Experimental Study on Variations of CO₂ Concentration in the Presence of Indoor Plants and Respiration of Experimental Animals

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Abstract. This study aims to suggest an improved experimental method to reveal the ability of indoor plants to reduce CO₂ concentrations, as well as to display the individual CO₂ reduction characteristics of various indoor plants in accordance with this improved method. In previous studies, experiments were conducted under the condition in which the CO₂ concentration in the experimental chamber is set only once to a high initial level of 1,000 ppm. However, in real conditions, CO₂ concentration gradually increases in a room after the occupants enter. Hence, the existing experimental method can be improved in view of “light saturation and CO₂ compensation”. Accordingly, in this study, the CO₂ reduction characteristics of indoor plants under 2 conditions used in the existing method of measurement (Case 1) and the condition in the new method, which considers that CO₂ concentration gradually increases through the respiration of experimental animals (Case 2)-were measured and compared against each other. For all plant samples, the level of CO₂ reduction was higher in Case 2 than in Case 1, and the rate of CO₂ reduction increases with time. The inflection point of CO₂ concentration appeared at leaf areas of 9,000 cm² in peace lily and areca palm, and 6,000 cm² in weeping fig.

Additional key words: CO₂ reduction quantity, compensation point, indoor air quality, respiration of experimental animals

Introduction

Previous studies have reported that urban residents spend more than 80% of their whole day indoors despite their busy and diversified lifestyles (Jenkins et al., 1992; Molhave et al., 2003; Orwell et al., 2004; US EPA, 2010; Wolkoff, 2003). Particularly for office workers, who stay for a long time in a single space, the quality of indoor air has a large influence on the condition of the human body. However, as most indoor air quality (IAQ) improvement methods suggested thus far (US EPA, 2011) require large energy consumption (Godish et al., 1989), their application ultimately and inevitably damage the balance among the components that provide comfort to humans. For this reason, interest in utilizing plants for passive methods such as cross-ventilating or mechanical air conditioning of the interior of buildings is increasing, as well as the number of researches reporting its efficacy.

From large trees that compose luxuriant forest to small plants that grow under the shade of these trees (which humans use as indoor plants under conditions of less-bright illumination), all plants create a microclimate environment around their leaves and roots for survival. Plants undergo photosynthesis from which nutritive elements are generated, using light, CO₂, and H₂O as raw materials (Wolverton, 1996). During photosynthesis, air pollutants are eliminated as the stomas of plants absorb the air pollutants together with CO₂ (Kondo et al., 1992). Most of the absorbed pollutants are used for plant growth (Chang et al., 2007; Winner, 1994). Moreover, plants eliminate air pollutants absorbed into the soil through the microorganisms in the rhizosphere (Orwell et al., 2004; Wood et al., 2002). Therefore, the natural survival activity of plants allows humans to live in a comfortable environment with fresh air.

Previous studies have suggested that plants eliminate volatile organic compounds such as benzene (Cornejo et al., 1999; NASA, 1989; Orwell, 2004; Yoo et al., 2006), ethylbenzene (Darlington, 2001), toluene (Cornejo et al., 1999; Darlington, 1989; Yoo et al., 2006), xylene (Darlington, 2001), and trichloroethylene (Cornejo et al., 1999; NASA, 1989), even formaldehyde (Giese et al., 1994; NASA, 1989). Plants have also been suggested to eliminate gas pollutants such as NOx (Fujii et al., 2005; Henrik, 1986; Wolverton, 1985), O₃ (Park et al., 1998), CO (Wolverton, 1985), and CO₂ (Fujii et al., 2005; Han et al., 1996; Lee, 2004; Oh et al., 2009), as well as
particulate matter (Lohr, 1996).

However, plants do not consistently maintain equivalent photosynthesis quantity [net photosynthesis quantity (NP)], and the apparent gross photosynthesis quantity (GP) varies depending on the environmental conditions. The formula for GP is given below.

Gross photosynthesis (GP) = Net Photosynthesis (NP) + Respiration (R)

If GP equals R, NP becomes zero. Relevant plants are considered to be at the compensation point, which is an indicator of the adaptability of a plant to the surrounding conditions. Although NP increases in proportion to the quantity of light, when the introduced light is small in quantity, in cases where variable levels of light are used, the reaction curve becomes horizontal. This means that another factor (normally CO₂ supply) besides the quantity of light limits photosynthesis. This condition is referred to as light saturation or CO₂ limitation (Ridge, 2008).

Photosynthesis generally varies in accordance with the balance of light quantity and CO₂ concentration in plant cells (Zeiger et al., 1982). That is, stronger light induces a higher photosynthetic rate and a lower concentration of CO₂ in the cells (Jarvis et al., 1981). If the CO₂ concentration is limited, the rates of stomatal conductance and photosynthesis also become limited (Farquhar et al., 1980; Hall et al., 1980; Tenhunen et al., 1984).

Oh et al. (2009) reported that plants adapted to low-light conditions showed no large difference in the quantity of CO₂ purification, even in the lower illumination intensity indoors (1,000 lx), which is below the compensation point (3,000 lx), if all other conditions are the same. Kil et al. (2008) also suggests that the quantity of photosynthesis and formaldehyde elimination is influenced by the presence or absence of light. However, the intensity of illumination almost has no influence on these factors. In reality, light strength inside offices is regulated by criteria on the illumination intensity on the work surface in many countries [i.e., 300 - 1,000 lx; in Korea, provision 3011 of KSA (Korean Standards Association 1991) is being implemented]. For indoor plants that are already adapted to low and homogeneous illumination conditions, CO₂ concentration becomes the major limitation factor for photosynthesis.

CO₂, which is generated by individuals occupying a space and by combustion apparatus, is an essential as well as limiting factor, as described previously. CO₂ is known to be an indoor air pollutant and an indicator of IAQ (Wargocki et al., 2000). Although CO₂ does not inflict harm on the human body by itself, an increase in its concentration sometimes indicates the deterioration of the normal thermal condition or the increase in different pollutant elements. High CO₂ concentra-

Regardless of the area, period, and time of inspection; air-conditioning systems; presence or absence of occupants; and nature of the office environment, the results of actual measurements of CO₂ inside offices conducted in many countries after the year 2002 show that CO₂ quantity is within international regulation criteria (1,000 ppm by ASHRAE) or the regulation criteria of the respective country (e.g., in Korea, the criteria for IAQ in facilities of mass use, as set by the Rule on Industrial Health Criteria, is 1,000 ppm) (Gupta et al., 2007; Hong et al., 2008; Jeong et al., 2006, 2007; Mui et al., 2008; Oh et al., 2010; Park et al., 2000; Sekhar et al., 2002, 2003; Wargocki et al., 2002). However, Kim et al. (1993) reported that more than half of the respondents of their questionnaire experienced SBS symptoms. Moreover, Lee et al. (1995) and Gupta et al. (2007) reported many cases in which the measured quantity of CO₂ satisfied the stipulated regulation criteria but not the occupants staying in the indoor space. In this regard, it seems that continuous reduction in CO₂ concentration is needed even for environments having a CO₂ concentration lower than the regulated values. Besides playing a role in the elimination of indoor air pollutants, indoor plants also contribute to conserving energy, providing a positive psychological effect on individuals, and improving the overall quality of indoor air.

However, since the initial study by NASA (1980), most of the studies on the role of indoor plants in the improvement of IAQ in many countries were conducted in which the initial concentration of pollutants was set as the general air-quality criteria regardless of the actual pattern of pollutant generation. This existing research method may be appropriate for comparison of IAQ improvement among various kinds of plants, or among various kinds of plants in diverse environmental conditions. However, it is inappropriate for real office conditions for which the means of maintaining CO₂ levels are different.

In the studies by Wood et al. (2006) and Kim et al. (2009), in which the plants were placed in real office space, the suggested volume of plants needed to maintain appropriate pollutant concentration was smaller than that suggested by previous studies in which experiments were performed in a chamber. This result was confirmed by a previous study (Oh et al., 2010) that used peace lily as the experimental sample. That is, CO₂ reduction seems higher when the CO₂ concentration is continuously increasing, such as in real space, compared to experiments in which the CO₂ concentration is set only once initially to a high extent, when the other environment conditions related to photosynthesis of plants are the same. Moreover, this difference in the reduction of CO₂ quantity increased with measurement time.

Accordingly, this study aims to reveal the air-purification