Chapter 12 Indoor air quality – as clean as you want it!

Thomas A. Cahill, Jeff March, and Marti Childs, authors; Publisher: Editpros, www.editpros.com; Please do not circulate beyond the Embassy personnel until the book comes out this July.

(Summary of earlier chapters)

We know from medical and epidemiological research that there are at least seven proven factors in air pollution that harm people:

1. Toxic metals, (see Appendix A)	
i. Coarse > PM$_{2.5}$	mercury, cadmium, lead, …..; serious health impacts, but handled well by simple face masks.
ii. Fine < PM$_{2.5}$	same list, but 10 to 20 times more dangerous because they go deeper into the lung and have to be cleared through the blood stream; face masks useless. Example – lead from cars, mercury, copper-
2. Coarse mass, all species	all dust, not very toxic; statistical association but little support from medical studies. Can reach enormous values in dusty storms, with fatalities.
3. Acidic aerosols	Damage the cilia and reduce the ling's defenses to all sorts of pollution and all sorts of infections. Example: World Trade Center smolder pile.
4. Biological aerosols	especially airborne bacteria and fungi, often traveling on fine dust: Examples: CA Valley Fever, (a fungus), Legionnaires Disease (bacterial)
5. Carcinogens	high temperature combustion. Example: diesel exhaust.
6. Very fine < 0.25 µm metals	Fe, Ni, Cu, Zn - damages lungs especially in children. Shows up in reduced lung function for children living near freeways. Example: many industries, metals dust from brake drums and pads
7. Ultra-fine particles < 0.25µm	Particles penetrate into the blood stream – leads to ischemic heart disease (requires years of exposure) Example: transition metals from brakes, zinc in lube oil, plus lead from cars, carcinogens from diesel exhaust.

In terms of personal protection, coarse mass is well screened out since any modern apartment. The problem comes from 1 i, 3, some of 4, and especially 5, 6, and 7. These penetrate easily into the average house or apartment, and face masks are useless.

Thus, the question comes one of removal from the air, since we can do little about sources. Below in Figure 1 I show removal from the atmosphere. Note that the vertical and horizontal scales are logarithmic, so these graphs represent an enormous range of values – factors of 10,000 in both cases.

The horizontal scale of particle size goes up to 40 micrometers, about the diameter of a fine human hair.

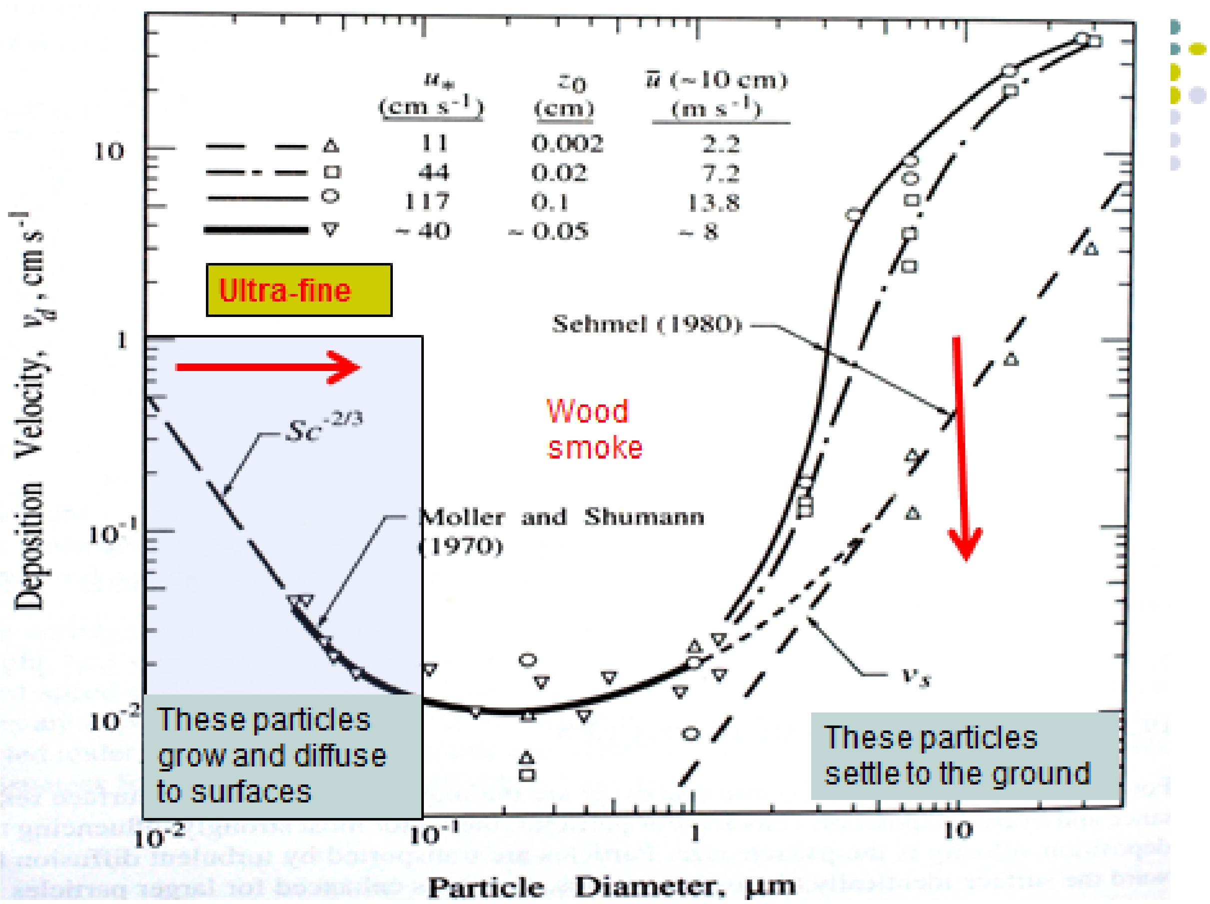


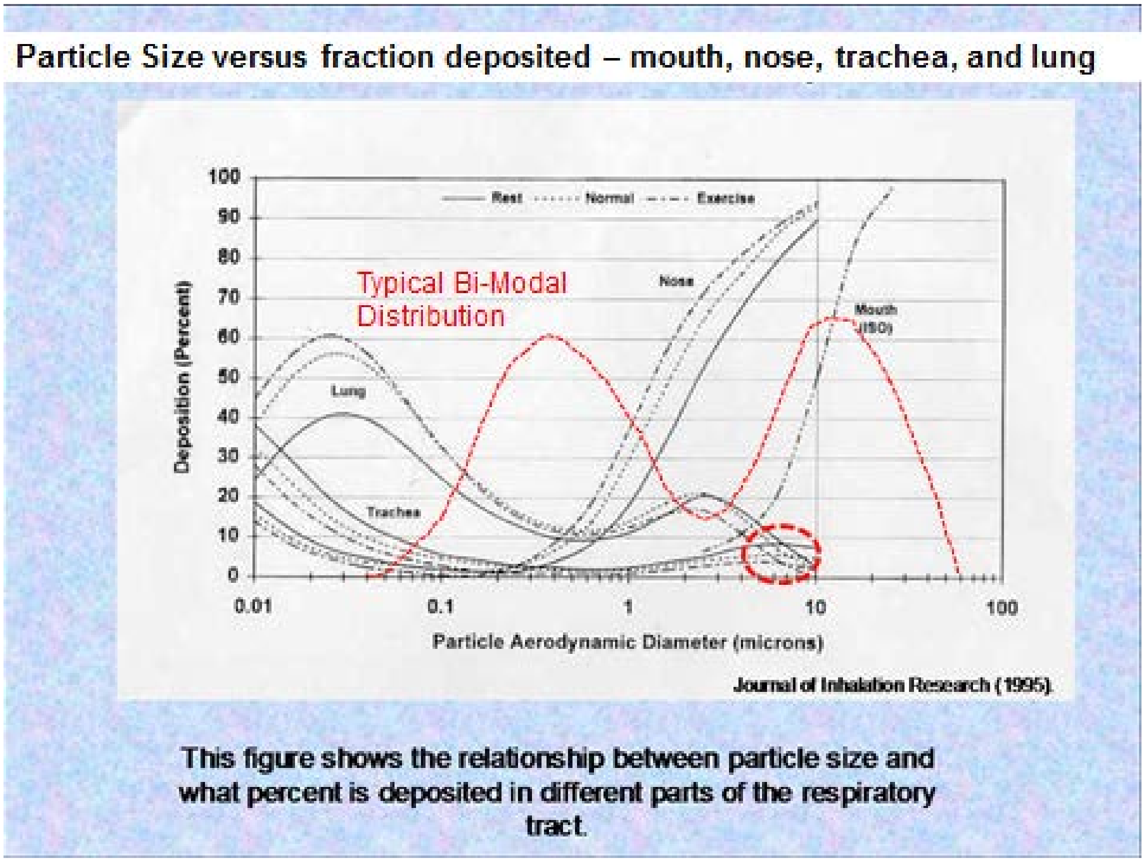
Figure 1 Removal of particles from the atmosphere.

On the right side of the plot are coarse and very coarse particles – easily made from dust, sea salt spray, agricultural operations, etc. They are made in abundance, for example in dust storms, but then settle to the ground rapidly. Only the finest stay in the air for a while, giving the right hand bump in ambient air concentrations – the so called "Mechanical Mode".

On the left side, we have particles that grow from gasses, nitrates, sulfates, etc., plus particle made in the fine mode by high temperature sources, such as diesel exhaust and some industrial processes. The first type grows by picking up gasses, including water, and eventually they get to the left hand bump – the “Accumulation Mode”, where they are too small to settle by gravity but too big to grow further.   Some particles, such as wood smoke, naturally occur in the “Accumulation Mode maximum This “Bi-Modal Distribution” was discovered in Southern California smog studies in the early 1970s, and is universal around d the world.

It is also important that light scatters from the accumulation mode, and that is the haze you see, a mixture of scattering from aerosols and absorption from soot.

Below in Figure 2, we can now match the “Bi-Modal distribution” to how your body collects aerso9ls.



Particle Size versus fraction deposited – mouth, nose, trachea, and lung

Journal of Inhalation Research (1995).

This figure shows the relationship between particle size and what percent is deposited in different parts of the respiratory tract.

Figure 2 Aerosol capture by the human body versus the “Bi-Modal Distribution” of ambient aerosols.

The coarsest particles are caught in the mouth, node, and throat, and are swallowed. This reduces the amount of toxics that get into the blood.

The finest modes are captured by the lung, and removal is mostly through the blood stream – a much more dangerous route, perhaps 10x worse than swallowing particles.

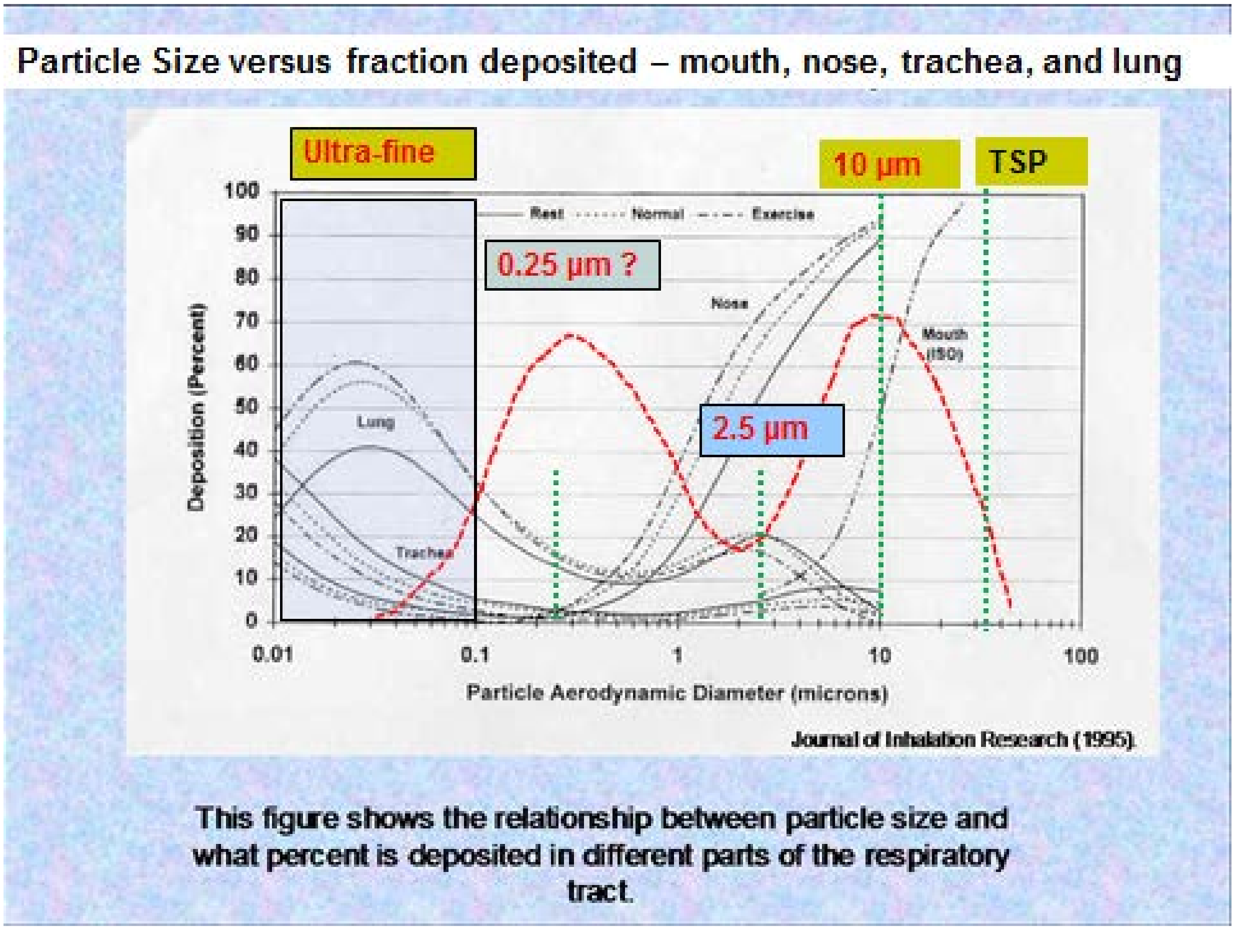

Particle Size versus fraction deposited – mouth, nose, trachea, and lung

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Figure 3 Past and current size cuts for US EPA Clean Air Act ambient air monitoring of particle mass.

TSP was basically a vacuum cleaner with a filter, and collected basically everything in the air. It was superseded by Total Suspended Particulates (TSP), or inhalable, circa 1987, to better match human collection. New research, and consideration of Figure 3, resulted in the current standard of $PM_{2.5}$, particles < 2.5 micrometers in diameter, set at 35 $\mu g/m^3$ for 24 hr, 15 $\mu g/m^3$- annual average.

It is clear that $PM_{2.5}$ includes a lot of mass that, in most cases, is relatively harmless. With this in mind, it is clear that we must efficiently remove the very finest particles from the air to foster human health. Regretfully, this is not easy, and next we will examine the methods.

Particle removal strategies

One of the key factors to discuss is ACH – air changes/hour, in a house or apartment. Cleary, and apartment cannot be hermetically sealed, or you would run out of oxygen. If the house or apartment is leaky, say 2 ACH, then new pollution is being constantly introduced into the apartment and removal must be vigorous. If the apartment or house is tight, such as ½ ACH, then removal has a better change of cleaning the air.

a. **Removal by electro-static devices –**
   a. Avoid at all cost! They don't work well, and make ozone. (viz. The "Sharper Image" late un un-lamented unit…)

b. **HEPA filters –** (High efficiency particulate absorption)
   a. This is a type of air filter. Filters meeting the HEPA standard must remove 99.97% of particles that have a size of > 0.3 μm (micrometers); Excellent for small volumes of air (a single room) in a low ACH apartment.

The problem with HEPA units is the 99.97% requirement. This is really overkill – 95% would be more than adequate for most purposes, but because it is so efficient, it takes a lot of energy to push air through the filter, A commercial example might clean the air twice/hr in a 700 ft^2 room at the highest setting, which could use about 50 watts. Some HEPA filters coat the fibers to trap biological aerosols better. So, volumes are limited for typical single room units.

c. High volume filters
   a. These are used as furnace filters, and while they can filter an enormous volume of air, they are hopelessly inefficient for any but the coarsest particles. Improvements are being made (the 3M Filtrete Series, for example) but because they have to have low pressure drops, their ability to handle the finest particles is poor.

Thus, the problem we face is how to remove the finest particles from the atmosphere – the ones with the highest toxicity and greatest lung capture - and still handle large volumes of air for a full apartment or house.

Fortunately, there is a solution.

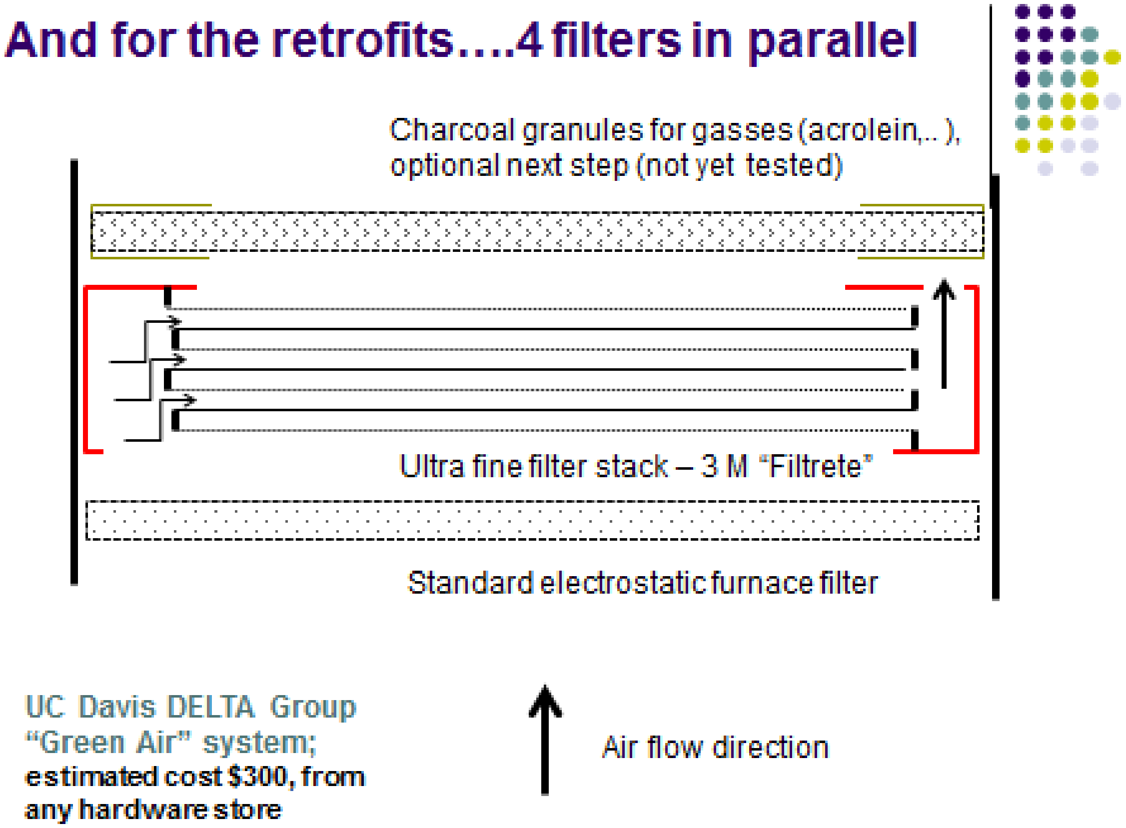
d. High volume low pressure drop HEPA-like filters

The solution is implicit in Figure 1. The ultra-fine and very fine particles are so small that they can easily diffuse to surfaces, if a surface is provided. That is why the removal rate goes up as the particles get smaller in the ultra-fine range.

Our approach is to take the full volume of air in a central house or apartment air system and have it pass through filters at such a slow velocity that the particles can strike the filters. Since they are mostly sticky, there they stay.

We built and tested a similar capability near the BNSF railyard in San Bernardino rail yard, and area with very high predicted cancer rates from the diesel exhaust from trains and trucks. There were old house adjacent to the year, and we were able to clean the air by injecting super clean air into the houses.

One has to slow the face velocity of the air through a filters by 4 to 5 times normal values to give the particles time to stick. We use a stack of 4 standard MMM Filtrete electrostatic filters (circa $120.) run in parallel in a flat pack that sits on top of the usual furnace filter.



And for the retrofits….4 filters in parallel

Charcoal granules for gasses (acrolein,..), optional next step (not yet tested)

Ultra fine filter stack – 3 M "Filtrete"

Standard electrostatic furnace filter

UC Davis DELTA Group
"Green Air" system;
estimated cost $300, from any hardware store

Air flow direction

Figure 4 One design of the UC Davis DEKTA Group high volume, high efficient air filtration system. This unit is designed to drop on top of a standard furnace filter.

The key to figure 4 are carefully designed baffles that force the air to go through the filters **in parallel,** thus slowing the air speed by a factor of 4, 5 6, whatever you need. There is some additional pressure drop (~ 30%) so the whole house air turnover is slightly slowed. The ultra-fine removal stack should last for years since so little mass exists in this size mode

A figuration like this has been tested, and achieved > 90% for very fine (0.26 to 0.09 µm) and a predicted > 95% efficiency for all ultra-fines.

The same result can be achieved by simply having a thin box with 4 or more filters, as shown below.

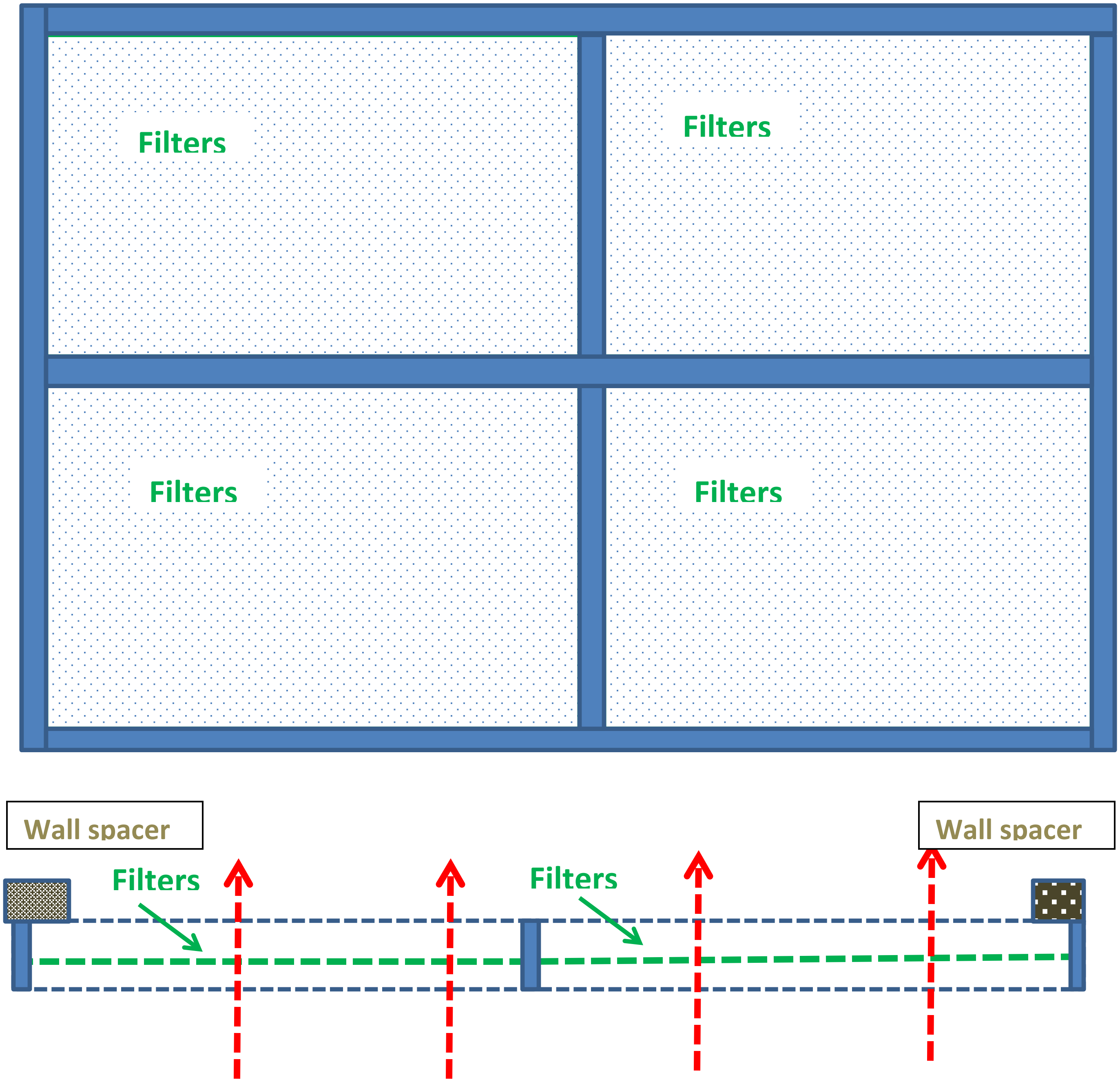


Figure 5 A flat configuration that achieves the same effect in a stack no more than 2 inches (5 cm) thick. This is suitable for placing over either air intakes or air returns in a forced air system.

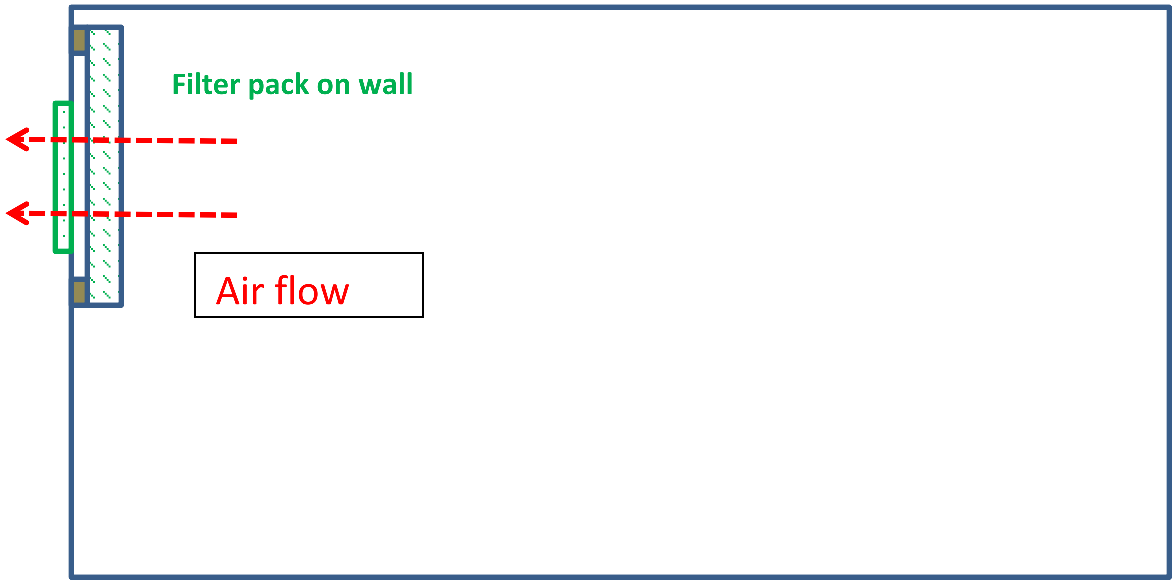
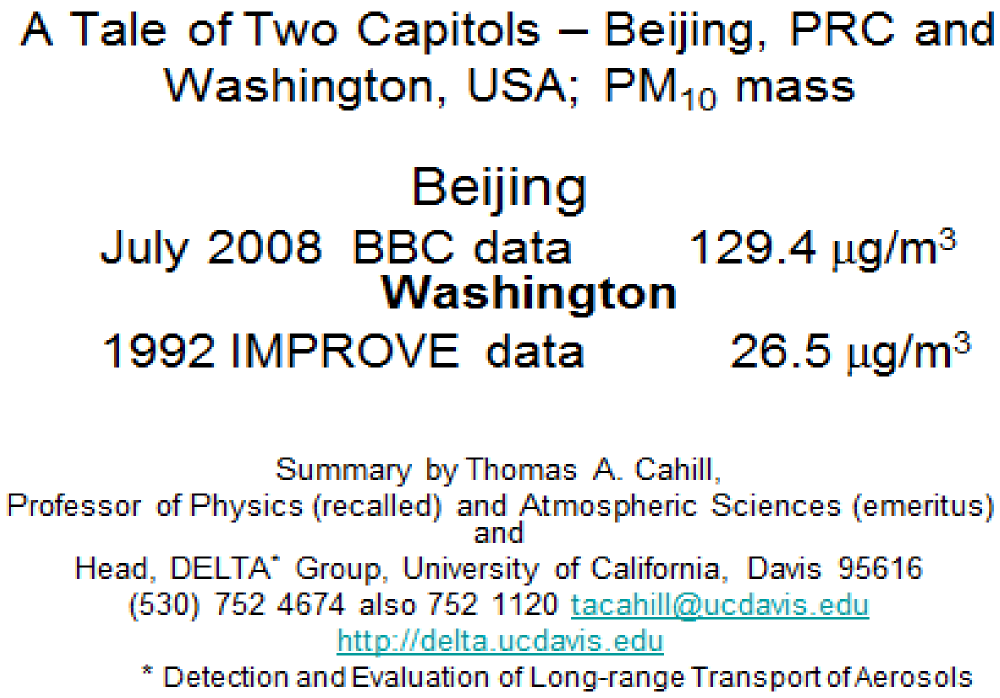


Figure 6. Possible arrangement in an apartment.

Appendix A



A Tale of Two Capitols – Beijing, PRC and Washington, USA; PM_{10} mass

Beijing

July 2008 BBC data 129.4 $\mu g/m^3$

Washington

1992 IMPROVE data 26.5 $\mu g/m^3$

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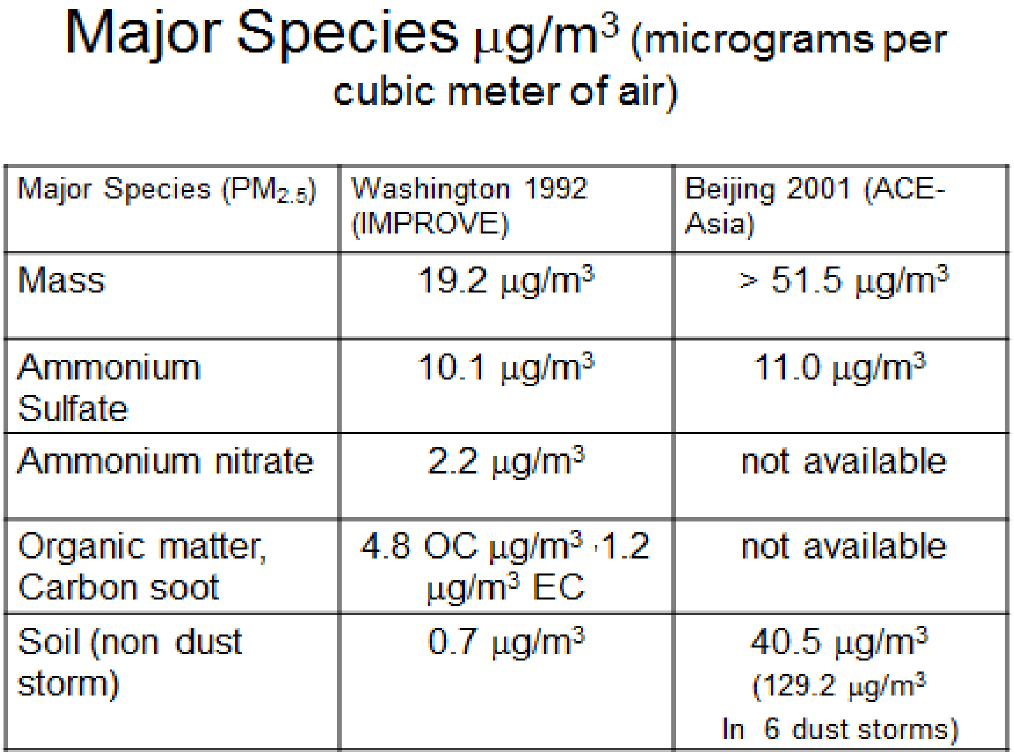
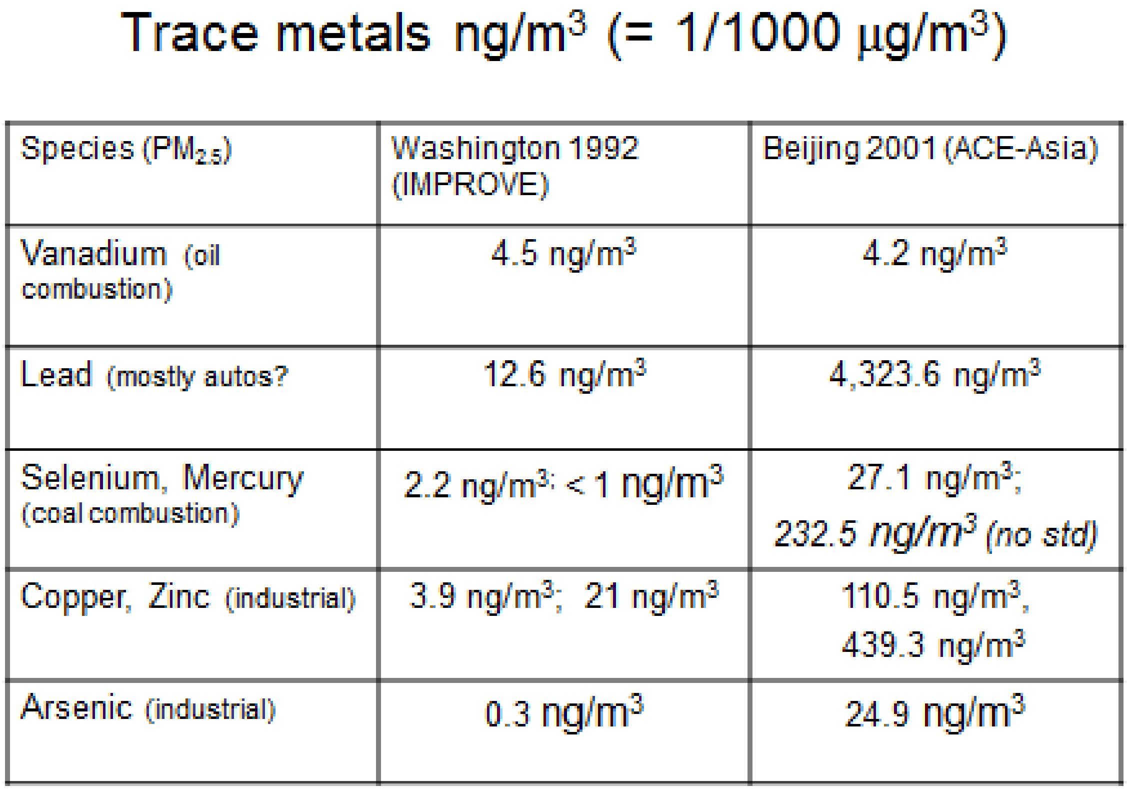
* Detection and Evaluation of Long-range Transport of Aerosols



Major Species $\mu g/m^3$ (micrograms per cubic meter of air)

Major Species ($PM_{2.5}$)	Washington 1992 (IMPROVE)	Beijing 2001 (ACE-Asia)
Mass	19.2 $\mu g/m^3$	> 51.5 $\mu g/m^3$
Ammonium Sulfate	10.1 $\mu g/m^3$	11.0 $\mu g/m^3$
Ammonium nitrate	2.2 $\mu g/m^3$	not available
Organic matter, Carbon soot	4.8 OC $\mu g/m^3$,1.2 $\mu g/m^3$ EC	not available
Soil (non dust storm)	0.7 $\mu g/m^3$	40.5 $\mu g/m^3$ (129.2 $\mu g/m^3$ In 6 dust storms)



Trace metals ng/m^3 (= 1/1000 µg/m^3)

Species ($PM_{2.5}$)	Washington 1992 (IMPROVE)	Beijing 2001 (ACE-Asia)
Vanadium (oil combustion)	4.5 ng/m^3	4.2 ng/m^3
Lead (mostly autos?	12.6 ng/m^3	4,323.6 ng/m^3
Selenium, Mercury (coal combustion)	2.2 ng/m^3; < 1 ng/m^3	27.1 ng/m^3; *232.5 ng/m^3 (no std)*
Copper, Zinc (industrial)	3.9 ng/m^3; 21 ng/m^3	110.5 ng/m^3, 439.3 ng/m^3
Arsenic (industrial)	0.3 ng/m^3	24.9 ng/m^3