space. As most households in Korea maintain indoor air with airtight conditions from October to March and with ventilation from April to September, air sampling for detailed measurement was conducted in January for the airtight period and in July for the ventilation period in 2005 and 2006.

For the detailed measurement of IAQ in new-built apartment houses, an active air sampler was set up at a height of 1.5 m above floor level in the living room. After a low-volume vacuum pump in the air sampler adsorbed formaldehyde into 2,4-dinitrophenylhydrazine (DNPH) cartridge and ozone scrubbers (Supelco, USA) at a flow rate of 0.5 L·min^{-1}, formaldehyde was quantitatively analyzed by high-performance liquid chromatography (HPLC) (Alliance 2690 & 2487, Waters, USA) of 0.32-mm id and 1-μm thickness with a 60-m long HP-1 capillary column (Agilent Tec., USA). In the air sampler, another low-volume vacuum pump adsorbed VOCs into Perkin Elmer Tenax-TA adsorbent tubes at a flow rate of 0.2 L·min^{-1}. BTEX was then removed using a coupling thermal desorption system (TDS) (Aerotrap 6016, Tekmar, USA) and quantitatively analyzed with the use of gas chromatography (GC) (Shimadzu G-14-B, Kyoto, Japan) of 0.53-mm id and 0.32-μm thickness with a 25-m long HP-20 column (Agilent Tec.) and a flame ionization detector (FID).

After the trap in TDS was thermally desorbed at 240°C for 3 min, the target compounds were cryo-focused at –110°C on the internal trap (0.1 mm glass bead). The cold trap was rapidly heated up to 225°C to flush into the cryo-focusing module in TDS. The module transferred the target compounds to GC. The initial oven temperature in GC was set at 50°C for 10 min and was ramped by 5°C every minute up to 200°C, and the target compounds were injected with helium carrier gas at a flow rate of 1 mL·min^{-1} at 150°C. Calibration curve was established at 0.5% for formaldehyde and BTEX. The desorbing efficiency for target compounds was higher than 85%.

Diagnosis on the symptom of sick building syndrome

The indoor-dwellers took a questionnaire to examine the degree of SBS symptoms. The questionnaire included 12 items dealing with allergic diseases of the eyes, nose, and throat and other subjective symptoms of headache, fatigue, and flushing. Participants answered each item as one of two degrees (symptom or no symptom). The questionnaire was conducted three times for each observation period: just after houseplant placement (early October in 2004 and 2005) and during the periods of airtight (following early January) and ventilation (following early July) in 2005 and 2006.

Results

Formaldehyde decomposition by houseplants

While a pot without plants slightly decreased formaldehyde content in a 1-m^3 airtight chamber, from 2,400 to about 2,300 μg·m^{-3} over 5 h, fatsia plants resulted in a clear decrease in content to around 1,700 μg·m^{-3} during the same period. Formaldehyde in an airtight chamber showed a regular decrease in its amount with a pot without plants during the observation period. A pot with fatsia plants led to a marked decrease in formaldehyde for the first 2 h, removing 450 μg, but induced a slight decrease for the next 3 h, decomposing approximately 240 μg. As a result, a pot plant had a reducing rate of 225 μg·m^{-3} for the first 2 h and around 80 μg·m^{-3} for the final 3 h (Fig. 2).

Evaluation on indoor air quality

In new-built apartment houses, airtight conditions of indoor air without houseplants resulted in distinct changes in air temperature and relative humidity after 90 days (from October to January) but showed little change in the content of carbon monoxide and carbon dioxide. Houseplants gave different results in general air conditions.

There was a marked decrease in air temperature within new-built apartment houses after a 90-d airtight period regardless of houseplants, falling from 28.6 to 21.5 or 22.0°C. The relative humidity of indoor air decreased from 60.8 to 45.4% after the 90-d airtight period, which was mitigated by houseplants, recording 53%. With initial values of 1.06 μg·m^{-3} carbon monoxide and 376 μg·m^{-3} carbon dioxide, households without plants showed little change in content, showing 1.05 μg·m^{-3} carbon monoxide and 377 μg·m^{-3} carbon dioxide. Households with plants experienced a significant decrease in the content of carbon monoxide and carbon dioxide, 0.96 and 335 μg·m^{-3}, respectively (Table 3).

As many researchers found that the VOCs responsible for SBS were chiefly formaldehyde and BTEX (Craighead, 1995; Sullivan et al., 2001; Wolkoff, 2003), detailed measurement of IAQ of those chemical substances were conducted. The overall view indicated that these chemical substances remained more content in the airtight period (January) than in the ventilation period (July) and persisted to some degree for at least one more year. The amount of benzene was too minute to trace indoors (data not shown), but those of other chemical substances showed specific tendencies.

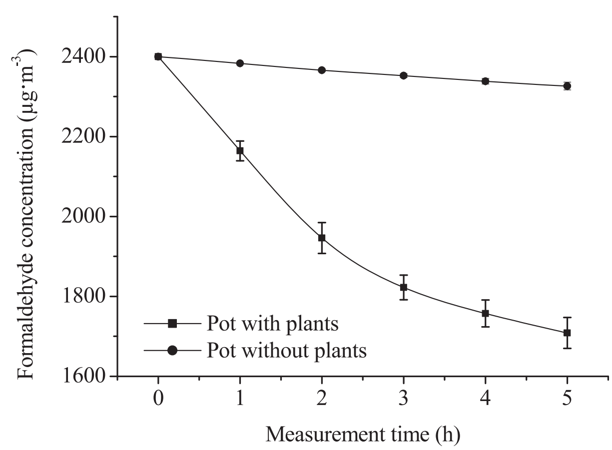

Fig. 2. Changes of formaldehyde content in 1-m^3 airtight chamber by pot installation with or without fatsia (*Fatsia japonica*) plants with time. Vertical bars represent SE of the means (n = 7).

Table 3. General observation of indoor air condition according to houseplants.

Air condition	Initial (October, 2004) (n = 82)	90 days later (January, 2005)	
		Without houseplant (n = 40)	With houseplant (n = 42)
Air temperature (°C)	28.6 ± 1.2^z	21.5 ± 2.8	22.0 ± 2.9
Relative humidity (%)	60.8 ± 3.4	45.4 ± 8.3	53.0 ± 6.4
Carbon monoxide (μg·m^{-3})	1.06 ± 0.45	1.05 ± 0.36	0.96 ± 0.38
Carbon dioxide (μg·m^{-3})	376 ± 87	377 ± 87	335 ± 53

^{z} Mean ± SE.

Table 4. Changes of the contents of chemical substances in indoor air according to houseplants.

Year	Houseplant placement	Measurement date	Formaldehyde	Toluene	Ethylbenzene	Xylene
			($\mu g \cdot m^{-3}$)			
2005	Non-placement	January	72.0 ± 7.88[z]	88.6 ± 12.22	0.9 ± 0.02	12.3 ± 2.84
		July	70.6 ± 13.49	19.1 ± 6.08	0.1 ± 0.02	2.4 ± 1.04
	Placement	January	33.7 ± 3.34	75.2 ± 5.66	1.3 ± 0.23	10.7 ± 4.68
		July	10.7 ± 1.88	15.9 ± 4.12	0.1 ± 0.01	1.0 ± 0.67
2006	Non-placement	January	85.1 ± 5.56	168.0 ± 25.06	19.1 ± 2.36	1.1 ± 0.06
		July	54.0 ± 8.40	48.2 ± 12.46	11.9 ± 0.74	1.2 ± 0.02
	Placement	January	44.7 ± 16.43	330.6 ± 16.71	35.2 ± 2.75	2.2 ± 0.25
		July	11.9 ± 3.29	39.5 ± 9.66	10.2 ± 0.35	1.2 ± 0.02

[z] Mean ± SE (n = 40 in households without plants; n = 42 in households with plants).

Formaldehyde

In the first year, households without plants showed little difference in formaldehyde content with time, 72.0 $\mu g \cdot m^{-3}$ in January and 70.6 $\mu g \cdot m^{-3}$ in July. Households with plants maintained a low level of formaldehyde, 33.7 $\mu g \cdot m^{-3}$ in January, which decreased to 10.7 $\mu g \cdot m^{-3}$ in July. In the second year, the airtight period (January) showed a higher content of formaldehyde than the ventilation period (July). Households with plants showed a lower content of formaldehyde than those without plants in both periods (January and July). It was noticeable that the initial values in 2006 were slightly higher than those in 2005 despite the passage of time (Table 4).

Toluene

In households without plants, ventilation decreased toluene content in both years from 88.6 to 19.1 $\mu g \cdot m^{-3}$ in 2005 and from 168.0 to 48.2 $\mu g \cdot m^{-3}$ in 2006. Households with plants failed to show a significantly lower content of toluene than those without plants regardless of the period in both years. Moreover, the observation in 2006 showed a considerably higher initial toluene content, especially in households with plants (Table 4).

Ethylbenzene

Ethylbenzene failed to show a particular trend in the first year because of its minute content in indoor air. In the second year, it decreased to around 10 $\mu g \cdot m^{-3}$ in the ventilation period (July) regardless of houseplants in spite of its different content in the airtight period (January). Additionally, ethylbenzene exhibited a higher content regardless of ventilation in 2006 (Table 4).

Xylene

In the first year, xylene showed a low content in the ventilation period (July), 2.4 and 1.0 $\mu g \cdot m^{-3}$, than in the airtight period (January), 12.3 and 10.7 $\mu g \cdot m^{-3}$. Houseplants showed little significance between the two groups. Unlike other chemical substances, the observation of xylene content in 2006 hardly showed a specific tendency because of its minute content in indoor air (Table 4).

Diagnosis on sick building syndrome

Figure 3 shows that the degree of SBS symptoms followed the decreasing trend with time and the symptom degree was lower in the ventilation period than in the airtight period. The figure also shows the severer degree of SBS symptoms in 2006 than in 2005. In the first year, indoor-dwellers in households without plants experienced steady degree of SBS symptoms from the initial time to the ventilation period (July) throughout the airtight period (January). Houseplants slightly decreased in the symptoms with time. In the second year, SBS symptoms in households without plants showed a similar trend to the first, sustaining a steady degree of more than 63% during the entire measurement period. Symptoms in households with plants showed markedly decreased SBS symptoms in the ventilation period (July), falling from 69 to 35% (Fig. 3).

Discussion

The airtight chamber was made only with stainless steel and glass to prevent the natural decrease of formaldehyde. Moreover, previous studies found three major channels of air-pollutant decomposition by houseplants: most air-pollutant decomposition was a result of photosynthesis by houseplants after absorbing air pollutants through the stomata (Kondo and Saji, 1992), and the remainder was adsorption by media (Orwell et al., 2006; Wood et al., 2002) or with the help of microbes in the rhizosphere (Godish and Guindon, 1989). In a 1-m^3 airtight chamber, a pot without plants caused about a 100-μg decrease in formaldehyde for 5 h but a pot of fatsia plants resulted in an approximately 700-μg decrease during the same period. Considering the results in Figure 2 with previous studies, the pot of fatsia seemed largely responsible for the decrease of formaldehyde content in the airtight chamber (Fig. 2).

Additionally, the reduction rate of formaldehyde was higher during the first 2 h than in the final 3 h in the airtight chamber with a pot of fatsia plants. Park and Seong (2007) postulated that the different efficiency of air purification by the same houseplants was a result of the physiological cycle of plants (Fig. 2).

In modern city life, indoor-dwellers can easily control indoor air temperature but there is not efficient way to

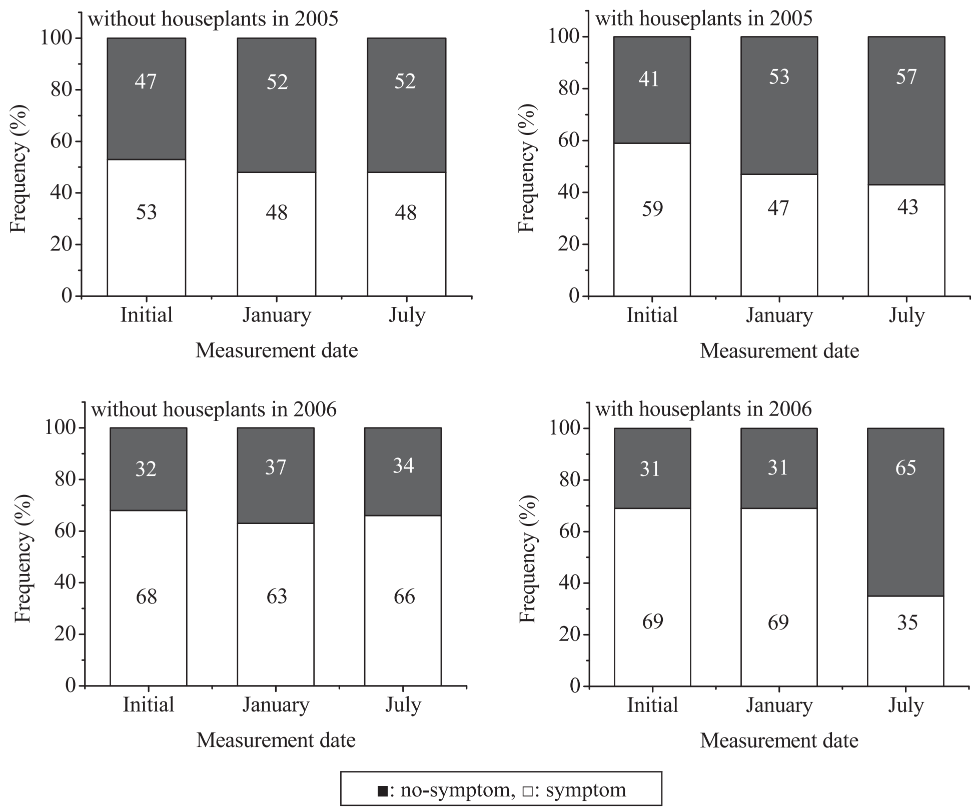

Fig. 3. Symptom evaluation of sick building syndrome according to houseplant placement (n=40 in households without plants; n=42 in households with plants).

control other indoor air conditions, such as relative humidity and the content of carbon monoxide and carbon dioxide, except ventilation. Houseplants made little difference to indoor air temperature but significant differences in other factors under airtight conditions. Houseplants increased relative humidity but decreased the content of carbon monoxide and carbon dioxide in indoor air. Considering the account of Shibata and Suzuki (2001) that houseplants could regulate indoor air conditions by an environmentally friendly method, the changes of indoor air conditions by houseplants could be regarded as a procedure of air condition regulation (Table 3).

The chemical substances in indoor air as air pollutants could be easily removed by ventilation, which was confirmed by Lim et al. (2006); however, households without plants showed no difference in formaldehyde content between the two periods: airtight (January) and ventilation (July). Houseplants caused a marked decrease in formaldehyde content in the airtight period (January), which was facilitated by ventilation, with a content of 10.7 $\mu g \cdot m^{-3}$ in July. In the second experimental period, ventilation caused significant decrease in formaldehyde content, falling from 85.1 in January to 54.0 $\mu g \cdot m^{-3}$ in July. Houseplants seemed to facilitate the decrease in formaldehyde content in both periods. Other indoor air pollutants did not follow the same trend as formaldehyde. Other chemical substances decreased during the ventilation period (July) in both experimental periods (2005 and 2006); however, houseplants failed to show an obvious decrease in the content of chemical substances with some exceptions. Therefore, it could be thought that ventilation was an efficient way of decreasing the amount of chemical substances in indoor air and houseplants provided only supplemental effects. Lim et al. (2006) agreed with these views.

On the other hand, the amount of chemical substances in indoor air was higher in the second experimental period (2006) than in the first experimental period (2005) despite the passage of time. Previous studies indicated that IAQ was affected by various internal and external factors and the present study suggested these factors in other ways. Initially, indoor air pollutants were consistently emitted from various sources in indoor space and ventilation was poor during the winter season (Lim et al., 2006). In particular, indoor-dwellers in new-built buildings did not have a consistent interest in IAQ, except for the first year after building completion. Moreover, indoor-dwellers in households with plants did not ventilate to protect their plants from cold injury; therefore, a series of factors seemed to contribute to the higher content of indoor air pollutant in the second experimental period (2006) than in the first period (2005). However, there are additional possible factors for the higher content of indoor air pollutants in the second experimental period. The present study used different houseplants for the installation in indoor space, as shown in Table 2. It is agreed that houseplants have different abilities in decomposing chemical substances in indoor air and plant systems, including plants, soil, and pots could be another source of VOC emission. Hence, the kinds of houseplants and the plant system for indoor use could be other factors to regulate the amount of indoor air pollutants (Table 4).

Considering the degree of SBS symptoms for indoor-dwellers, as shown in Figure 3 with the observation of IAQ in Table 4, some chemical substances in indoor air seemed to have a certain relation with SBS symptoms of indoor-dwellers. Although it is generally accepted that ventilation is efficient for reducing indoor air pollutants, the present experiment failed to show a clear result in decreasing for SBS symptoms. Houseplants resulted in a significantly lower frequency of SBS symptoms of indoor-dwellers. There are various symptoms of SBS, such as allergic diseases of the eyes, nose, and throat, and other discomforts, including asthma, dizziness, and physical fatigue (Godish, 1990). Indoor-dwellers required diverse approaches to improve their mental health. Houseplants could be one of the most efficient ways to decrease the degree of SBS symptoms as well as to regulate IAQ.

The initial value of the degree of SBS symptoms showed a higher frequency in the second observation period than in the first observation period. As mentioned above, various factors affect IAQ and SBS symptoms. These factors could be the ventilation condition or the kinds and methods of houseplant use between the two experimental periods (Fig. 3).

Acknowledgements

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Literature Cited

Bennett, J. H. and A. C. Hill. 1973. Absorption of gaseous air pollutants by a standardized plant canopy. J. Air Pollut. Contr. Assoc. 23: 203–206.

Brasche, S., M. Bullinger, H. Gebhardt, V. Herzog, P. Hornung, B. Kruppa, E. Meyer, M. Morfield, R. V. Schwab, S. Mackensen, A. Winkens and W. Bischof. 1999. Factors determining different symptom patterns of sick building syndrome-results from a multivariate analysis. In: Proceedings of Indoor Air '99. The 8th International Conference on Indoor Air Quality and Climate, August, 1999, Edinburgh, Scotland, August, UK, 5: 402–407.

Carpenter, D. O. 1998. Human health effects of environmental pollutants: new insights. Environ. Monit. Assessmt. 53: 245–258.

Carrer, P., D. Alcini, D. Cavallo, F. Visigalli, D. Bollini and M. Maroni. 1999. Home and workplace complaints and symptoms in office workers and correlation with indoor air pollution. In: Proceedings of Indoor Air '99. The 8th International Conference on Indoor Air Quality and Climate, August, 1999, Edinburgh, Scotland, UK, 1: 129–134.

Craighead, J. E. 1995. Indoor air quality and pollution. p. 29–39. In: Craighead, J. E. (ed.). Pathology of Environmental and Occupational Disease. Mosby Year Book, St. Louis.

Fanger, P. O. 2006. What is IAQ? Indoor Air 16: 328–334.

Giese, M., U. Bauer-Doranth, C. Langebartels and H. Sandermann Jr. 1994. Detoxification of formaldehyde by the spider plant (*Chlorophytum comosum* L.) and by soybean (*Glycine max* L.) cell-suspension cultures. Plant Physiol. 104: 1301–1309.

Gilbert, O. L. 1968. Bryophytes as indicators of air pollution in the Tyne Valley. New Phytol. 67: 15–30.

Gilbert, O. L. 1971. Urban bryophyte communities in north east England Trans. Brit. Bryol. Soc. 6: 629–634.

Godish, T. 1990. Residential formaldehyde. Journal of Environmental Health 53(3): 34–37.

Godish, T. and C. Guindon. 1989. An assessment of botanical air purification as a formaldehyde mitigation measure under dynamic laboratory chamber conditions. Environ. Pollut. 61: 13–20.

Hartig, T., M. Mang and G. W. Evans. 1991. Restorative effects of natural environment experiences. Environment and Behavior 23: 3–26.

Herzog, T. R., A. M. Black, K. A. Fountaine and D. J. Knotts. 1997. Reflection and attentional recovery as distinctive benefits of restorative environments. J. Environ. Psychol. 17: 165–170.

Hong, J., J. S. Lee and C. H. Pak. 2005. Selection of indigenous plants tolerant to volatile organic compounds and their purifying mechanism in indoor environment. Kor. J. Hort. Sci. Technol. 23: 97–103.

Kondo, N. and H. Saji. 1992. Tolerance of plants to air pollutants. J. Japan Soc. Air Pollut. 27: 273–288.

Lim, Y. W., J. Y. Yang, H. H. Kim, Y. G. Lee, Y. S. Kim, S. K. Jang, J. R. Son, Y. M. Roh and D. C. Shin. 2006. Health risk assessment in terms of VOC at newly built apartment house. J. Kor. Soc. Indoor Environ. 3: 211–223.

Lohr, V. I. and C. H. Pearson-Mims. 1996. Particulate matter accumulation on horizontal surfaces in interiors: influence of foliage plants. Atmospheric Environ. 30: 2565–2568.

Orwell, R. L., R. A. Wood, M. D. Burchett, J. Tarran and F. Torpy. 2006. The potted-plant microorganism substantially reduces indoor air voc pollution: Laboratory study. Water, Air, Soil Pollut. 177: 59–80.

Park, S. Y. and K. J. Seong. 2007. Plant effects on indoor formaldehyde concentration. J. Kor. Environ. Sci. Soc. 16: 197–202.

Raza, S. H., G. Shylaja, M. S. R. Murthy and O. Bhagyalaksmi. 1991. The contribution of plants for CO_2 removal from indoor air. Environ. Int. 17: 343–347.

Seo, B. R., M. H. Jung, J. M. Jeon and H. S. Shin. 2006. The characteristics of aldehyde emission in new apartment houses. J. Kor. Soc. Indoor Environ. 3: 158–169.

Shibata, S. and N. Suzuki. 2001. Effects of indoor foliage plants on subject's recovery from mental fatigue. North American Journal of Psychology 3: 385–396.

Sullivan Jr., J. B., M. D. Van Ert, G. R. Krieger and B. O. Brooks. 2001. Indoor environmental quality and health. p. 669–704. In: J. B. Sullivan Jr. and G. R. Krieger (eds.). Clinical environmental health and toxic exposures (2nd ed., p). Lippincott Williams & Wilkins, a Walter Kluwer Co., Philadelphia, PA, USA.

Wolkoff, P. 2003. Trends in Europe to reduce the indoor air pollution of VOCs. Indoor Air 13 (Suppl. 6): 5–11.

Wood, R. A., R. L. Orwell, J. Tarran, F. Torpy and M. Burchett. 2002. Potted plant/growth media interactions in capacities for removal of volatiles from indoor air. J. Hort. Sci. Biotechnol. 77: 120–129.