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Variation of clean air delivery rate and effective air cleaning ratio of room air cleaning devices

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ABSTRACT

Air cleaners have been normally used to remove airborne particles from indoor air, and these devices are normally rated according to their clean air delivery rate (CADR), which is a measure of the delivery of contaminant-free air. This study evaluated and compared the performance of room air cleaning devices in removing submicron-sized particles. Most of the CADRs that were experimentally obtained were lower than that stated by the manufacturer. The difference between the experimental measurements and the device specifications gradually increases as the CADR increased. For the same air cleaning device, the experimental CADR decreased as the size of the test chamber increased. The effective air cleaning ratio (EACR) was newly defined to provide an accurate measure of the CADR. The EACR is the ratio of the real CADR to the stated CADR. The experiments and simulations revealed that the EACR of the air cleaning devices was in the range of 0.70–0.83. The ECAR is little changed with respect to the size of the test chamber and the flow rate of the air cleaning devices, unlike the experimental CADR. The real CADR is affected by the filtration efficiency, the flow rate, and the design of the air cleaning device as well as the size of the test particles. The real CADR decreases as the particle size increases. Therefore, the recommended CADR of air cleaning devices for use in facilities with sensitive populations or hospitals must be higher than that for general purpose use.

1. Introduction

Room air cleaning devices have been used to control airborne particles in indoor air, and in this way to reduce human mortality and morbidity. Various technologies can be used for such devices, including HEPA filters, electrostatic precipitators (ESPs), ion generators, composite filters comprised of activated carbon and HEPA filters, and so on [1,2]. Room air cleaning devices are generally rated according to their clean air delivery rate (CADR), which is defined as the measure of the delivery of contaminant-free air [3]. The CADR is expressed as the product of the volume of the test chamber and the difference in the particle removal rates when the air cleaning device is in operation and that of the natural decay rate [3,4]. The CADRs have been evaluated in a range from near zero to about 12 m^3/min, depending on the air cleaning device type and the size of the particles being considered [5,6]. Room air cleaning devices with HEPA filters and ESPs are typically at the high end of the CADR range [1,2,5–8].

Recently, the average CADR of room air cleaning devices sold in Korea has had a tendency to increase due to the development of multi-functional home devices, such as room air conditioners and portable humidifiers/dehumidifiers that include high-efficiency particulate air filters. Multi-functional home devices generally require the cleaning area to be as large as that covered by the cooling, humidification, and de-humidification functions.

However, the standards used to measure the performance of the room air cleaning devices have defined limits in terms of the measurability [3,4]. For submicron-sized particles, the defined limit for CADR in the Association of Home Appliance Manufacturers' (AHAM) standard is of 10.8 m^3/min [3]. Due to this limitation, the performance test for room air cleaning devices with a CADR higher than 10.8 m^3/min can't be carried out, and it is therefore necessary to develop new measures. It is common sense that the removal rate of an air cleaning device cannot be accurately evaluated when an air cleaning device with a higher CADR is operated in a small-sized chamber. Therefore, the size of the test chamber was considered to be enlarged from 30 m^3 to 50 m^3 to test the air cleaning devices with a CADR higher than 10.8 m^3/min in the Korea Air Cleaning Association (KACA).

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This study evaluates and compares the performance of room air cleaning devices in the removal of submicron-sized particles for two chambers of different sizes. The CADRs were measured, and the difference in particle removal rates was investigated for some measurement points. The effective air cleaning ratio (EACR) was defined as a new measure that can accurately describe the real CADR of the device, and it was investigated against variations in the size of the test chamber and the type, flow rate, and discharge angle of the room air cleaner. Also, the real CADR was evaluated according to filtration efficiency, flow rate, and design of the air cleaning device and the size of the test particles.

2. Research methods

2.1. Experimental measurement

The room air cleaning devices were tested according to the KACA standard [4] with two different volumes for the chamber. The dimensions of the chambers were 4.0 m (L) × 3.0 m (D) × 2.5 m (H) and 5.0 m (L) × 4.0 m (D) × 2.5 m (H), respectively. The air cleaning devices were placed in the center of the chambers, and an optical particle counter (Grimm, Model 1.109) was used to measure the concentration decay of 0.3 μm-sized particles. Potassium chloride (KCl) was used for the test particles, and the initial concentrations were of 10^8–10^9 particles/m^3. The sampling time was set to 1 min and all data were sequentially sampled for over 20 min Fig. 1 shows the schematic of the test chamber specified in KACA to evaluate the performance of the air cleaning devices.

Twenty eight room air cleaning devices with high-efficiency grade filters or ESPs were used to investigate the CADRs in removing submicron-sized particles. All room air cleaning devices were obtained from their manufacturer and were in a new condition. The devices were mainly table-type and stand-alone type, and the airflow rates through the air cleaning devices were set at maximum.

In terms of the performance metric for room air cleaning devices, CADR was used as follows [3],

$$\mathrm{CADR} = V(k_e - k_n) \tag{1}$$

where, V is the volume of the test chamber (m^3), k_e is the particle decay rate with the air cleaning device in operation (min^{-1}), and k_n is the natural decay rate (min^{-1}). The CADR can be generally obtained from the chamber test by using Eq. (1), and it is hereafter referred to as the "experimental CADR."

Also, many manufacturers simply define the CADR as the product of the filtration efficiency and the volumetric airflow through the device. This represents the amount of cleaned air transferred into a space through the air cleaning device. For this definition, the volume of the space and the mixing characteristics of the air cleaning device are not considered. Hereafter, this measure is referred to as the "stated CADR" in order to avoid confusion.

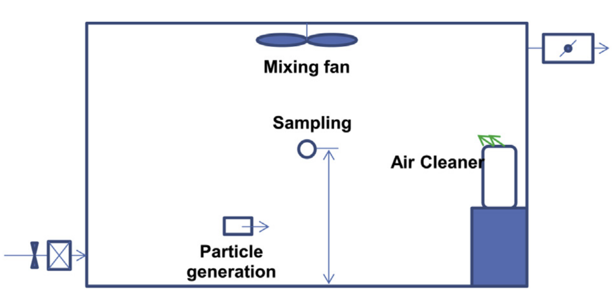

Fig. 1. Schematic of the test chamber specified in KACA to evaluate the performance of the air cleaning devices.

2.2. CFD simulation

Generally, the particle concentrations are not evenly distributed in the space where an air cleaning device is in operation since the device can't uniformly deliver air over the entire space. Also, an uneven distribution of the particle concentration can occur in the chamber depending on the design of the device. Therefore, the experimental CADR measured at the center of the test chamber would not represent the mean value. A CFD simulation was used to overcome these experimental limitations, and the CADRs were investigated with respect to various measures, including the airflow rate, discharge angle, and the design factor.

In the CFD simulation, the flow was assumed to be steady and incompressible in the space. The standard k-ε turbulence model was used, and the airflow transport was described by the following the time-averaged Navier-Stokes equation:

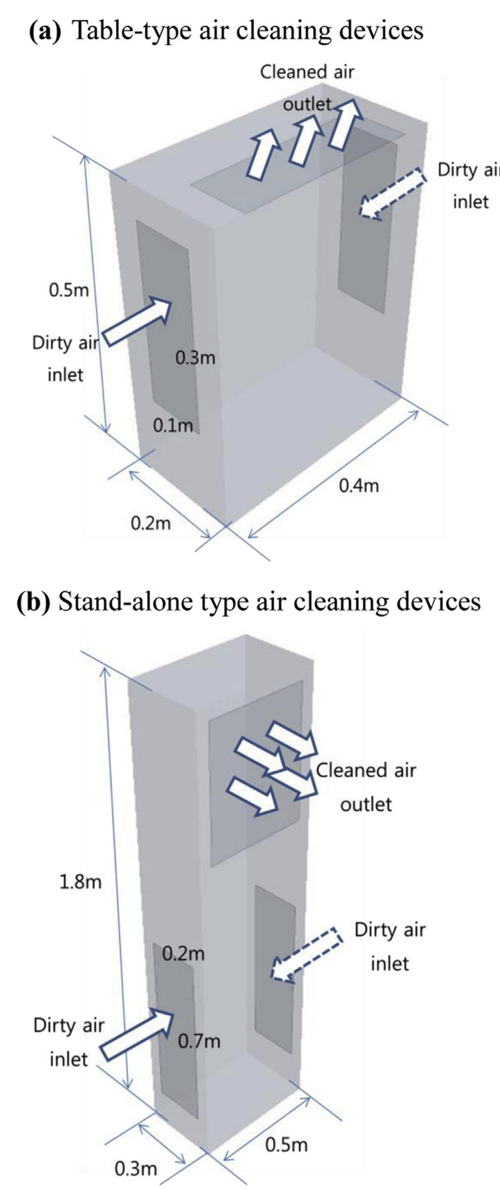

Fig. 2. Table-type and stand-alone type air cleaning devices modeled in the simulation (a) Table-type air cleaning devices (b) Stand-alone type air cleaning devices.