Comparative study of commercial home air cleaners

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Abstract. Pollution levels and increasing airborne diseases are today key factors driving the dynamic market of home air cleaners. Numerous air purifiers of varying shapes and sizes are now commercialized, often constituted of passive filters (pre filter, HEPA filter, Activated Carbon filter) and sometimes of active systems (photocatalysis for instance). Manufacturers tend to make bold claims regarding the efficiency of their products, but those claims are not often substantiated by hard evidence. We present here comparative laboratory tests conducted at CEA and inspired by the American, Chinese and French standards, of six commercial air cleaners suitable for medium-sized rooms. The purpose is to measure and compare their Clean Air Delivery Rates for particulate matter, and filtration efficiencies for Volatile Organic Components. The air cleaners are found to be effective against particulate pollution, but their performance against gaseous pollutants is on the whole disappointing.

1. Objectives
Because of public demand for better indoor air quality, many types of home air cleaners can be found on the market. As abundantly described in commercial documentation, these air cleaners can use a host of filtration devices, including pre filters, HEPA filters, electrostatic filters, ionisers, activated carbon, plasma-catalytic filters, photocatalytic filters… Commercial documents often mention efficiency against many types of contaminants: fine particles, pollens and dusts, viruses, bacteria, fungi, volatile organic compounds… but these claims are not always supported by convincing experimental evidence.

Government agencies have been publishing guidelines and recommendations for the public, for instance the US EPA in 2009 [1] or more recently the French ANSES [2]. Standards have also been issued in an effort to acquire reliable information on the performance of air cleaners [3–5] and some results can be found in the literature [6–8]. But standardised tests are costly to make and relevant data seems to remain scarce.

Within this context, we present here a comparison of several popular home air cleaners in terms of performance for removing fine particles and Volatile Organic Compounds (VOCs). This comparison is limited in scope but we believe it provides useful information and can help characterise and understand the benefits and limitations of existing appliances.

2. Tested air cleaners
A total of six commercial air cleaners were tested. They are intended for use in medium-sized rooms in homes. They shall be denoted in the following as A1 – A4 and B1 – B2. The “A” air cleaners use classical HEPA filters and adsorbents as the principal means for the removal of particulate and gas pollutants. The “B” air cleaners use more innovative techniques for one or the other. Their main characteristics are given in Table 1.
Table 1. Main characteristics of tested air cleaners.

| Technique for particle removal | Technique for gas removal                      |
|--------------------------------|-----------------------------------------------|
| A1  HEPA filter               | Adsorbent + small photocatalytic filter        |
| A2  HEPA filter               | Adsorbent                                      |
| A3  HEPA filter               | Adsorbent                                      |
| A4  HEPA filter               | Adsorbent (including specific material for formaldehyde) |
| B1  Electrostatic filter      | Adsorbent + plasma-catalytic filter            |
| B2  Fibrous filter            | Photo-electrochemical oxidation               |

Certain HEPA filters are apparently electrets (A1 and A4). The adsorbent is basically activated carbon. It can be used as a continuous layer of small (submillimetre) particles (A2 and A3), a loose array of larger pellets (A1 and A2) or embedded in a honeycomb grid (B1).

All air cleaners were tested with unused particle and gas filters. In the case of B1 however, the honeycomb grid filter mentioned above had undergone two months of trial in fairly harsh conditions before the gas removal test was made. According to the manufacturer, this filter need not be replaced but the fact should be borne in mind when analysing the results of this test.

3. Test methods

3.1. Particle Clean Air Delivery Rate (CADR)

The Clean Air Delivery Rate (CADR) of an air cleaner is defined as the product of its actual air flow rate by its removal efficiency with respect to a given pollutant [3–5]. We chose this quantity to characterise the removal of particles and measured it using a variant of the method described in the American and Chinese standards for air cleaners [3,4]:

![Figure 1. Measurement of the CADR for particles.](image)

A test aerosol was injected in a closed room until a given level of concentration was reached. Injection was stopped and the air cleaner was switched on. The aerosol concentration consequently decreased. The experiment was stopped when it was back to its initial level. During the whole of the experiment, the air in the room was mixed thanks to a fan. Aerosol concentrations were measured with a Condensation Particle Counter (CPC).

An exponential was fitted on the concentration decrease, which gave a decay rate constant for the air cleaner. The experiment was also made without the air cleaner, which gave a natural decay rate constant. The difference multiplied by the volume of the room is equal to the CADR.

Particulate CADRs are usually given for three classes of particles: “cigarette smoke”, “dust” and “pollen”. We used a submicron aerosol of salt particles. The CADRs reported here are therefore similar to “cigarette smoke” CADRs. Uncertainty is estimated at ± 30 m³/h.
3.2. Volatile Organic Compounds (VOCs) removal efficiency

CADRs can also be defined for gaseous pollutants and measured in the same way. This was unfortunately not possible for us, since our equipment for the production and the analysis of gas pollutants is not transportable and could not be brought to the test room.

We chose instead to measure a “removal efficiency”, along the lines of the French standard for air cleaners [5]. This efficiency is the ratio of the pollutant flow rate adsorbed/destroyed to the pollutant flow rate into the air cleaner. In practice, a given concentration of pollutant is injected (and measured) at the inlet of the air cleaner and the remaining concentration is measured in the outlet:

![Diagram of air cleaner system](image)

**Figure 2.** Measurement of the efficiency for VOCs.

The French standard requires that the flow rates into and out of the air cleaner be controlled so that the pressure drop across the air cleaner is zero. This was difficult to achieve with our experimental setup. We therefore made the measurements with a flow rate of 50 m$^3$/h imposed by the setup. Relative humidity was 50%. The “passive” air cleaners (A1 to A4) were kept switched off (not a problem since they are by nature passive). The other ones: B1 and B2, had to be turned on. With air cleaner B2 it was possible to keep the flow rate at 50 m$^3$/h; with B1 some adaptation was necessary and the resulting flow rate was about 120 m$^3$/h.

Three gas pollutants were injected at a concentration of 50 ppb: acetaldehyde, acetone and toluene. All three belong to the category of Volatile Organic Compounds and are mentioned in the French standard. The latter also requires injection of formaldehyde and heptane, but this was not feasible in the present study.

VOCs concentrations were measured by means of a thermodesorber coupled to a gas chromatograph equipped with a Flame Ionisation Detector (FID). Precise evaluation of uncertainties is difficult but measurements in the 50 ppb range obviously remain challenging. We estimate that uncertainties can hardly be less than ± 20%.

4. Results

4.1. CADRs for particles

Measured CADRs are reported in Table 2. In all cases, the air cleaners were at full capacity.

| CADR (m$^3$/h) | Filtration technique |
|----------------|----------------------|
| A1  | 230 | HEPA filter |

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*IAQVEC*  
IOP Conf. Series: Materials Science and Engineering *609* (2019) *042076*  
doi:10.1088/1757-899X/609/4/042076
These values are quite classical for portable home air cleaners (a bit weak for A2 and B2, though) and call for little comment. According to AHAM guidelines [3], the best air cleaners would be suitable for rooms 25 m² in size (8 m² only for the weakest one). One salient fact is that the best performance is observed with the electrostatic filter.

Air flow rates measurements were attempted by the tracer technique (not reported here because not all of them were successful); they suggest that particle removal efficiencies should be high: at least 70% in most cases.

Out of the six air cleaners, only one (A4) appears in the Verifide database (http://ahamverifide.org). Its value for tobacco smoke is 280 m³/h, which is quite close to our own measurement.

4.2. Removal efficiencies for VOCs

Removal efficiencies do vary as a function of time, because of gradual saturation of the adsorbents. Table 3 summarises the results in terms of 3-hours averages (following once again the indications of French standard (5)).

|       | Acetaldehyde | Acetone | Toluene | Flow rate (m³/h) |
|-------|--------------|---------|---------|------------------|
| A1    | 0            | 10      | 10      | 50               |
| A2    | 0            | 70      | 100     | 50               |
| A3    | 10           | 40      | 90      | 50               |
| A4    | 0            | <5      | <20     | 50               |
| B1    | <5           | <5      | 10      | 120              |
| B2    | 0            | 0       | <5      | 50               |

Values denoted “<5” indicate that some effect was noticeable but could not be quantified with any certainty. In the case of toluene in air cleaner A4, only an upper bound could be obtained.

Various observations can be drawn:

- Results are on the whole disappointing – at any rate far inferior to particle removal.
- Efficiency against acetaldehyde is at best poor (A3 and possibly B1) and nil in most cases.
- Adsorbent-based air cleaners do have an effect on acetone.
- The best efficiency is obtained with toluene. It can actually reach 100%.
- “Conventional” air cleaners (A1 to A4) perform on average better than the “unconventional” ones (B1 and B2). It can be argued that the latter were not tested in optimal conditions (fan switched on and yet air flow rate imposed by the setup). This remark may have some weight in the case of air cleaner B1, but the fact remains that a large proportion of injected pollutants remained unaffected.
- Adsorbents are more efficient when used in a layer of small particles (A2 and A3, as compared to A1 and A4). On the other hand, saturation may be faster than in the case of large pellets. Our experiments unfortunately did not last long enough to check this hypothesis.

Another unpleasant, though not unexpected, finding is that adsorbents only act as “concentration buffers”, and for a limited period of time only.

Figure 3 shows the history of concentrations out of air cleaner A2 as an example (the other ones do not perform any better). Capture of acetone is almost 100% at the beginning but falls to zero after only 15 hours. Also, it is released from the adsorbent after pollutant injection is stopped; our experiment
had unfortunately to be stopped before desorption of acetone was complete and the mass balance could therefore not be computed.

This figure also illustrates the difficulty of multi-pollutant capture: toluene is effectively arrested while acetaldehyde is not. And there is some reason to believe that the results will depend on the nature and the composition of the pollutants cocktail.

![Figure 3. Typical concentration history.](image)

5. Conclusions
The performance of six commercial air cleaners with respect to particulate and gaseous pollution has been assessed.

Regarding particulate matter, a Clean Air Delivery Rate (CADR) could be measured for each air cleaner running at full capacity, following the main requirements of the American and Chinese standards for air cleaners. CADRs ranged between 90 and 300 m³/h, which corresponds to rooms 8 to 25 m² in surface according to those standards. Those values are quite typical and unsurprising. All air cleaners used HEPA/fibrous filters except one; the latter, equipped with an electrostatic filter, proved to have the largest CADR.

Regarding gaseous pollutants and particularly Volatile Organic Compounds (VOCs), only a filtration efficiency could be measured and at a quite limited flow rate of 50 m³/h. The methodology was inspired by a part of the French standard for air cleaners. Given the present paucity of results on the subject, we believe this information is however valuable. Three VOCs were tested simultaneously: acetaldehyde, acetone and toluene, at a concentration level of 50 ppb. Air relative humidity was 50%.

Filtration efficiency for acetaldehyde was found zero for all air cleaners but one (and no more than 10% in the latter case). Acetone was effectively retained by three air cleaners, but signs of saturation were observed in most adsorbent-based appliances after only 15 hours. The best performance was attained with toluene; filtration efficiency remaining close to 100% after the same period in two air cleaners. For all three VOCs, the “conventional” air cleaners using adsorbents performed markedly better than the “unconventional” ones using advanced technologies like plasma-catalysis or photo-electrochemical oxidation.

Acknowledgements
The authors are grateful to Guard Industrie for financial support.
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