ASSESSING THE PERFORMANCE OF ROOM AIR CLEANERS USING A ROOM ENVIRONMENTAL CHAMBER

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ABSTRACT

Models are presented for describing the performance of room air cleaners in removing pollutants from indoor air, particularly the levels of removal that can be achieved in practice. Controlled levels of pollutant were generated in a room environmental chamber, and the performance of a commercial room air cleaner was assessed according to the models. The room environmental chamber was operated in static (sealed) or dynamic (ventilated) modes. Similar cleaner performance levels were found for both modes, although the dynamic mode provided a better understanding of cleaner performance and more closely simulated practical operation.

Keywords: Air cleaning, chamber study, ETS, modeling.

INTRODUCTION

While many commercial room air cleaners are now available, their performance in removing pollutants from air is often poorly specified or assessed. As a result, it is difficult to estimate the extent to which they can reduce indoor air pollutant levels. For example, some manufacturers claim high removal "efficiencies" (e.g. >99%) based on pollutant removal over an indeterminate (or unrealistically long) period of time in a sealed chamber. In practice, indoor pollutant levels are dynamic, i.e. they are continually generated from sources (indoor and outdoor) and are continually removed (e.g. with ventilation air). It is necessary to know the conditions of operation of the room, the air cleaner and the pollutant sources before an estimate can be made of pollutant reductions in the room. In particular, it is necessary to know the pollutant removal *rate* associated with the room air cleaner.

This report presents:
(a) simple models for describing room air cleaner performance which include the conditions of pollutant generation and the operation of the room and the air cleaner;
(b) an assessment of a commercial room air cleaner with tobacco smoke particles in a room chamber using these models; and
(c) recommended procedures by which room air cleaners should be assessed.

MODELS

Constant pollutant source in a ventilated room

A constantly emitting pollutant source, with emission rate ER (µg/hour), in a constantly ventilated room (N air changes/hour) of volume V (m^3) will reach an equilibrium pollutant concentration C_e (µg/m^3) where:

$$C_e = ER/V.N \qquad ...(1)$$

or rearranging

$$ER = C_e.V.N \qquad ...(2)$$

If an air cleaner is operated in the room and it removes the pollutant at a constant removal rate of RR (µg/hour), then a new equilibrium pollutant concentration $C_{e/c}$ (µg/m^3) will be established in the room, where:

$$RR = (C_e - C_{e/c}).V.N \qquad ...(3)$$

RR/ER is a dimensionless performance factor that measures the proportional reduction in pollutant concentrations in a room operating at the same conditions as used in the experiment. For other building conditions, it is useful to know the effective air cleaning rate of the cleaner N' (h^{-1}):

$$N' = Q.f/100.V \qquad ...(4)$$

where Q = airflow rate through the cleaner (m^3/hour);
V = room volume (m^3); and
f = efficiency of pollutant removal from air (%).

It can be derived that:

$$N' = N \frac{RR/ER}{1 - RR/ER} \qquad ...(5)$$

N' measures the effective cleaning rate of the cleaner, relative to the volume of the room in which it operates. It estimates the effectiveness of the cleaner in terms of the equivalent ventilation rate that provides the same performance. N' will be estimated for the following experiments in a room chamber of volume 33.6 m^3; for rooms of other volumes, equation (4) can be used to estimate the values of N' that would be applicable.

Spot pollutant source in a sealed room

If a "spot" release of pollutant in a sealed room generates a concentration C_o (µg/m^3) and a cleaner is operated that removes the pollutant at a constant efficiency, then the pollutant concentration C_t will decrease according to:

$$C_t = C_o \exp(-N't) \qquad ...(6)$$

Equation (6) will be used to estimate N' from measurements of pollutant concentrations which are continuously logged. If pollutants were measured only at the start (C_i) and end (C_a) of a period of operation (t) of the cleaner, an effective removal rate N' will be estimated for these pollutants, provided $C_a > 0$, from:

$$N' = (\ln C_i - \ln C_a)/t \qquad ...(7)$$

METHODS

Room environmental chamber

This has been described in detail previously [1,2]. It consisted of a 33.6 m^3 fully-welded stainless steel room, operated at 23±0.5°C and 50±5% RH, and with an air recirculation system to ensure well-mixed conditions, generally operated at 10 chamber volumes recirculated per hour (RPH). In dynamic (ventilated) experiments, purified supply air (TVOC <20 µg/m^3) was delivered to the chamber to ensure a ventilation rate of 2 air changes per hour (ACH) ± 0.05 ACH. In static (sealed) experiments, the supply air was stopped after the above temperature and humidity conditions were reached, and the chamber was sealed for several hours during measurement of cleaner performance.

Room air cleaner

This was a commercial, freestanding device for removing airborne particles from room air, based on a particle charging process. It functioned by drawing in air at a height of approximately 0.7 m, directly across the charging electrodes. The air then passed over an air-conditioning coil before leaving the device at approximately 1.5 m. In the present experiments, the device operated at its highest airflow rate, specified by the manufacturer as 17 m^3/minute. For all experiments, the device was sited against one wall of the room chamber, discharging air along the central 4 m length of the chamber.

Pollutant source

The pollutant source was environmental tobacco smoke (ETS) generated from smouldering cigarettes (<8 mg tar; preconditioned at 23°C and 50% RH) at the opposite end of the room to the air cleaner. Two types of ETS sources were used:

(a) ETS constant emission source in a ventilated room: one cigarette was allowed to smoulder in the chamber for 1 minute in every 10 minutes for a period of several hours. Preliminary experiments in the room chamber ventilated at 2.0 ACH verified that this acted as a constant source of respirable particles without significant chamber sink effects (Figure 1). With such a source and under these conditions of chamber operation, the pollutant concentration in the chamber should reach 95–98% of its equilibrium value by 1.5–2.5 hours (the delay period selected for particle concentration measurement in the experiments).

(b) ETS "spot" emission source in a sealed room: 2 or 5 cigarettes were allowed to smoulder for 4 minutes (burning to approximately 10 mm from the filter) in the chamber, which was sealed without ventilation. (Note: separate injections of SF_6 tracer gas showed that air leakage rate from the sealed chamber was <0.01 ACH.) This procedure established a peak ETS concentration in the chamber within several minutes, and pollutant concentrations were logged in the sealed chamber for several hours afterwards, during which the room air cleaner operated in different modes.

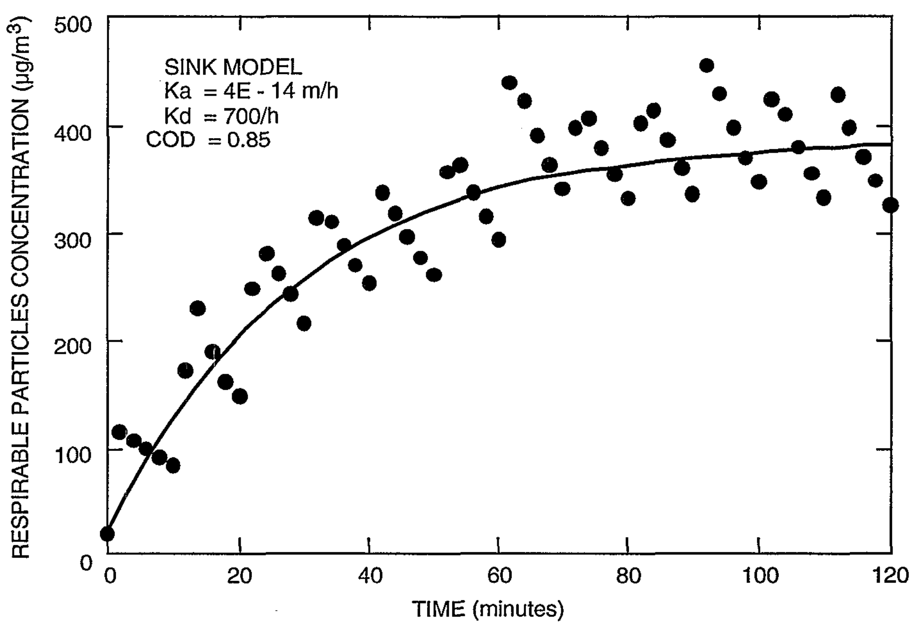

Figure 1. ETS build-up in room chamber at 23°C, 50% RH, 2.10 ACH, 10 RPH

Pollutant measurements

Respirable particle concentrations in the room were measured using a Dustrak Aerosol Monitor 8520 (TSI, USA) with a 4.0 μm (50% cut-point) cyclone sampling head; concentrations were logged at one-minute intervals. In one experiment, UV particulate matter (UVPM) was measured using a draft ASTM Standard method "Standard test methods for estimating the contribution of ETS to respirable suspended particles based on UVPM...". This method estimated combustion-derived particulate matter to ensure ETS levels were not overestimated. Air was collected in a mini-cyclone onto a 1.0 μm Fluoropore membrane filter at a flow rate of 2.3 L/minute (this provided a 50% cut-point for particle capture at an aerodynamic diameter of 4.0 μm) for 45 minutes.

Pollutant removal experiments

Each experiment was preceeded by a period during which the chamber conditions were stabilised to 23°C and 50% RH. Chamber temperature, relative humidity and ventilation rate were logged remotely at 5-minute intervals and were averaged for each experiment. Generally the ETS source was introduced into the chamber with the air cleaner operating in fan-only mode for 1.5–2 hours, after which the pollutant concentrations in the chamber were measured for 45–60 minutes. The air cleaner was then operated in fan-plus-particle charge mode for a further 1.5–2 hours before pollutant concentrations were remeasured. Specific schedules for each experiment will be presented with results.

RESULTS

Experiment 1 – constant ETS source in a ventilated chamber

The schedule for Experiment 1 was:

Time (hh:mm)	*Activity*
00:00	Chamber stabilised at 23°C, 50% RH, 10 RPH, 2.12 ACH, Dustrak Aerosol Monitor on
01:30	Air cleaner – fan-only mode
01:30	ETS source (1 cigarette for 1 minute every 10 minutes) started
03:15	UVPM sample (45 minutes) started
03:00 to 04:00	Dustrak signal averaged to provide C_e (equation 1)
04:00	Air cleaner – fan-plus-particle charge mode
05:45	UVPM sample (45 minutes) started
05:30 to 06:30	Dustrak signal averaged to provide $C_{e/c}$ (equation 3)
06:30	ETS source stopped, SF_6 tracer injected
08:30	END

The equilibrium respirable particle concentrations (Dustrak) without and with the particle charge on were found to be 301 μg/m^3 and 80 μg/m^3, respectively. Thus, from equation (2) the respirable particle emission rate of the source was:

$$
\begin{aligned}
ER &= 301 \times 33.6 \times 2.12 \\
&= 21{,}400 \ \mu\text{g/hour}
\end{aligned}
$$

and from equation (3) the respirable particle removal rate was:

$$
\begin{aligned}
RR &= (301-80) \times 33.6 \times 2.12 \\
&= 15{,}700 \ \mu\text{g/hour}
\end{aligned}
$$

Thus the air cleaner removed 73% of the respirable particles generated by the source in this experiment. Using equation (5) it is calculated that the effective cleaning rate of the device was 5.7 h^{-1}. From equation (4) and assuming Q = 17 m^3/minute (data from manufacturer), it was estimated that the efficiency of pollutant removal from air was 19%.

The UV particulate matter measurements were 129 $\mu g/m^3$ without and 30 $\mu g/m^3$ with particle charge mode of cleaner operation. This corresponds to a removal of 77% of UV particulate matter and verifies the removal efficiency measured by the Dustrak monitor.

Experiment 2 – 'spot' source of ETS into sealed chamber (no ventilation)

The schedule for Experiment 2 was:

Time (hh:mm)	*Activity*
00:00	Chamber stabilised at 23°C, 50% RH, 10 RPH, 2 ACH; Air cleaner – fan-only mode, Dustrak on
01:25	Chamber ventilation stopped, recirculation decreased to 1 RPH, chamber sealed; 5 cigarettes burnt in chamber for 4 minutes
03:25	Air cleaner – fan-plus-particle charge mode
05:25	SF_6 tracer injected to check leakage (<0.01 ACH)
06:30	Clear chamber for 30 minutes; then seal chamber again
07:00	Air cleaner – fan-only mode
07:00	5 cigarettes burnt in chamber for 4 minutes
07:08	Air cleaner – fan-plus-particle charge mode, logged by Dustrak for 2 hours
09:10	END

The decay of respirable particle concentrations (Dustrak) in particle charge mode was analysed using equation (6) and showed that there was a delay in the effectiveness of the air cleaner after it was switched on. This affected the degree of fit to equation (6) and the consequent estimate for N'. It was found that precise fit to equation (6) occurred using data from 10 minutes after the particle charge mode started (Figure 2) and so all performance evaluations used this delay before analysing the data.

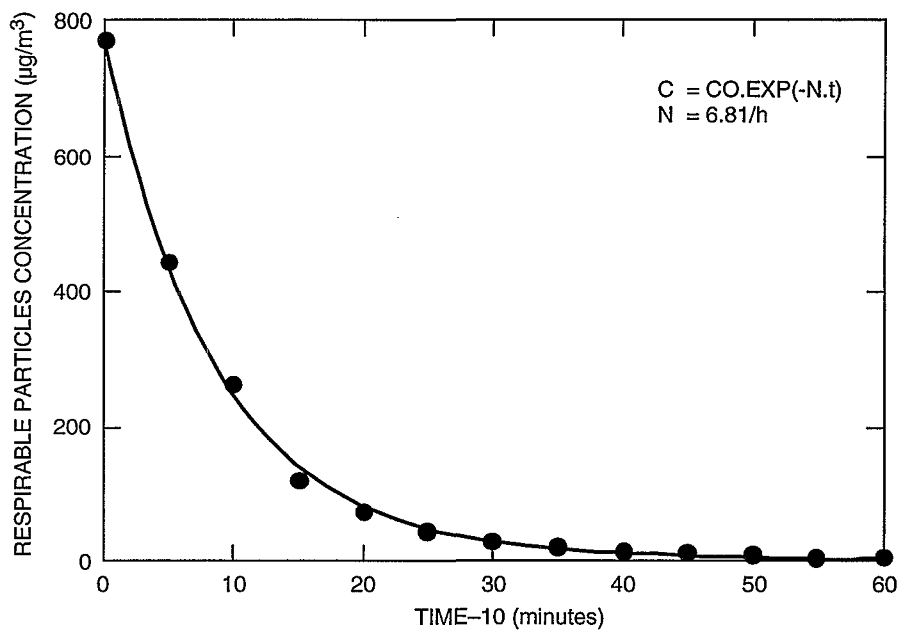

Figure 2. Removal of respirable particles ($\mu g/m^3$) from 5 cigarettes in a sealed room by air cleaner

The effective cleaning rates (N') were found to be:

(a) Experiment 2a – 5.49 h^{-1}; and

(b) Experiment 2b – 6.81 h^{-1}.

These compare favourably with the estimate of 5.7 h^{-1} found in Experiment 1.

Experiment 3 – 'spot' sources of ETS into sealed chamber

This experiment repeated Experiment 2 with fan-plus-particle charge mode, but with ETS generated from 2 instead of 5 cigarettes. The decrease in respirable particle concentrations in particle charge mode was evaluated using equation (6). Data fit to the equation was exact with $N = 7.6\ h^{-1}$.

DISCUSSION

The experiments have shown that the room air cleaner was consistently effective in removing respirable particles from environmental tobacco smoke. For the three separate experiments, the effective cleaning rate was 6.4 ± 1.0 h^{-1}, i.e. in a room with the volume of the room environmental chamber, the respirable particle removal rate was equivalent to having the room ventilated at 6.4 ACH. Alternatively, the performance of the room air cleaner can be expressed as its efficiency f (equation 4), which was 21%. This performance measure does not depend on the size or ventilation rate of the room; assuming f is constant at different airflow rates through the cleaner and with continued operation of the cleaner, it can be used to estimate effective cleaning rates or proportional reductions in pollutant levels for any building scenario.

While good agreement was found between assessments made in a ventilated chamber and a static chamber, there are advantages to the former. For example, it relies on equilibrium conditions being achieved in the experiments, a factor that eliminates short-term influences on performance measurements (e.g. the delayed operation of the cleaner observed in the static experiments). Also, the constant source–ventilated chamber approach could be used to evaluate whether pollutant removal efficiency remained constant, either with time or at other environmental conditions. On the other hand, the spot source–static chamber approach offers a more simplified experimental procedure, and may be more appropriate for quality assurance evaluations.

CONCLUSIONS

The performance of room air cleaners in removing pollutants from indoor air can be assessed using appropriate models of cleaner efficiencies and environmental chamber experiments to derive model parameters. The model parameters should be independent of the room size and ventilation rate and allow the pollutant removal rate to be estimated for any room scenario. Also, the model parameters should reliably demonstrate performance levels of different cleaners such that they can be compared.

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