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Method for Evaluating Efficiency in Removing Perceived Air Pollutants by Air Cleaners

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Abstract

The results of subjective experiments to evaluate the efficiency of portable air cleaners for perceived air pollutants generated by tobacco smoke are described. The efficiency of the five types of air cleaners to remove perceived air pollutants was evaluated by a panel using the decipol unit, and the efficiency to remove particulate was evaluated from concentrations of particulate. It was found that the efficiency of the air cleaner in removing perceived air pollutants was quite different from that in removing particulate.

KEY WORDS:
Tobacco smoke, Perceived air quality, Air cleaner, Trained panel

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Introduction

Environmental tobacco smoke is a common indoor air pollutant. One strategy for controlling indoor air quality polluted by tobacco smoke in residences that is receiving increased attention is air cleaning (Offermann et al., 1985). Air cleaners are available as both in-duct devices, integrated with mechanical air heating/cooling system and as unducted portable devices. The latter room-size air cleaners, which are designed to remove smoke, noxious gases, particulate, and odors in occupied spaces, are increasing rapidly as people tend to reduce air change rate (Hollowell et al., 1979) for conserving energy. The efficiency of such air cleaners depends on a complex set of dynamic variables, i.e., air pollution source strength, type of pollution source, ventilation rate, adaptation to perceived air pollutants, and other physical and psychological variables (Whitby et al., 1983).

Yaglou et al. (1936) reported that the odor intensity caused by human bioeffluents was greatly reduced when the air passed along the wet surfaces in the recirculation loop of an air conditioning system.

Clausen et al. (1987) studied air polluted by tobacco smoke, with and without an air washer in operation in the recirculation loop of the air conditioning system. They found that the air when the air washer was in operation was perceived as fresher and more acceptable than without the air washer, though the odor intensity did not decrease with the air washer in operation.

Cain et al. (1987) reported that electrostatic precipitation of the particle matter of tobacco smoke diminished the magnitude of irritation and odor consistently, though not dramatically, and that it had a less consistent effect on dissatisfaction.

However, few studies on evaluating the efficiency of room-size, portable air cleaners for perceived air quality have been completed. In this experiment five types of room-size air cleaners were used to determine the removal efficiency of perceived air pollutants and particulate both generated from tobacco smoke. The perceived air quality voted by occupants exposed to tobacco smoke, was compared with that voted by the trained panel, who were visitors.

Experimental Method

Test Facility

Tobacco smoke generated by a smoker was used as air pollution source in the indoor air quality test chamber as shown in Figure 1. The volume of the chamber is 11.7 m^3. The smoker (experimenter), who occupied the chamber at the position shown in Figure 1 beforehand, made one cigarette of tobacco (brand "Mild seven") burn continuously during the whole period of experiment. The air change rate of the chamber was controlled by variable speed fans and four stirring fans were installed for mixing the air. A measuring point and tobacco burning point were set up at 110 cm height in the chamber (see Figure 1). The judges sniffed the air at the measuring point of the chamber through a sniffing diffuser.

Experimental Types

Table 1 shows six different types of air cleaners used for controlling indoor air quality polluted by tobacco smoke: Type A with an air cleaner of filter-filtration type, Type B with aqua type, Type C with odor cleaning filter-filtration type, Type D with honeycomb electrostatic type, Type E with electrostatic type, and Type F without air cleaner and with double the amount of outdoor ventilation. The recirculation rate through the air cleaner and the ventilation rate of the chamber are also given in Table 1.

Experimental Procedure

Figure 2 shows the experimental procedure. Each experiment was divided into two sessions: Tobacco smoke was generated withouth operation of the air cleaner in Session 1. The concentration of particulate, CO, and perceived air pollution level increased in this session as shown in Figure 2. Session 1 continued until the steady-state level of perceived air pollution in decipol, particulate, and CO was reached at the measuring point.

In Session 2, the air cleaner was in operation with a constant amount of air flow. The concentration of contaminants was planned to decrease in this session. Then the experiment was continued until the steady-state level was reached again.

Thirty-six subjects served as judges, and 24 other people served as occupants. Before the experiment the judges completed training to familiarize them with the reference gas of acetone (2, 5, 10, 20 decipol level). A trained panel (Bluyssen et al., 1989) of six judges and four occupants participated in each experiment. One at a time the judges went to the sniffing station where they evaluated air from the chamber. Immediately after sniffing the air, the

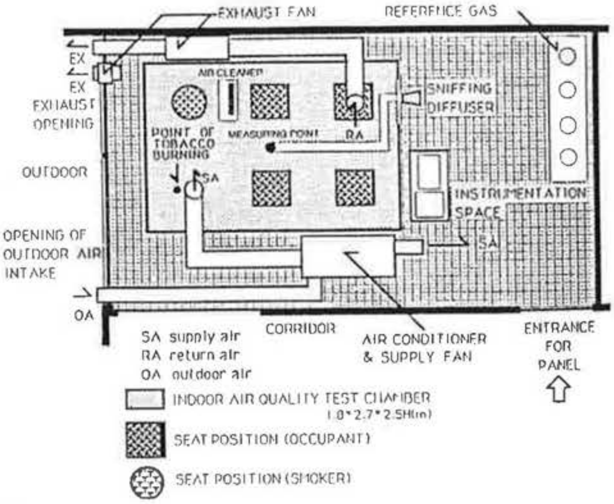

Fig. 1 Floor plan of the indoor air quality test chamber.

Table 1 Experimental types

Type	Air cleaner	Recirculation rate through air cleaner [l/s]	Ventilation rate of chamber [l/s]
A	Filter-filtration type	30.56	30.00
B	Aqua type	33.33	30.00
C	Odor cleaning filter-filtration type	31.67	30.00
D	Honeycomb electrostatic type	33.33	30.00
E	Electrostatic type	33.33	30.00
F	–	–	60.00

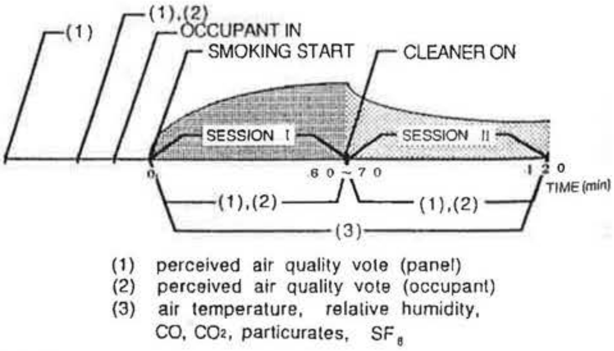

Fig. 2 Experimental procedure.

judge rated the perceived air quality in decipol (Fanger, 1988) and the odor intensity on Yaglou's scale: 0) No odor, 1) Slight odor, 2) Moderate odor, 3) Strong odor, 4) Very strong odor, 5) Overpowering odor. Each judge performed the one-minute voting every 10 minutes to obtain the immediate impression of the air.

The impression of the air felt by the occupants, who may have been adapted, was also investigated. The occupants rated the odor intensity, eye irritation on Cain's scale (Cain et al., 1987), and acceptability every 10 minutes during the period of experiment. Following numbers are assigned to the acceptability scale (Gunnarsen and Fanger, 1988): (1) Clearly acceptable, (0) Neutral, (−1) Clearly not acceptable. Table 2 shows the questionnaire for occupants. These number are assigned to Cain's eye irritation scale: (0) No irritation, (1) slight irritation, (2) Moderate irritation, (3) Strong irritation, (4) Very strong irritation, (5) Overpowering irritation. The steady-state concentration of tobacco smoke with corresponding levels of CO of about 4.5 ppm above outdoor air was tested without the air cleaner in operation, in Session I. Air temperature was kept constant at 24 °C, and the relative humidity between 40 and 60%. The air change rate was determined by decay of SF_6 concentration.

Table 2 Questionnaire for occupants

Question 1
How strong is the odor?
Please mark on the scale.
- No odor
- Slight odor
- Moderate odor
- Strong odor
- Very strong odor
- Overpowering odor

Question 2
Imagine that you frequently during daily work were exposed to the air in this room. How acceptable do you find the air?
Please mark on the scale.
- Clearly acceptable
- Just acceptable
- Just not acceptable
- Clearly not acceptable

Question 3
Please mark the line to indicate magnitude of eye irritation:
Eye
- No irritation
- Slight irritation
- Moderate irritation
- Strong irritation
- Very strong irritation
- Overpowering irritation

Results

Relationship Between Perceived Air Quality Evaluated by the Panel and Particulate/CO Concentration

Figure 3 shows the mean odor intensity and the mean perceived air quality by the trained panel as a function of the particulate concentration above outdoor air for all air cleaners. The data of the whole experiment, i.e., Session 1 and Session 2, were used for this figure based on an assumption that air cleaners did not change quality of air pollutants from tobacco smoke. Since the data were classified by the particulate concentration level, each plot represents the mean value of votes included in each level of range and includes different number of votes. Size of the plots is proportional to number of votes included in each level. The correlation coefficient (R) between the mean odor intensity and the particulate and that between the mean perceived air quality and

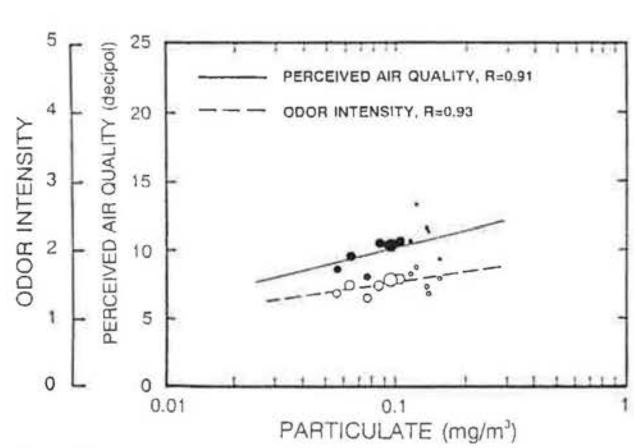

Fig. 3 Mean odor intensity and mean perceived air quality as a function of particulate concentration above outdoor air.

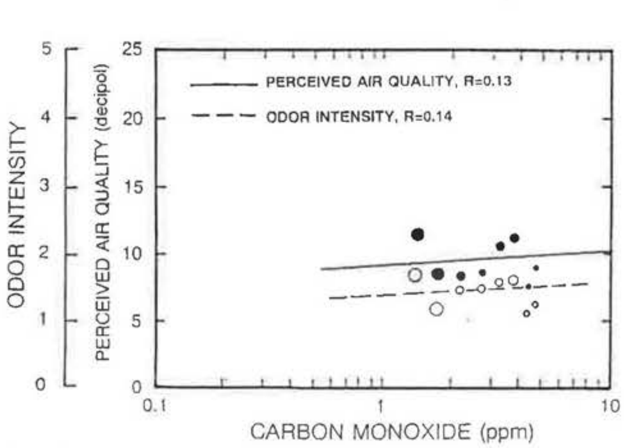

Fig. 4 Mean odor intensity and mean perceived air quality as a function of CO concentration above outdoor air.

the particulate were both rather high, though the slope of regression line for the decipol values was slightly steeper than that for the odor intensity.

The mean odor intensity and the mean perceived air quality by the panel as a function of the CO concentration during the whole period of experiment are shown in Figure 4. Since a different number of votes were obtained at each CO concentration level, the difference of the number is shown as size of plots. The correlation coefficient between the mean odor intensity and the CO concentration and that between the mean perceived air quality and the CO were both low, and the both slopes of the regression line were very low. Clausen (1988) reported good correlation between dissatisfaction and CO concentration. However, the plots in Figure 4 did not indicate a good correlation between them.

Relationship Between Perceived Air Quality Evaluated by Occupants and That by the Trained Panel

Figure 5 shows the relationship between the mean odor intensity voted by the occupants and that by the trained panel. As the data were classified by the level of votes by occupants, each plot in Figure 5 includes different number of votes by the panel. Therefore, the difference in the number of votes by the panel are represented as size of plots. It was found that the odor intensity voted by the occupants was lower than that by the panel at the same conditions of air. The odor intensity of 1.3, which causes 20% dissatisfaction (Kimura et al., 1988), voted by the panel corresponded to that of 1.0 by the occupants. The olfactory sense of the occupants, which is sensitive to odors, may have been adapted. For predicting the perceived air quality voted by panel by using the relationship between the odor intensity voted by occupants and that by the panel as shown in Figure 5, the time-course of exposure will have to be considered.

Figure 6 shows the relationship between the mean eye irritation voted by the occupants and the mean perceived air quality voted by the panel. The data were classified by the level of eye irritation. Since each plot includes different numbers of votes of perceived air quality, size of plot is proportional to number of votes. Engen (1986) described that tobacco smoke contains many irritative agents which may stimulate the general chemical sense. In this experiment, eye irritation scale was selected to estimate human chemical sense against tobacco smoke. It seems possible to predict eye irritation of occupants using the vote in decipol by the panel.

The relationship between the mean acceptability voted by the occupants and the perceived air quality by the panel is presented in Figure 7. The data were classified by the level of acceptability. Each plot represents number of votes of perceived air quality. The acceptability scale was used for investigating both the olfactory and chemical senses. It seems also possible to predict the acceptability to the occupants from the vote in decipol by the panel.

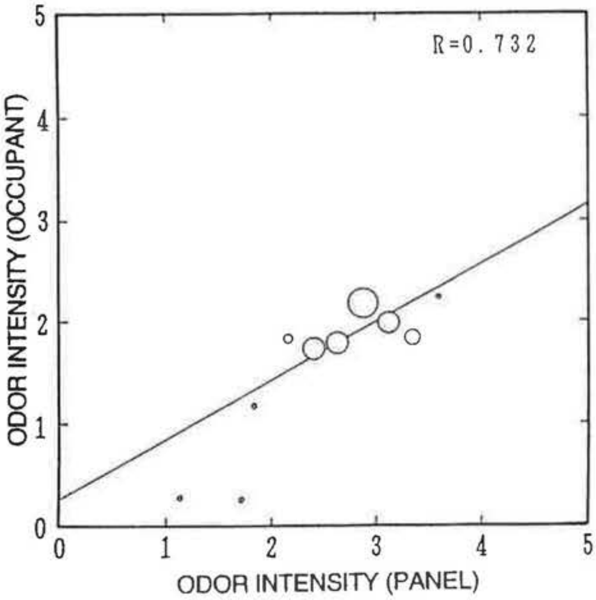

Fig. 5 Relationship between the mean odor intensity voted by occupants and that by panel.

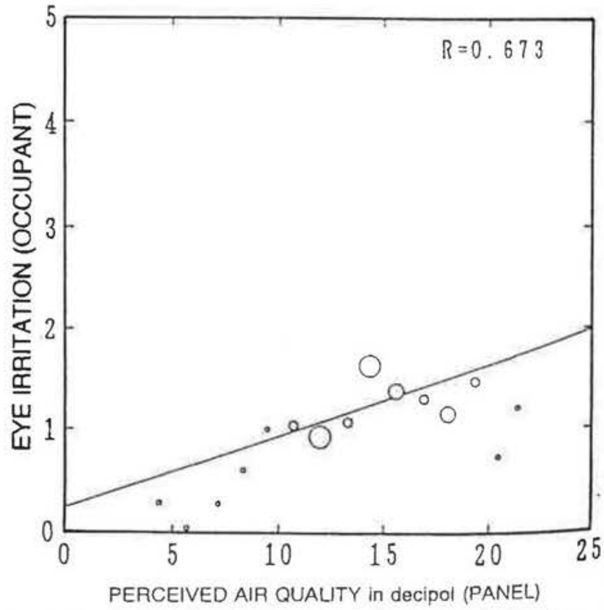

Fig. 6 Relationship between the mean eye irritation voted by occupants and the mean perceived air quality in decipol by panel.

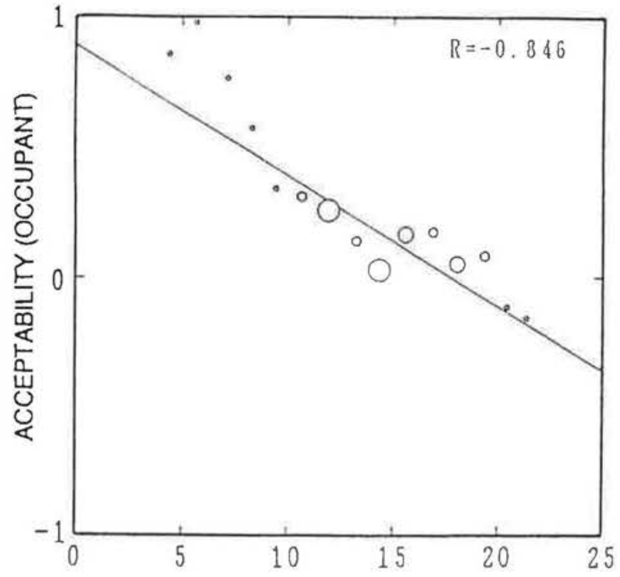

Fig. 7 Relationship between the mean acceptability voted by occupants and the mean perceived air quality in decipol by panel.

Efficiency of Air Cleaners in Removing Particulate

When an air cleaner is being operated in a well-mixed room of volume V, with ventilation at a rate Q, and a particulate source strength G_p, the mass balance for particulate can be expressed by:

$$V\frac{dC_i}{dt} = G_p - Q \cdot C_i - \eta_p \cdot Q_r \cdot C_i \qquad (1)$$

where

C_i: indoor concentration of particulate above outdoor air at any time t [mg/m^3]
Q: ventilation rate of a room [m^3/h]
Q_r: recirculation rate through an air cleaner [m^3/h]
G_p: particulate source strength [mg/h]
V: room volume [m^3]
η_p: efficiency of air cleaner in removing particulate, fraction

When the steady-state level of the particulate concentration is reached, equation (1) approaches the following:

In this experiment, the particulate source strength can be calculated in the following way:

$$C_i = \frac{G_p}{Q + \eta_p \cdot Q_r} \qquad (2)$$

$$G_p = Q \cdot C_{i1} \qquad (3)$$

where

C_{i1}: indoor concentration of particulate above outdoor air at steady-state level in Session 1 (without air cleaner in operation) [mg/m^3]

The efficiency, η_p, is then determined from the following equation derived from equation (2) and (3).

$$\eta_p = \frac{Q \cdot C_{i1}}{Q_r \cdot C_{i2}} - \frac{Q}{Q_r} \qquad (4)$$

$$= \frac{Q}{Q_r} \cdot \left[\frac{C_{i1}}{C_{i2}} - 1\right] \qquad (5)$$

where

C_{i2}: indoor concentration of particulate above outdoor air at steady-state level in Session 2 (with air cleaner in operation) [mg/m^3]

Table 3 shows the results of the steady-state concentration of particulate in Sessions 1 and 2, and the efficiency of the air cleaners in removing particulate. The mean efficiency of the five types of air cleaners was 0.62.

Efficiency of Air Cleaners in Removing Perceived Air Pollutants

When an air cleaner is operated with ventilation at a rate q and perceived air pollution source strength G, the steady-state perceived air quality is expressed as:

$$PAQ = 10 \cdot \frac{G}{q + \eta_d \cdot q_r} \qquad (6)$$

where

PAQ: perceived air quality above empty chamber level [decipol] (perceived air quality of empty chamber was 2 decipol)

Table 3 Steady-state concentration of particulate and efficiency of air cleaner in removing particulate

Experimental type	Steady-state particulate concentration in Session 1 [mg/m^3]	Steady-state particulate concentration in Session 2 [mg/m^3]	Efficiency of air cleaner against particulate
A	0.133	0.079	0.652
B	0.087	0.070	0.212
C	0.127	0.067	0.830
D	0.088	0.058	0.451
E	0.112	0.053	0.949
F	0.056	–	–

Table 4 Steady-state perceived air pollution level in decipol in Session 1 and Session 2, and efficiency of air cleaner in removing perceived air pollutants

Experimental type	Steady-state perceived air quality in Session 1 [decipol]	Steady-state perceived air quality in Session 2 [decipol]	Efficiency of air cleaner against perceived air pollutants
A	11.9	9.6	0.23
B	10.5	7.6	0.34
C	10.4	8.8	0.17
D	6.5	5.0	0.25
E	10.8	9.4	0.13
F	8.4	–	–

q: ventilation rate [l/s]
q_r: recirculation rate through an air cleaner [l/s]
G: perceived air pollution source strength [olf]
η_d: efficiency of air cleaner against perceived air pollutants, fraction

Then the efficiency, η_d, was determined:

$$\eta_d = \frac{q}{q_r} \cdot \left[\frac{PAQ_1}{PAQ_2} - 1\right] \quad (7)$$

where
PAQ_1: perceived air quality above empty chamber level at steady-state level in Session 1 [decipol]
PAQ_2: perceived air quality above empty chamber level at steady-state level in Session 2 [decipol]

Table 4 shows the steady-state perceived air pollution level in decipol in Sessions 1 and 2, and the efficiency of the air cleaners in removing perceived air pollutants. Since the steady-state perceived air quality was determined by non-linear regression analysis with each vote, test of significant difference between the perceived air quality in Session 1 and that in Session 2 was not conducted. The efficiency of each type of air cleaner in removing perceived air pollutants was surprisingly low compared with that against particulate, and the mean efficiency in removing perceived air pollutants turned out to be only 0.22.

Discussion

In this study, we used the judges and occupants regardless of their smoking habit, since only the ratio of the perceived air quality in Session 1 to that in Session 2 was needed. As judges who had smoking habit tended to vote the lower perceived air quality than those by non-smoker judges, smoking habit should be considered for selection of subjects in experiments where the absolute values of perceived air quality are needed.

It was found that type E, an electrostatic type with four layers of filter showing highest JIS (Japanese Industrial Standard) Dust Spot Efficiency represented the highest efficiency in removing particulate, and type B, an aqua type mainly for odor removal showed the lowest. However, type E represented the lowest efficiency in removing perceived air pollutants and type B showed the highest. There was a large difference between the efficiencies of the air cleaner in removing perceived air pollutants and those in removing particulate (Table 3 and Table 4). This results agree with the results of Clausen et al. (1987, 1988) where they found that cleaning tobacco smoke for particulate had little impact on perceived air quality. Perceived air pollutants from tobacco smoke might not depend on particle-phase.

Conclusions

Five different types of unducted (room-size) air cleaners were examined in an air quality test chamber, using trained panel, for evaluating the efficiency of air cleaners in removing tobacco smoke. The following conclusions were obtained:

1) The correlation between the particulate concentration and the perceived air pollution in decipol, and that between the particulate and the odor intensity voted by the panel were found both high.
2) A relationship between the sensation of the air voted by the occupants and that by the panel was found. It seems possible to predict acceptability, eye irritation, and odor intensity as if voted by occupants, using the perceived air quality in decipol voted by the trained panel.
3) The method for estimating the efficiency of air cleaners in removing perceived air pollutants was proposed. It was found that the efficiency of the air cleaner in removing perceived air pollutants was quite different from that in removing particulate.

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