The Effect of Portable Indoor Aerosol Filters on Indoor Air Quality (IAQ), Evidence from Different Sites in China

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INTRODUCTION

Indoor air pollution is a major issue impacting the health and livelihood of hundreds of millions of people around the world [1], [2]. One major source of indoor air quality is the transport of aerosols and gasses from outdoors via doors, windows, ventilation systems, etc.[3], [4]. Another major source consists of emissions sources inside the building, which include but are not limited to cooking [5] and other open flames, intentional burning such as mosquito coils [6].

For these reasons, there has been a considerable amount of time and effort put into ways to reduce the loading of aerosols in the indoor environment [7]. One of these methods is to find filters or other materials that are capable of removing these aerosols and gasses directly from the enclosed air inside [8], [9].

There are many such filter materials that claim to remove upwards of 99.97% of aerosols with a diameter of 2.5 microns and smaller [PM2.5], which following their standards tend to be tested inside of sealed boxes or other containers, exposed to low overall concentrations of mostly sea salt and other ionizable aerosols, with the exposure taking place over an extended period of time [10]–[12]. However, inside a real indoor location, such idealized tests do not offer a fair representation of reality [13].

To address these issues, a new systems approach is introduced to comprehensively analyze the loadings of aerosols, their size distributions, and the time-rates of their changes, as they occur inside actual indoor residential environments. A box model is applied to evaluate the transport of aerosols from outside to inside, the amount of aerosols when there are mosquito coils burning inside, as well as the deposition of aerosols to the room and the filter. These measurements are designed to test the efficiency of home-made fan-powered new materials to control the levels of aerosols indoors under realistic conditions, following the initial trial done by [14].

DATA AND METHODS

Three experiments were conducted in Zhuhai (Guangdong), Shunde (Guangdong), and Xuzhou (Jiangsu) in China. In Xuzhou, conditions also included burning, manipulating when the filter was turned on and whether the windows were closed or open.

The measurements at all sites, both indoor and outdoor are made using the same low-cost sensors, taking measurements on a 2-minute basis continuously over a minimum of 21 days.

In specific we analyzed the retrieved number concentrations of aerosols over 5 size ranges from 0.3 to 10 microns, as well as calculated values for dry PM1 and PM2.5 based on number concentration measurements and assumptions of aerosol density.

For the measurements in Zhuhai and Shunde, measurement data was separated into two parts, those representing "pseudo-equilibrium" or typical conditions and "events", or short-term enhanced pollution conditions by separating data iteratively using a statistical variance maximization method.

For the "pseudo-equilibrium" condition, removal efficiency, i.e. indoor measurements/outdoor measurements was calculated and then fitted into lognormal distribution.

For the "events" condition, decay time and normalized drop were calculated for each case.

For the measurements in Xuzhou, additional factors to account for emissions, removal, and transport also need to be included.

The following box model was applied to accomplish this.

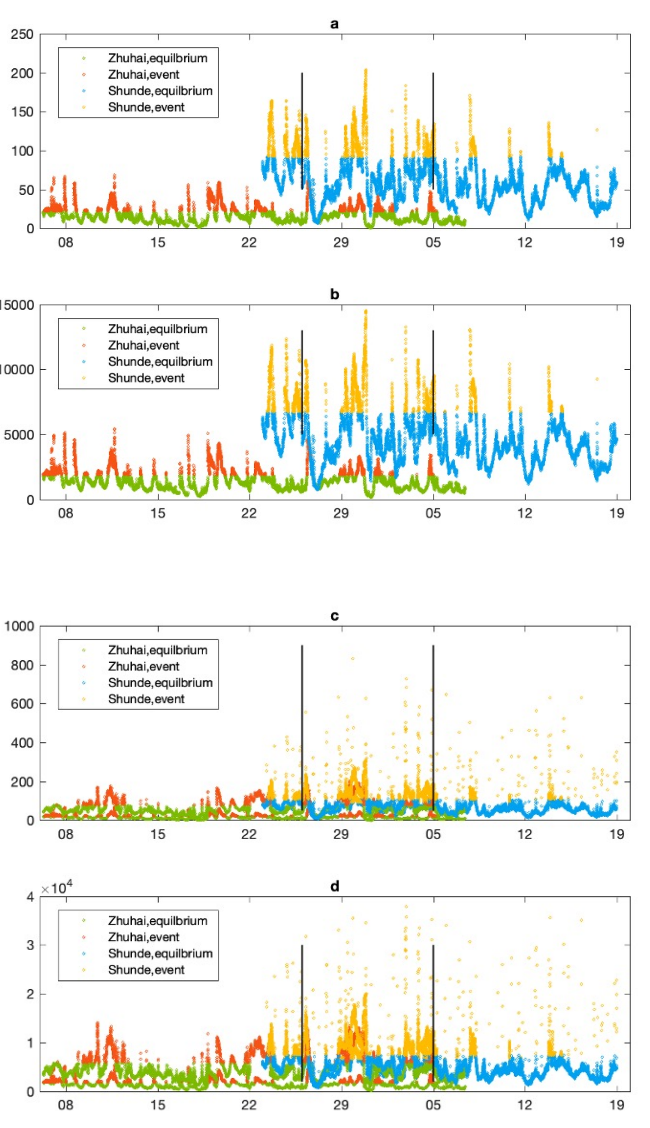
Linear regression was used to fit the model parameters to the data.

Cubic spline interpolation was applied to reduce measurement noise.

Regression with R^2 lower than 0.3 was excluded.

$$\frac{dm}{dt} = -(D_{room} + D_{fan})M_{in} + T(M_{out} - M_{in}) + c + E$$

RESULTS

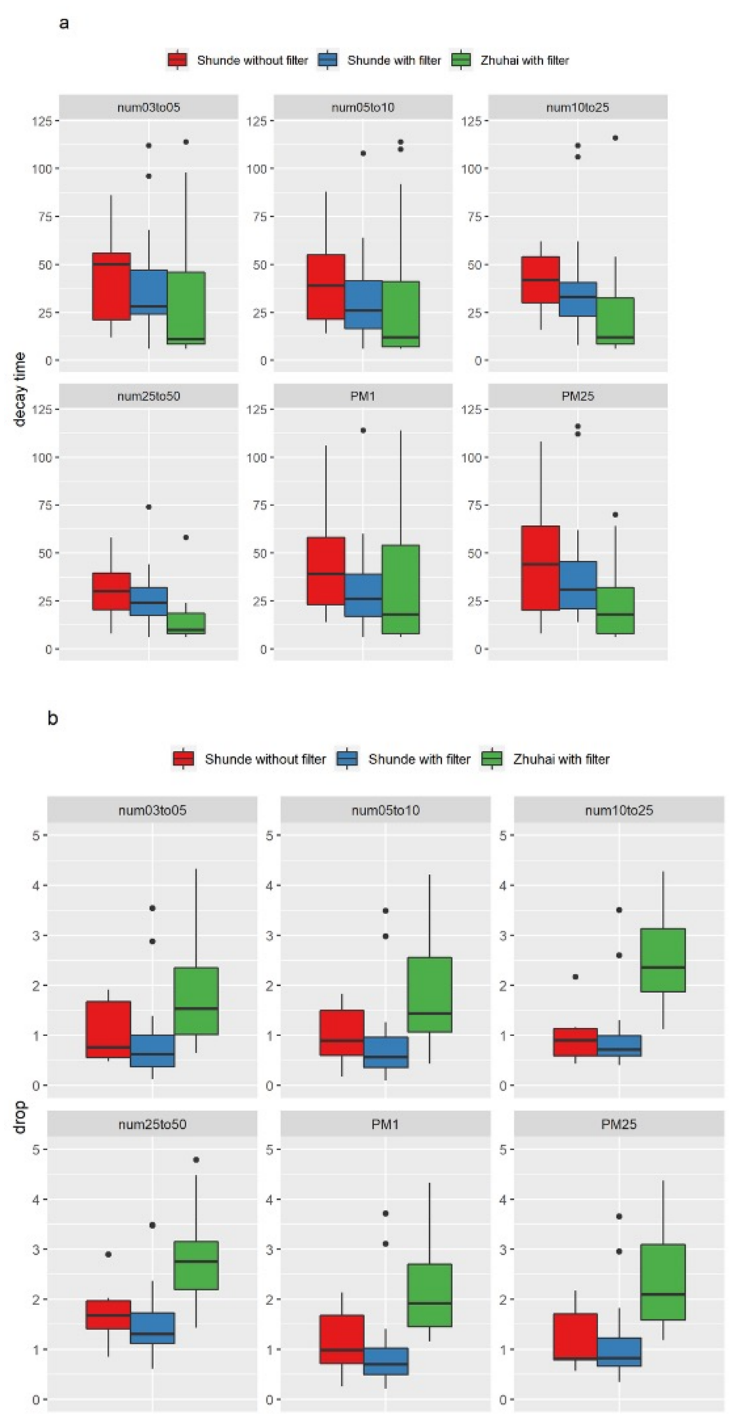


Time series of the entire (a) indoor PM2.5 data, (b) indoor number concentration from 0.3um to 0.5um data, (c) outdoor PM2.5 data, and (d) outdoor number concentration from 0.3um to 0.5um data, at Zhuhai and Shunde. The black vertical lines separate the Shunde time series into 3 periods: the background period (filter off), the bedroom period (filter on in bedroom), and the living room period (filter on in living room). The data points are labeled as "pseudo-equilibrium" or "event". The measurements were taken from 2019.12.06 to 2020.01.19.

RESULTS

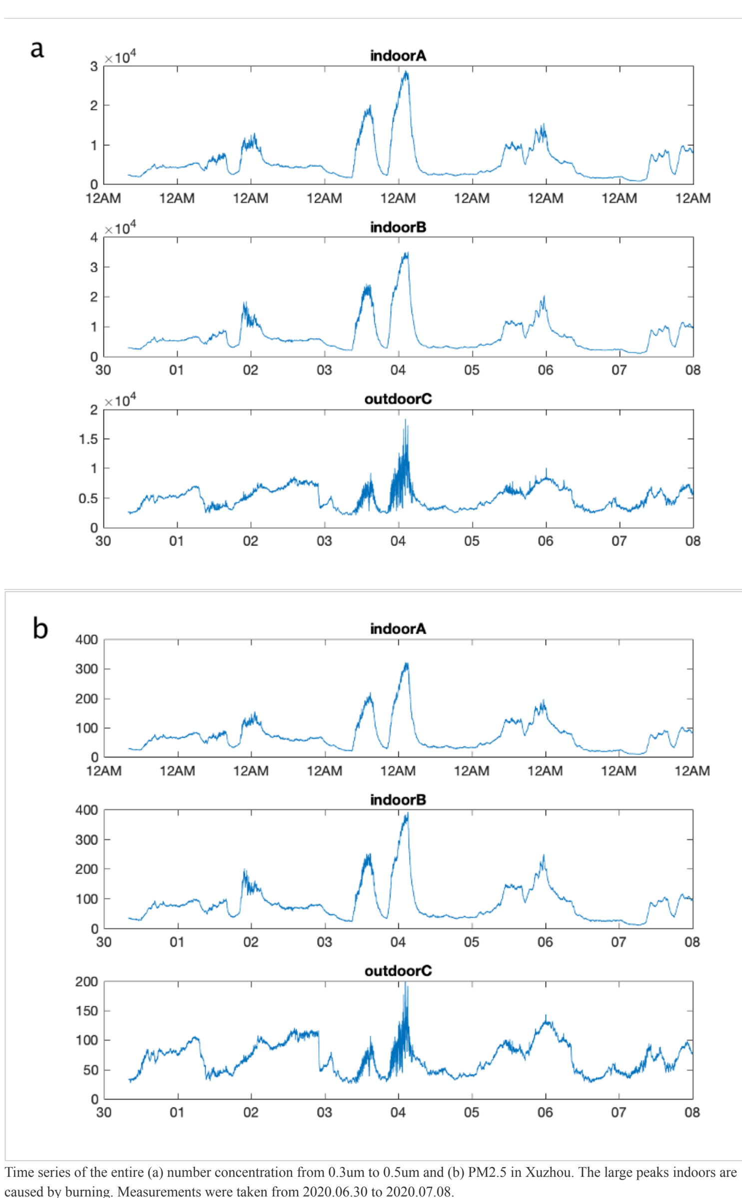
	Zhuhai (filter on)			Shunde (filter on)			Shunde (filter off)		
	μ	e^{μ}	σ	μ	e^{μ}	σ	μ	e^{μ}	σ
PM_1	-1.42	0.242	0.447	-0.462	0.630	0.190	-0.102	0.903	0.0887
$PM_{2.5}$	-1.43	0.238	0.435	-0.494	0.610	0.206	-0.129	0.879	0.0964
Num 0.3 to 0.5	-1.23	0.291	0.363	-0.403	0.668	0.178	-0.0661	0.936	0.0852
Num 0.5 to 1.0	-1.25	0.286	0.358	-0.422	0.656	0.173	-0.0854	0.918	0.0845
Num 1.0 to 2.5	-1.47	0.231	0.401	-0.604	0.547	0.217	-0.235	0.791	0.109
Num 2.5 to 5.0	-1.26	0.284	0.642	-0.347	0.707	0.290	0.0560	1.06	0.173

Parameters (exponential mean, μ; actual mean e^{μ}; and variance σ) of best-fit lognormal distributions of the PDF of the Removal efficiency distribution, as a function of site and filter status.



Box and whisker plots of the decay time and normalized drop for the event data The black dots are outliers (4 outliers in (a) not shown).

RESULTS



Time series of the entire (a) number concentration from 0.3um to 0.5um and (b) PM2.5 in Xuzhou. The large peaks indoors are caused by burning. Measurements were taken from 2020.06.30 to 2020.07.08.

Transport ratio and deposition ratio under burning and no burning conditions in Xuzhou. The R^2 range from 0.32 to 0.80.

CONCLUSIONS

Low-cost air sensors have demonstrated the clear ability to differentiate aerosol number concentration loadings from 0.3um to 10um as well as aerosol mass concentrations of PM1 and PM2.5 under both indoor and outdoor conditions, both with and without the use of new fan-powered filter material.

These results clearly demonstrate that under some conditions the source of pollution inside originated from outside, while under other conditions the source of pollution outside originated from inside.

Two new analytic measures were introduced in order to better constrain the impact that indoor aerosols and their reduction: the magnitude of the drop from extreme events back to equilibrium, and the time for this drop to decay.

The average reduction in indoor aerosol loadings ranges from 23% to 29% in Zhuhai, while it ranges from 55% to 71% in Shunde probably due to differences in the ages of the buildings, the leakiness, and the surrounding environment.

The fan-powered filter material was found to lead to both a slightly increased overall drop, as well as to a much faster time for the perturbation to reach equilibrium.

The reduction of PM2.5 is larger than the reduction for every other measure analyzed.

A box model was applied in order to efficiently evaluate the indoor emissions, deposition, and outdoor-indoor transport of aerosols. The parameters were estimated by linear regression with acceptable or good R^2.

These best-fit results are able to provide a quantitative treatment to assess the effects of windows, emissions location, and filtration on the loadings both inside and outside, at a time resolution of minutes to hours.

Transport ratios under no-burning conditions were relatively consistent across different species. Aerosols were transported from outside to inside, with an effective transport of 3 to 4 times more when the windows were open as compared to closed.

When there was burning inside, however, aerosols were transported from inside to outside for all particles smaller than 5um. This is especially so for moderately sized particles.

Compared with the no-burning condition where deposition using fan filter was consistent and significant across species, deposition of smaller particles increased even to 400 under burning condition, which shows that using fan-power filter largely reduces indoor smaller particles when there are fresh indoor emissions, coupled with a high amount of indoor air circulation.

ABSTRACT

People spend most of their time indoors, and therefore exposure to aerosols and precursor-gasses in the indoor environment is of extreme concern with respect to people's health, well-being, working efficiency, and overall life quality. Such sources include both those emitted inside as well as those which may intrude from the outside. To better quantify and understand these sources and their impacts we employ multiple air quality monitors and simple models, both within and outside of various residential environments located in different cities of different development levels in China.

To enhance the livability of the indoor environment, we further work to quantify two newly relevant factors: portable indoor aerosol filters and the idea of "increased ventilation". The combined goal of this work is to understand the combination of factors leading to an improvement in Indoor Air Quality (IAQ), including but not limited to: mass transfer to/from the indoor environment, removal and/or enhancement due to the filters and ventilation, removal from the room itself, emissions, and other possible non-linearities not accounted for on this list.

Concentrations of aerosols across different sizes from 0.3um to 10um are measured and analyzed at 2-minute intervals over a minimum of 20 days, allowing for an analysis that encompasses all of the possibilities of natural and anthropogenic variability typically encountered in a real environment. This includes analysis both with and without filters, under extreme outdoor loading conditions, with intense indoor emissions sources, pseudo-equilibrium conditions, and measurements made during different meteorological events, both with and without high rates of indoor to outdoor air exchange.

Results show that the impacts are relatively large under both equilibrium and high event conditions, include both the magnitude of the drop as well as the time taken to achieve the reduction. A further conclusion is that increased ventilation may lead to a worsening of IAQ. A final conclusion is that larger particles more likely associated with PM2.5 are removed at a different rate from much smaller particles more associated with PM0.5 or PM1.

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