I spent 4 stimulating days at Indoor Air 2016 conference. This conference is a biennial event on research in the field of IAQ (indoor air quality) gathering most of the international community (labs, companies, public agencies, etc.). Obviously, any air quality professional should attend this conference.
This article is an illustrated list of informations I am taking away of the conference. I'm happy to share it with anyone who will consider it useful.

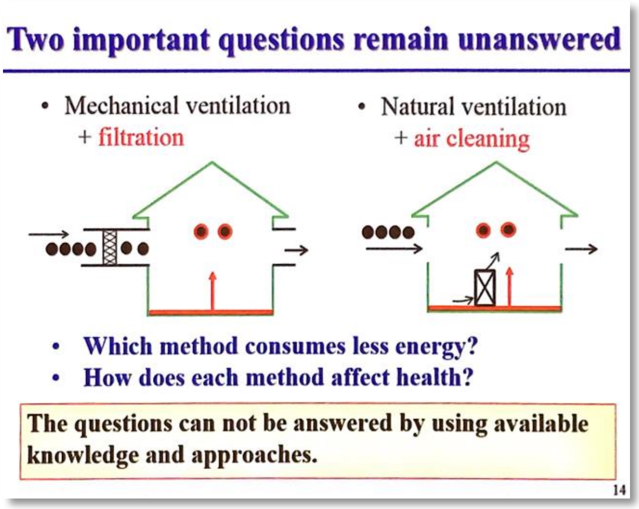
Pierre Guitton

Indoor Air Cleaning must be energy-efficient.

Indoor Air community put much focus and concern about sustainability and responsibility. Which is great of course!
Hal Levin (buildingecology.com) and Mariachiara Tallacchini (philosopher) both raised key questions in this area during their keynotes:

- Shall we focus on securing Air Conditioning for 1.5G people, or food and education for 5.5G?
- Shouldn't we adapt the level of comfort we consider as acceptable, to enable more cost & energy-efficient approaches?
- Should we apply precautionary principle (if there is a risk even small, don't go this way) or assess risk (if risk is reasonable, try it)?

Pr Yinping Zhang (Tsinghua University, Beijing) also emphasized energy efficiency as the key objective when designing the best policy for China against IAQ. And he gives an orientation against air filtration integrated to HVAC system: natural ventilation + in-room air cleaning is a best architecture from an energy efficiency perspective.

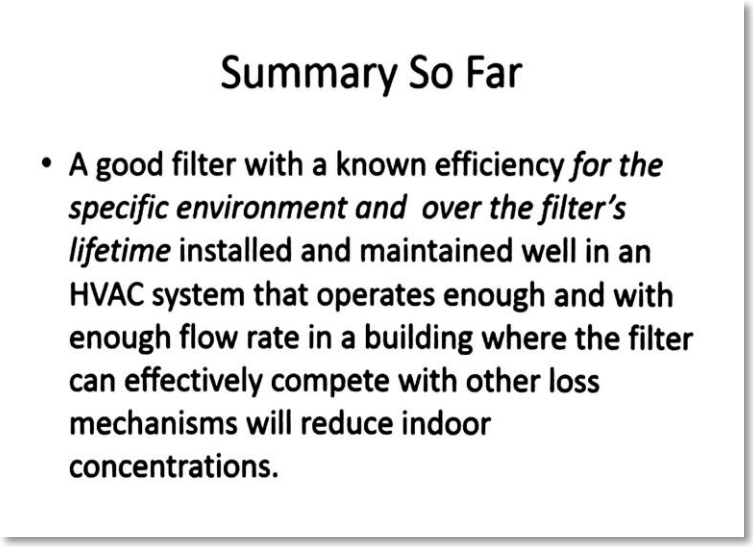


Mr Zhang also promotes an innovative approach towards IAQ monitoring: since measuring air pollutants is so complex and costly (at least because of the number of pollutants and because of the tricky particles topic with their many possible compositions, size, structure), and since at the end of the day the goal is to protect the health of people, why not evaluate air quality, and tomorrow maybe monitor and control it, based on biomarkers? Mr Zhang provides evidence that some biomarkers are very sensitive to air pollution. Work under progress in China!

This priority to energy efficiency is at the core of European Union policy, and French public agencies works (ANSES, CSTB) and universities. And China, obviously.

Current air cleaning technologies are questioned. Gas filtration is not mature yet.

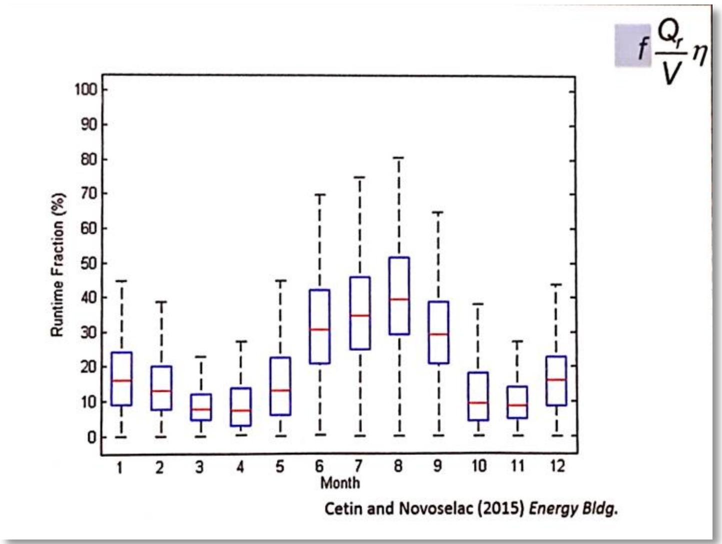
Jeffrey Siegel (Toronto University) provides a depressing overview regarding the efficiency of filters, which are well summarized on this humorous slide:



In other words, HVAC-integrated filters real-life efficiency relies on so many assumptions that it does not reliably cleans the indoor air in many situations!
Jeffrey Siegel relies on strong evidences to make his point:

- Filters efficiency varies with particle size and is lower on ultrafine particles (10-100 nm range)
- Efficiency varies with air speed and can lose another 10% in the 100nm particle size region when speed increases
- Efficiency varies with humidity, but varies differently with the filter…
- Last but not least, efficiency varies heavily over time: always in the 100nm particle size range, effiency loss can be up to 75% after 3 months of operation!

Finally, Mr Siegel provides figures regarding the *runtime fraction* of filtration in the US: it is very seasonal and goes down to 10-20% during the 8 coldest months. Basically, the usage rate is too low for a continuous and efficient air cleaning to happen.



It is to be noted that during his keynote Pr Yinping Zhang agreed with this views on air filtration (integrated to mechanical ventilation).

While HEPA-based purifiers cannot be confused with MERV-standard in-duct filters, they share some drawbacks, regarding performance change over time (10% over a few months) but also and probably more importantly regarding their runtime fraction: many contributors agree that they are not comfortable and savvy enough for users, leading to a fragmented use only over time.
Gas filtration is even more an open field today: M. Nozaki (Japan) reports a 60% efficiency loss over a one-month period for some purifiers! Adsorption mechanisms depend heavily on environmental conditions (humidity especially) and saturation, PCO (photocatalysis) generates by-products potentially more harmful than primary pollutants, Plasma generates ozone which remains n°1 public enemy, both because it is by itself a pollutant, but also because it triggers reactions generating ultrafine particles.

The plenary session on air cleaners raised 4 interesting questions I share here, along with some key points raised among contributors :

1. Can we use technology which adds harmful substance (such as ozone) in the process?
    a. This is a tricky question because it opposes two adverse positions on technology:
        i. « passive filters » pros (primarily adsorption filters), which do not generate any by-product in the process
        ii. « active filters » pros (PCO, plasma, ions) which generally emit ozone or other by-products
    b. Everyone agrees on the fact that ozone is the number 1 chemical component to avoid. Monitoring ozone in consumer products is not currently possible, the minimum concentration detected being way to high (around 30ppb). This disqualifies options relying on monitoring to keep air purification process on the safe side.
    c. It is now established that ultrafine particles are more dangerous than VOCs - and ozone triggers ultrafine particles generation. This to say that ozone is toxic by itself, but also because it triggers reactions leading to other pollutants. It illustrates that we must be very cautious with energetic processes.

d. On the other hand, consumers don't like adsorption-based filters (e.g. activated carbon) because what is adsorbed can be desorbed (as is well-known). So what is the best solution? Open question!

2. How much clean is clean? When it is enough?
    a. Again, two opposite standpoints compete:
        i. Recent studies tend to prove that ultrafine particles are toxic at very low concentrations (« from the first microgramme »), so the Precautionary Principle should apply and we should aim at the purest possible air.
        ii. For most pollutants, evidences for toxicity at very low concentration are scarce. Then, risk assessment should apply (remember Mariachiara Tallacchini!) to design *reasonable* solutions and avoid over-sizing the air purifying function. We must ensure that air purification is energy-efficient!
3. What should be the emission level of O3 for air cleaner in lab and real building?
    a. Regulation exist, but is widely considered as too permissive. It is admitted that regulation is going to move downwards on ozone emission by air purifiers.
    b. California was first in fixing the 50 ppb threshold, but they are not happy with this and will probably move on reducing the threshold.
4. What kind of low cost and low pressure drop gaseous filter for air cleaners should be developed ?
    a. This question illustrates the fact that satisfying solutions for gas purification are not there yet. However, no option seems to get traction in the community currently.

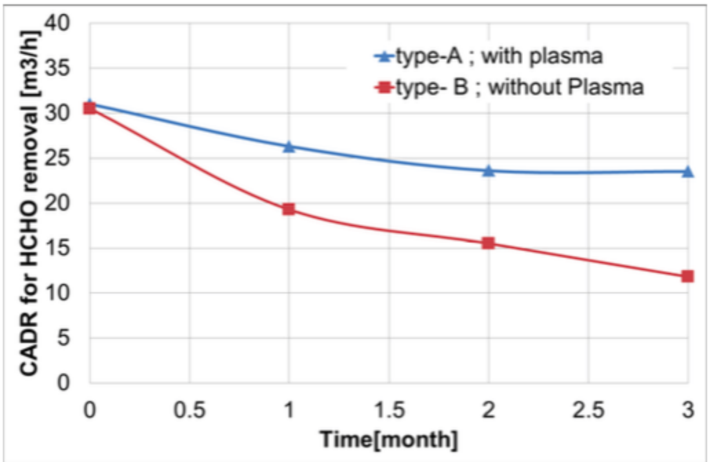
In addition to these considerations, the conference was an opportunity to get valuable data from the chinese context. University of Chongqing run a field study jointly with Boulder University, USA, and University of Reading, UK, where the overall performance of HEPA filters appears not to be as high as we could expect (rougly 30% reduction of PM2.5) :

Table 1. Indoor air pollutant levels (mean ± std) of $PM_{2.5}$, O_3, NO_2, and BC

Pollutants	Concentrations without HEPA filter	Concentrations with HEPA filter	P-value
$PM_{2.5}$, $\mu g/m^3$	43.7 ± 17.8	30.0 ± 18.2	0.003
O_3, ppb	11.6 ± 10.1	8.9 ± 8.5	0.07
NO_2, ppb	109.0 ± 56.1	78.4 ± 44.4	0.011
BC, $\mu g/m^3$	5.4 ± 1.6	3.4 ± 1.6	< 0.001

These results are said in the paper to be consistent with studies run in the US and UK.

Another topic of discussion is the reliability of air purifiers over time. The below graphics shows the CADR evolution for Formaldehyde removal for two types of technologies : adsorption and adsorption+plasma. You can note that even the « good » purifier has a 20% efficiency loss over a 2 months period of time!



Daikin, Japan

Regarding HEPA filters, things are unclear. There filtering power increase over time because fibers get obturated by the « particle cake ». But some « talks » report a loss of 10% over a few weeks, at filter level (not device level), which seems strange. Anyway, CADR at device level can decrease due to the loss in airstream capacity (because of increasing pressure drop).

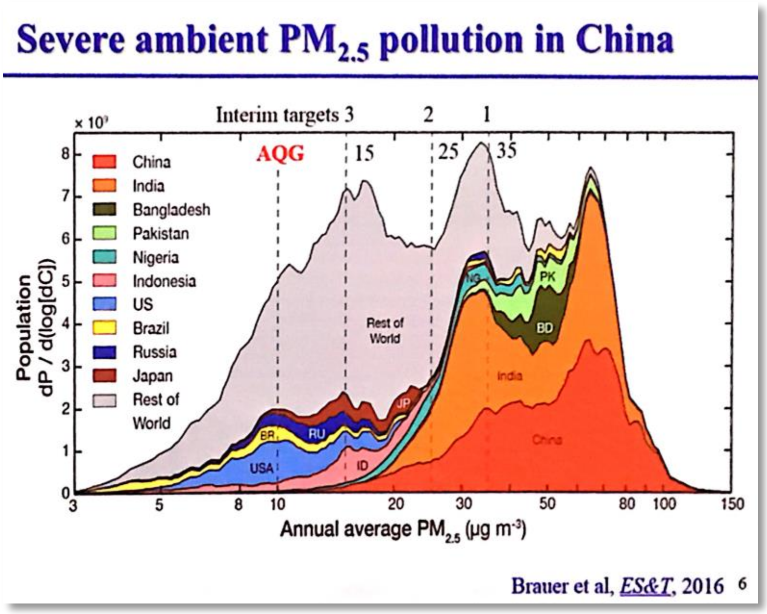
Particles are still considered as the most prominent pollutant.
Measuring PM2.5 is not enough to assess indoor air pollution.

First, as already said, particles keep being a major health concern indoor, and some in the US consider it is the most prominent health risk among indoor pollutants. The reason for this is that particles are a carrier for very toxic chemicals, such as heavy metals and SVOCs.
In France only, a report by ANSES in 2014 establishes that particles are responsibles for 80%+ of mortality caused by indoor air pollution:

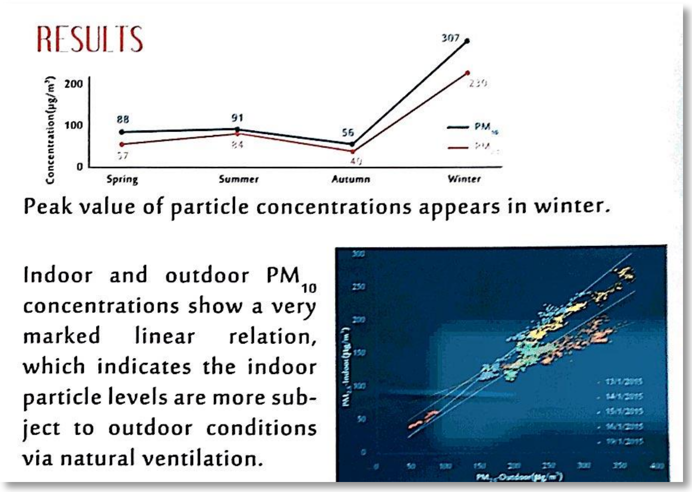
La mortalité totale engendrée par les polluants de l'air intérieur est de 19 884 personnes par an, réparties comme suit :

- 342 décès liés au benzène suite à une leucémie ;
- 20 décès par cancer du rein engendré par le trichloréthylène,
- 2 074 décès par cancer du poumon associé à une exposition au radon résidentiel ;
- 98 décès d'une intoxication au CO ;
- 16 236 décès associés à une exposition aux particules dont 10 006 d'origine cardiovasculaire, 2 074 par cancer du poumon et 4 156 des suites d'une BPCO.
- 1 114 décès par la fumée de tabac environnementale dont 152 par cancer du poumon, 510 par infarctus, 392 par accident cérébral et 60 des suites d'une BPCO.

And France is far from being the most impacted country by particles pollutions, as shows this spectacular graphics by Pr Yinping Zhang :



Particles can be find in large quantities indoor. Some of our customers in China report PM2.5 levels above 100 ug/m3, measured with cheap consumer sensors. At IA2016, scientific measurements confirm that such a level of pollution can penetrate indoor, coming from outside, such as in Qatar (80 ug/m3 PM2.5) even in modern and tightly sealed air conditioned buildings. A field study carried out by Chongqing University (China) and the University of Reading (UK) in Chongqing public schools raises much higher pollutions levels indoor, avec very linked to outdoor pollution, when the building is naturally ventilated:



Many research works perform measurements where PM1 and below are measured. For several reasons:

- Penetration rate of particles (the quantity of outdoor particles getting inside) varies hugely with there size, and the smallest the most penetrating. The smaller the outdoor pollution, the easier it gets inside. Penetration rate can go up to 70% for ultrafine particles. Indoor, submicronic particles are the vast majority of particles in the air.

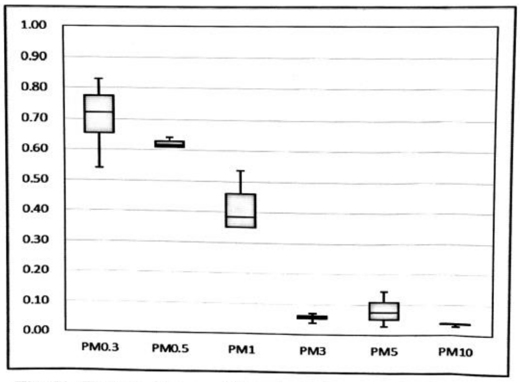
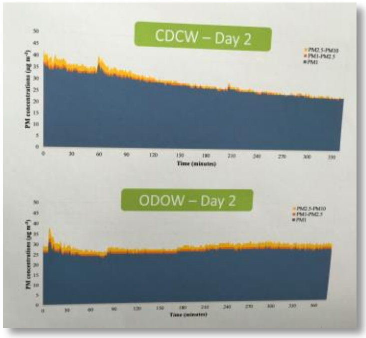


Fig 11. Penetration coefficient of size-resolved particles

University of Seoul, Korea (in a study on thr relationship between indoor and outdoor particle concentrations by penetration coefficient and deposition rate in office building)



❖ **Ratios between PM fractions:**

Ventilation Setting	PM1/PM10	PM1/PM2.5	PM2.5/PM10
CDCW	0.95 ± 0.04	0.98 ± 0.02	0.97 ± 0.03
CDOW	0.90 ± 0.06	0.96 ± 0.03	0.94 ± 0.05
ODCW	0.95 ± 0.03	0.97 ± 0.03	0.98 ± 0.03
ODOW	0.93 ± 0.03	0.98 ± 0.02	0.96 ± 0.03

- The fraction of PM1 accounted for 90% or more of PM10

University of Lisboa, Portugal (in a study on indoor air quality during sleep)

- The community widely considers that low cost particles sensors are unreliable.

  Now let’s take a low cost sensor for particles, sensors that are used in consumer products. They all rely on light scattering phenomenon. The size of particles they can detect is directly linked to the wavelength of the light source they use. Commonly, the physical limit of detectable particle will be around 600 um. And it is the physical limit, it does not mean that they can reliably detect and count all of them. This means that such sensors cannot be reliable for ultrafine particles (0.1 um range and below). The only thing possible is to calibrate them using samples of pollutants. But if the profile of pollution changes (esp. the repartition of particles according to size), then the sensor will provide wrong results. And since for indoor air it has to extrapolate big numbers of « 1um and below » particles based on smaller « 0.5um and above » particles counting, the result can be hazardous…

- DYLOS sensor is considered by some experienced users as +/-20% accurate (estimate by an experienced Korean user). BUT it is in the case you calibrate its results by comparing them with a reliable sensor, for your profile of pollution. Profile that can vary greatly depending on where you live (coal eletrical plants or not, diesel or gasoline cars, gas, coal or electrical building heating, etc.)

SVOC are the new research focus among indoor air pollutants. Particles play an important role in SVOC pollution.

SVOC stands for Semi-Volatile Organic Compounds. Semi means that these chemicals are found both in the form of gas and particles in usual indoor air conditions.
SVOC, among which phtalates account for an important group, are found in many common materials and products you'll find indoor :

- **Plasticizers and flame retardants are semi-volatile organic compounds (SVOCs) added to building materials and consumer products. They are ubiquitous contaminants in indoor environments. Exposure to these SVOCs may be related with asthma and allergic symptoms of children.**
- **SVOCs sorb strongly to dust and airborne particles which may be inhaled.**

A very significant fraction of SVOC is found in the particle form. Particles act as « sponges » for SVOC: at IndoorAir 2016, Tsinghua Universtity (China) and Virginia Tech (US) presented a joint experimental work where the total mass of DEHP transferred from a DEHP surface to the air was increased by a factor 2 to 3!
A French research team has also published a study, funded by ADEME and ANSES, which measured the concentration of 15 VOC and 9 SVOC in the air in 150 dwellings. Phtalates, aldehydes, BTEX and THM were fund widely present in indoor air, for some of them in concentrations exceeding the guidelines values issued by WHO or to values associated with health effects in epidemiological studies.