EXPERIMENTAL EVALUATION OF CIGARETTE SMOKE REMOVAL PERFORMANCE OF VARIOUS INDOOR AIR CLEANING DEVICES

Muhsin Kılıç*[1], Mustafa Mutlu**, Ayşe Fidan Altun*
[1]Author for correspondence
*Bursa Uludag University, Departmant of Mechanical Engineering, Bursa,Turkey
** Bursa Uludag University, Yenisehir Ibrahim Orhan Vocational School Bursa,Turkey
E-mail: mkilic@uludag.edu.tr

ABSTRACT

Air cleaning devices (ACD) with many different specifications are used indoors to improve air quality and remove pollutants from the indoor environment. With the Covid 19 pandemic, the use of these devices has increased significantly. Many people continue to smoke indoors while using these devices. The performance of ACDs for cleaning cigarette smoke and their effects on indoor air quality is not well known. In this study, the cigarette smoke cleaning performance of four different ACDs in a room where ambient conditions can be controlled was experimentally investigated. While two of these devices work with the ultra violet beam (UV-C) cleaning principle, the other two clean the indoor using different air filters. CO_2, VOC, CH_2O, PM10 and PM2.5 measurements were made during the experiments to determine the concentration values change of these pollutants over time. It has been observed that filtered ACDs more effectively remove particulate matter from the environment than devices operating with the UV-C principle. Besides, it has been found that UV-C devices do not change the VOC concentration in the environment. It has been also noticed that different air cleaning technologies used in air purification devices have other by products on the indoor air. Reported measurement results are compared and discussed.

INTRODUCTION

Many people work in closed environments and spend most of their time in offices. People with cigarette addiction show smoking behaviour even in their offices. Cigarette smoke has serious and deadly health effects [1], and governments restrict its use in public places. Besides, with the pandemic's effect, air cleaning devices' usage increases [2]. End users also use these devices to clean the ambient air from cigarette smoke. Therefore, many researchers have used cigarette smoke to evaluate air cleaning devices' performance[3], [4].

The most important pollutants emitted from cigarette smoke are PM2.5 and PM10 particulate matter [5]. While there are studies declaring that air cleaning devices are effective in reducing PM2.5 concentration [6]–[8]. However, there are some studies reporting that ACDs are not able to clean air in aspects of PM2.5 concentrations [9]. Huang and Kim [10] found that ACDs were successful in removing particulate matter from the environment, but were not effective in reducing air nicotine and urine cotinine concentrations. Since cigarette smoke is an important pollutant, special air cleaning devices are developed for this pollutant [11]–[14].

Although cigarette smoke is a vital pollutant, the cleaning performance of different ACD is not detailed. In particular, the cigarette smoke cleaning performance of UV cleaning devices is poorly understood. In this study, the performance of four different ACDs, two of which are UV cleaning devices, in removing cigarette smoke from the room was experimentally investigated. Cigarette smoke in the test room with a 30 m^3 volume was removed by operating the ACDs. VOC, PM2.5, PM10, CH_2O and CO_2 measurements had been made during experiments. The experimental data showed that the tested ACDs were insufficient to remove the VOC and CH_2O pollutants emitted from cigarette smoke from the environment. It has been observed that the filtered ACD can only remove PM10 and PM2.5 contaminants from the environment. Moreover, CO_2 concentration does not increase by lighting a cigarette.

Consequently, it has been seen that it is not possible to remove all pollutants in the environment emitted from cigarette smoke with ACDs that used in this study. Different filtration techniques should be investigated in order to remove cigarette-borne gaseous pollutants from the environment.

EXPERIMENTAL SETUP

A room that had internal surfaces made of stainless steel with interior dimensions of 3×3.75×2.7 m was used in measurements (Figure 1). Air is taken into the room by conditioning and passing through the HEPA filters through the ceiling's blowing vent. There is also a suction vent in the room to discharge the air to the outside. There is a propeller in the room to ensure that the pollutants are mixed homogeneously.



Figure 1 View of test room and experimental design

While there is an air purifying device on one wall of the room, measuring instruments are placed on the wall opposite the device. The cigarette was lit in the middle of the room (Figure 1). During the air cleaning process, CH_2O, VOC, PM10, PM2.5 and CO_2 measurements were made. The properties of the sensors are given in Table 1.

Table 1 Specifications of pollutants measuring probes

Sensors	Sensor Type	Range	Accuracy	Resolution
CH_2O	Gas Sensitive Electrochemical	0 - 10 ppm	<∓0.05ppm 0 - 0.5 ppm <∓10% 0.5 - 10 ppm	0.01 ppm
VOC	Photo Ionization Detector	0 - 30 ppm	<∓0.02ppm + 10%	0.01 ppm
PM10	Laser Particle Counter	0.001 - 1.000 mg/m^3	<∓0.005 mg/m^3 + 15%	0.001 mg/m^3
PM2.5	Laser Particle Counter	0.001 - 1.000 mg/m^3	<∓0.005 mg/m^3 + 15%	0.001 mg/m^3
CO_2	Non-dispersive Infra-red	0 - 5000 ppm	<∓20 ppm + 5%	1 ppm

EXPERIMENTAL PROCEDURE

Before the measurements started, a 15-minute cleaning process was applied to ensure that the room air was immaculate. During this process, the door was kept closed and the air taken from outside was passed through the HEPA filter. Although the fresh air taken from outside is adjusted to 20°C, it heats up to 25°C at the beginning of the cleaning process due to the algorithms of the conditioning device. During the cleaning process, the temperature of the air does not vary much. The average temperature was calculated as 20.49°C and the maximum temperature was measured as 23.3°C. A similar change was observed in the relative humidity of the air. During the cleaning process, the average relative humidity was determined to be 33.31%. At the same time, the air inside the room is thrown out through the suction grille. The propeller in the room has also been switched on. After the cleaning process, the clean air intake and air suction fans were turned off and the cigarette was lit. During this time, the propeller was operated to ensure that the pollutants are homogeneously distributed throughout the room. The cigarette burns for about 8 minutes. When the cigarette goes out, the propeller is also turned off and the ACD is operated. Measurements are taken for 40 minutes after the ACD is turned on. One measure covers all three steps and takes about 63 minutes. Normalized values were obtained with Eq.1 for each pollutant to compare ACDs.

$$\Phi^{**} = \frac{\Phi_i - \Phi_{min}}{\Phi_{max} - \Phi_{min}} \quad (1)$$

In order to demonstrate the effectiveness of the devices, a case without using an air cleaner was also tested and presented for comparison. Thus, the normal decay characteristic of pollutants was determined.

AIR CLEANING DEVICES

In this study, two different UV-C ACDs and one filtered ACD were used. Illustrations of devices were given in Figure 2. The air cleaning performance of UV-C ACDs is highly dependent on the properties of the UV lamps used. The characteristics of the lamps in these devices were given in Table 2. Although the wavelengths are given 254 nm in both devices, these values indicate the dominant radiation wavelength. While UV intensity of ACD1 at 254 nm wavelength is given 150 $\mu W/cm^2$, radiation power of ACD2 between 200 and 280 nm is given 4.9 W.



Figure 2 View of cleaning devices used in experiments

Table 2 Properties of UV lamps

	Power (W)	Wavelength (nm)	Lamp Voltage (V)	Lamp Current (A)	Length (m)	Diameter (m)
ACD1	65	254	98	0.425	0.843	0.015
ACD2	15	254	55	0.33	0.438	0.026

The device flow rates were obtained by measuring the air velocities in the device's blowing position in the experiments. ACD1 has one axial fan, while ACD2 has two fans. ACD3 has one radial fan. Testo 435 data logger and 0635/1535 air velocity measuring probe were used to determine devices' volumetric flow rate. The specifications of this device were given in Table 3. According to these measurements, ACD1 and ACD2 flows are calculated as 97 m^3/h and 131 m^3/h, respectively. The flow rate of ACD3 varies between 175 - 551 m^3/h, depending on the fan level.

Table 3 Specifications of air velocity measuring probe

	Range	Accuracy
Temperature	-20°C - 70°C	∓0.3 °C
Humidity	0 - 100%	∓0.2 %
Velocity	0 - 20 m/s	∓0.3 m/s

RESULTS

When the pollutant concentration variations by time are examined, the normalized concentration values fall to zero at the end of the cleaning process. That is, the lowest contaminant concentration values were measured at the end of the cleaning process. The maximum contaminant concentration was measured at the time the cigarette was put out. With the extinguishing of the cigarette, the concentration of pollutants in the room decreases over time.

When examining the CH_2O removal characteristics, it was seen that no device was useful (Fig. 3). On the contrary, operating the device allows the CH_2O pollutants to stay in the air more. Operation of the air conditioner has more negative results in terms of CH_2O concentration compared to other devices. The similar characteristics of ACD1 and ACD2 show that UV-C radiation does not affect the CH_2O concentration. On the other hand, ACD3 showed a worse trend than the concentration values in normal decay, although it gave slightly better results than other ACDs. The highest CH_2O concentration measured during the measurements is 0.57 ppm.

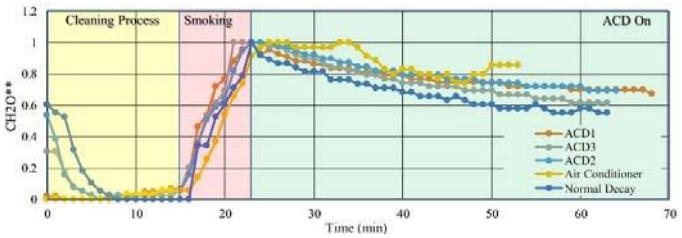


Figure 3 Normalized CH_2O concentration variation by time

When the VOC was examined, it was seen that the ACD2 device was separated from other devices. While the VOC concentration decreases when other devices are switched on or off, the VOC concentration remains constant when the ACD2 device is switched on. Therefore, it can be concluded that VOC was produced during this process. In the use of another device with a UV-C lamp (ACD1), the VOC level decreases over time. It can be concluded that the properties of the respective lamps affect the pollutant concentration in the environment. Similar to CH2O concentration variation, the use of the device worsens the VOC presence in the environment. During the measurements, the highest VOC concentration was 0.24 ppm.

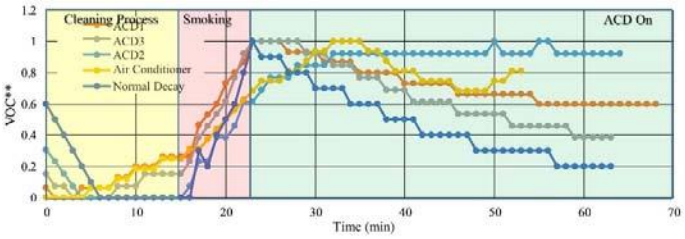


Figure 4 Normalized VOC concentration variation by time

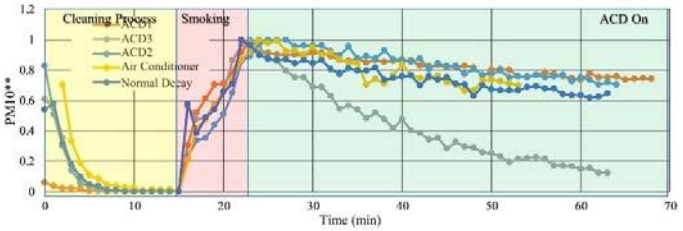


Figure 5 Normalized PM10 concentration variation by time

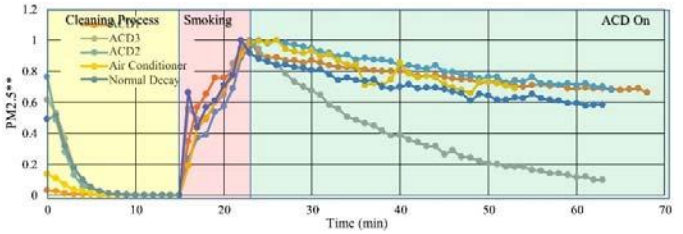


Figure 6 Normalized PM2.5 concentration variation by time

It was clearly seen that ACD3 cleans better than other devices in terms of PM10 and PM2.5 concentrations (Figures 5, 6). In the case of ACD1 and ACD2 with UV lamps, slightly higher concentration values were measured than in the normal case. The operation of the air conditioner has shown a similar trend with

the normal situation. On the other hand, ACD3 rapidly reduces PM10 and PM2.5 concentrations thanks to its filters. The highest PM10 and PM2.5 concentrations measured during the measurements are 259 ppm and 219 ppm, respectively.

Contrary to expectation, CO_2 changes did not occur to a great extent (Figure 7). It can be said that the reason for stable CO_2 concentrations is only one cigarette burns in the room and there is no other source to produce CO_2. When all measurements are considered, the highest and lowest CO_2 concentration values measured are 482 ppm and 409 ppm, respectively. Therefore, it has been observed that the CO_2 concentration in the environment cannot be significantly affected by the burning of a cigarette. Therefore, it is not meaningful to compare the changes in CO_2 concentrations of cleaning devices.

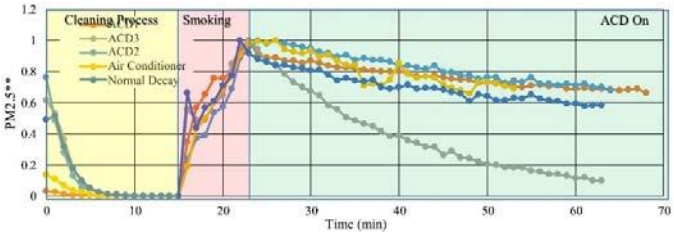


Figure 7 Normalized CO2 concentration variation by time

CONCLUSION

The PM10, PM2.5, VOC, CH_2O and CO_2 concentrations emitted from a cigarette lit were measured in a 30 m^3 test chamber that was made of stainless steel. Four different air cleaning methods have been used to remove these pollutants from the room, and the following conclusions have been reached:

- Gaseous pollutants concentrations like VOC and CH_2O could not be removed by any cleaning method. Moreover, the use of air cleaning devices may extend the pollutants removal time from the environment due to the air flow that they cause. Thus, normal decay gives better results in terms of decreasing the VOC and CH_2O concentrations.
- It has been observed that the properties of the lamps used in UV devices affect the concentration of pollutants in the environment. In particular, when the VOC concentration is considered, it has been determined that the VOC concentration in the environment does not decrease when the ACD2 device is used and concentration remains constant at a certain value.
- PM10 and PM2.5 concentrations are rapidly removed from the room by only the ACD3 which has filters. The PM10 concentration, which increased to 259 ppm, drops to 50 ppm within 22 minutes. Similarly, the PM2.5 concentration, which increases to the 219 ppm, decreases to 25 ppm within 28 minutes.
- It has been observed that cigarette smoke has no effect on the CO_2 concentration in the room.

ACKNOWLEDGEMENT

This study is supported by Scientific and Technology Research Council of Turkey (TÜBİTAK), under project number 218M604. Authors would like to thank TÜBİTAK for his support.

REFERENCES

[1] WHO, "Tobacco," 2020. [Online]. Available: https://www.who.int/news-room/fact-sheets/detail/tobacco.

[2] Statista, "Size of the residential air purifier market worldwide from 2015 to 2021," 2021. [Online]. Available: https://www.statista.com/statistics/735835/air-purifier-market-size-worldwide/#statisticContainer.

[3] Küpper M., Asbach C., Schneiderwind U., Finger H., Spiegelhoff D. and Schumacher S., "Testing of an indoor air cleaner for particulate pollutants under realistic conditions in an office room," *Aerosol Air Qual. Res.*, vol. 19, no. 8, pp. 1655–1665, 2019.

[4] Pei J., Dai W., Li H. and Liu J., "Laboratory and field investigation of portable air cleaners' long-term performance for particle removal to be published in: Building and environment," *Build. Environ.*, vol. 181, no. June, p. 107100, 2020.

[5] Mu G. *et al.*, "Assessment for personal PM2.5 exposure with a modeling method: A panel study in Wuhan, China," *Atmos. Pollut. Res.*, vol. 11, no. 11, pp. 1991–1997, 2020.

[6] Rice J.L. *et al.*, "The feasibility of an air purifier and secondhand smoke education intervention in homes of inner city pregnant women and infants living with a smoker," *Environ. Res.*, vol. 160, no. September 2017, pp. 524–530, 2018.

[7] Chan W., Lee S.C., Li D. and Chen X.Q.K., "Cigarette induced PM2.5 in hotel rooms: An assessment of the effectiveness of management's mitigating measures," *Int. J. Hosp. Manag.*, vol. 60, pp. 42–47, 2017.

[8] Miller S.L. and Nazaroff W.W., "Environmental tobacco smoke particles in multizone indoor environments," *Atmos. Environ.*, vol. 35, no. 12, pp. 2053–2067, 2001.

[9] Al-sarraf A.A., Yassin M.F. and Bouhamra W., "Experimental and computational study of particulate matter of secondhand smoke in indoor environment," *Int. J. Environ. Sci. Technol.*, vol. 12, no. 1, pp. 73–86, 2015.

[10] Huang F. and Kim J.S., "A randomized trial of air cleaners and a health coach to improve indoor air quality for inner-city children with asthma and secondhand smoke exposure," *Pediatrics*, vol. 130, no. SUPPL.1, pp. 741–749, 2012.

[11] Kim M., Jung H., Park E. and Jurng J., "Performance of an air purifier using a MnOx/TiO2 catalyst-coated filter for the decomposition of aldehydes, VOCs and ozone: An experimental study in an actual smoking room," *Build. Environ.*, vol. 186, no. June, p. 107247, 2020.

[12] Purio M.A.C., Acebuche J.C., Barallas J.B., Merjudio K.L.C., Obico P.N. and Raguindin E.Q., "A system for reducing third-hand smoke," *IEEE Reg. 10 Annu. Int. Conf. Proceedings/TENCON*, vol. 2016-Janua, pp. 8–12, 2016.

[13] Kim D.H., Kim M.S., Khan M.A. and Kim H.J., "Analysis of fine dust removal time using circular hole electrodes of various sizes by corona discharge," *Energies*, vol. 11, no. 8, 2018.

[14] Ochiai T. *et al.*, "An effective method for a separation of smoking area by using novel photocatalysis-plasma synergistic air-cleaner," *Chem. Eng. J.*, vol. 209, pp. 313–317, 2012.