Trosa 2015 04 15

Indoor Air Quality Report

Location : Swedish Embassy London

Administration offices

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Report: A Hedström

Nbr: 201510-24

Contents

Introduction

Background

Camfil AB had a request from Swedish UD and Swedish Government Property Board to do a full scale indoor air quality test at the Swedish Embassy office building located in central London. At the present time the city of London suffers from frequent high levels of outdoor air pollution sourced from traffic.

The aim of this report is to evaluate the building indoor air quality testing five different standard types of comfort air filters. These filters clean the main Air handling unit (AHU) supply air coming from the outside into the building.

Based on the results of these tests this report will show how indoor air quality can be best improved.

An additional evaluation was made by installing three standalone mobile air cleaners in order to assess if indoor air quality cleanliness could be further enhanced by also cleaning indoor sourced air pollutants.

Figure 1. The Camfil team from the left Robin Svedlind Lab technician R&D, Gertrud Nilsson Deputy Lab Manager R&D, Peter Dyment Air filtration Products & Services, Anders Hedström Global Indoor Air Quality Manager Camfil AB, Sven Petersen Project manager R&D and the Camfil team: Anders Olsson Techn. Support CamCleaner.

Executive summary:

The selected five AHU filter types were each fitted and tested when filtering the air being taken from outside.

The AHU filters were tested alone and then the reference filter City Flo only was tested in conjunction with the standalone Air purifiers inside the office area.

The filters were also tested before the project in our R&D department in Trosa according to EN 779 with reference to EN13779. Also a real life test was made according to the EN 779 test cycle in the actual AHU using atmospheric particle challenge. The Filter types tested were CityFlo F7, Hi Flo F7 and F9, Opakfil F7, and City Carb.

Two full size filter modules were used per test and the AHU had a rotating wheel heat exchanger. The test measuring points were outside and inside the supply air inlet. This was because we did not want to get room air mixed with incoming air, to really see the effect of a specific filter in the AHU.

The outdoor air measured had extremely high concentrations of fine particles in both by number and mass-weight during the four test days which was gave a significant challenge to the air filters. The highest mass reading was 360µg/m3 of PM2.5 and at that time nearly 400 000 000 particles of diameter 0.3µm/m3 by number outdoors.

We took samples of Volatile Organic Compounds (VOC) Microbial Volatile Organic compounds (MVOC) and other emissions together with Gigacheck samples, indoors and outdoors. The results on 0.4µm diameter particle size count made clear that CityCarb had 80% efficiency and CityFlo 55%, HiFlo F9 had 85% efficiency. Opakfil was at 51% level.

The Conclusion is that on these days London air contained high level concentrations of very small combustion particles and of these (85%) were captured with F9 particulate filters. However we needed to capture also molecular pollutants and many of the smallest particles sized close to molecular size. The City Flo has a perfect combination of particle and molecular filter for removing background ambient air pollution and also City Carb compact filter showed very high efficiency. The City Carb however as purely a gas phase filter needs a preferred F7 class pre filter to operate satisfactorily.

The test with Air purifiers showed extremely good results, CityFlo together with City M Air Purifier reduced the indoor air particulate level by at least 90% against outdoor air within 30 minutes. The results we also got were interesting in that with Air Purifiers the VOC's were reduced by 50% and the value with CityFlo and CityM showed decreases of 67% after the test time of 8 hours.

The results clearly showed that when outdoor traffic air pollution levels are elevated use pre filters of M5 class and then a at least F7-F9 filter and a combination of molecular filtration and particle filtration gave a reasonable level of protect inside buildings. However when you have really polluted outdoor air then additional Air Purifiers with molecular filters may be needed to ensure the clean healthy indoor air.

Finally the London outdoor air carries a high amount of 1µm diameter particles probably composed of clusters of minerals and also sand. We found high levels of smaller particles<0,3 µm coming from combustion of fossil fuels, other different kind of oxides were found which we need more outdoor testing to produce define a better definition.

Overall we are able to claim that we can protect building occupants extremely well even in an area with concentrated outdoor air pollution with standard products and with normal supply and exhaust air ventilation with rotating wheel heat exchanger.

Measurement Information

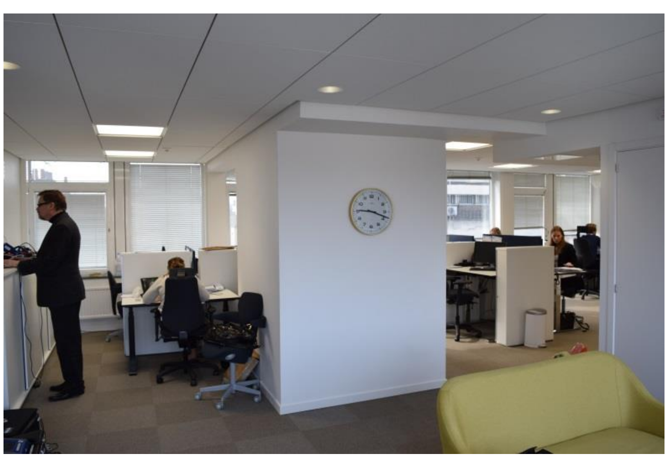

Figure 2. Picture of the Business of Sweden office area where the indoor air testing was undertaken.

Business of Sweden is located in the top floor of the Swedish Embassy at Montague Place 11 in urban London. The office was renovated 2013.

The office was chosen due to its easily accessible new AHU and the good location of the embassy. The office area is about 250 m^2 with 6- 8 people working there during a normal day. The AHU delivered an air exchange rate of 0.8 Air Changes per hour in the office area.

The staff were informed prior to the test measurements and during the whole period of testing they worked without changing their normal activities. The only exception was that the windows had to remain closed so as not to interfere with the results.

The test conducted on the filters were EN 779 in situ and the filters were also tested in the Camfil AB lab facility in Sweden. Tests were made during the period 16-20th of March with 1-2 filters of different filter classes tested each day. The main values tested were number of particles/m^3 and PM2.5 (the mass weight of particles up to 2.5µm diameter).The outdoor air and the supply air along with the indoor air were tested. Other air quality analysis performed were Scanning Electron Microscope (SEM) analysis, emission testing and measurements of the CO_2 level.

Measuring points

Outside location to measure outdoor air beside the HVAC intake		

Inside, close to the supply air grille		
Emissions outdoors and Indoors		

EN 779 test in the AHU

The different filters were tested in line with the EN 779 standard directly before and after the filter.	

Picture of the probes used for the in situ test.	

Instruments and test methods

AeroTrak Optical particle counter (OPC) 0.3µm-10µm	**TSI Aerotrak 9306-01 Six-Channel Handheld Airborne Particle Counter** Six fixed channels, factory-calibrated at 0.3, 0.5, 0.7, 1, 2, and 5 microns, flow rate 0.1 cfm (2.83 lpm).	
DustTrak OPC (Optical Particle Counter) PM2.5 and PM 10	The DustTrak™ II Aerosol Monitor 8530 is a desktop battery-operated, data-logging, light-scattering laser photometer that gives you real-time aerosol mass readings. It uses a sheath air system that isolates the aerosol in	

	the optics chamber to keep the optics clean for improved reliability and low maintenance.	
P Trak 0.02µm-1.0µm Condense Particle Counter	The TSI's P-Trak® Ultrafine Particle Counter (UPC) 8525 is an ideal instrument measuring workplace ultrafine particulate levels, as well as helping eliminate indoor air quality (IAQ) problems. This portable instrument detects and counts ultrafine particles (smaller than 1 micrometer) that often accompany or signal the presence of a pollutant that is the root cause of complaints.	
Velicocalc TSI, CO_2 and VOC direct reading	Straight Air Velocity Probe 964 measure air velocity, temperature and relative humidity Includes differential pressure sensor, Best-in-class air velocity accuracy, Optional "smart" plug-in probes, including VOC, CO_2, and rotating vane probes, Accommodates up to two K-alloy thermocouples	

I A Q Multiscreen, including MVOC, VOC and spores	Tracking MVOC . VOC in indoor air, microbiological and normal Volatile organic compounds In the case of London project we also trapped PAHs which is not standard for the IAQ MultiScreen product	
SEM analysis	This analysis gives an indication of the particle trapped on the surface and could give the customer information about IAQ. SEM photo also gives more info about the structure of particles. The method applied to this measurement is air analyzes; when doing an air analysis a vacuum pump is used for sampling, a membrane to trap particles and a sample holder. Afterwards the air is compared with previous tests based on shape, size, elements and amount.	
Gigacheck indoors and outdoor air, passive measurements.	Passive diffusion: VOC, Ozone, nitrogen dioxide gives the mean over the week installed.	
EN779:2012 at the Tech center in Camfil AB Trosa Sweden	The test is done in a rig qualified according to filter test standard EN779:2012. All required data of the air flow rate and pressure drop are measured. The particulate air filters is	

	be tested with an synthetic aerosol of DEHS, this fine aerosol is used for measurement of filtration efficiency as a function of particle size within a particle size range 0.2 µm to 3.0 µm, The filter elements are tested for particle removal efficiency in different particle size ranges.	

Filter types tested in the actual AHU

Filter no	Picture filter	Type of filter
1		**City Flo XL F7,** A bag filter with Molecular layer behind the particle filtration, glass fibers
2		**Hi Flo XLT F7** A Bag filter with F7 class, glass fibers

3		**Hi Flo F9, a** bag filter but with F9 class
4		**CityCarb** A Compact filter, with Molecular in woven in the fibers
5		**Opakfil F7** A Compact filter F7 class, very high surface
Air Cleaner 3 installed during the test. The where installed in the office on the floor.		City M Air Cleaner. An Certified Air Cleaner ECARF and H13 filters and also molecular filtration

Filter Classification

Filter Class in EN779:2012	**F7**	**F8**	**F9**
Minimum Life Efficiency limits at 0.4µm	> 35 %	> 55 %	> 70 %

EN779:2012

The new European standard for air filters (EN779:2012) came into force in 2012. Its purpose is to classify air filters based on their lowest filtration efficiency. This latter is also referred to as minimum efficiency (ME). The standard is an initiative that we welcome and a step towards better indoor environments.

The new standard will help to eradicate a number of problems. One of these is presented by electrostatic charged synthetic filters. Synthetic medium air filters can demonstrate good initial filtration efficiency, but the electrostatic charge in the medium can discharge extremely rapidly. This entails a critical loss in their air cleaning capability.

Unfortunately, one result of the foregoing is that far too many European buildings have HVAC systems now using F7 class filters that have ME values of between 5 and 10 percent. This means that as much as 90 to 95 percent of the toxic contaminants in the outdoor air can enter buildings, polluting the indoor environment , causing damage to health.

By basing classification on ME value, the new standard forces these inadequate filters out of the market. At the same time, it will contribute to the development of synthetic filter materials offering considerably higher particle separation. Regrettably, the price for this will include higher pressure drops and increased energy consumption.

The problem with the new EN779 classification is that, although the worst filters will vanish from the market, there is room for good filters to be made worse. Although energy savings can be achieved by having the lowest possible pressure drop, such development could be retrograde. For example, with 0.4 µm diameter particles, our Hi-Flo XLT7 (class F7) filter has an ME value of a full 54 percent. However, for classification as an F7 filter, the standard requires no more than 35 percent.

As we have already made clear, we will not be lowering the efficiency of our Hi-Flo filters. That would result in an approximately 40 percent worsening of air quality. However, there is a risk that some manufacturers will not think the same way. Instead, they may see the standard as an opportunity to reduce pressure drop and, thereby, energy consumption. This will result in poorer air quality.

Results

No	Picture filter	Type of filter	Date tested in situ	EN779 Lab test result. 2 filters	EN779 in situ test. At site (0.3-0.5µm)	TVOC and other emission	PM 0.4µm Outdoor Millions /m^3 max. value	PM 0.4µm Indoor Millions /m^3 max. value
1		**City Flo XL F7,** A bag filter with Molecular layer behind the particle filtration, glass fibers	19/3	1. 161Pa 67%±0.4 2. 158Pa 67.7±0,	1 and 2 54,2±1,2	230ug/m^3 There were DMS along with increased levels of 1-Butanol and Limonene.	352	161
2		**Hi Flo XLT F7** A Bag filter with F7 class, glass fibers	16/3	3. 144Pa 61.9±0. 2. 144Pa 62.2±0,	3 and 2 50.7±1,9	180 Higher values of Naphthalene	285	139
3		**Hi Flo F9, a** bag filter but with F9 class	17/3	339Pa 91±0.5 339Pa 91.1±0.1	79.9±2.5	n.a.	330	60
4		**CityCarb** A Compact filter, with Molecular in woven in the fibers	18/3	147Pa 80.8±0.5 144Pa 79.9±0.2	93.3±0.3	190 Higher values of 1-butanol	245	17
5		**Opakfil F7** A Compact filter F7 class, very high surface	17/3	77Pa 50.1±0.8 78Pa 50.7±0	51±0.9	n.a.	356	178
No	**Picture filter**	**Type of filter**	**Date tested in situ**	**EN779 Lab test result.**	**EN779 in situ test.**	**TVOC and other emission**	**PM 0.4µm Outdoor**	**PM 0.4µm Indoor**

				2 filters	At site (0.3-0.5µm)		Millions /m³ max. value	Millions /m³ max. value
6		City M Air Cleaner. An Certified Air Cleaner ECARF and H13 filters and also molecular filtration	18/3		80% +-0.5	100 No deviating values from what is considered as normal.	130	40
		This test shows that when using Air Cleaners the total concentration of VOC may be decreased with 50% for benzene the value was 67% less with CityFlo and Air Cleaner than with only a CityFlo filter.						

Outdoor vs Indoor Air Particle levels.

There are variations of particle concentrations during these measurements where the average outdoor particle concentration was around 314 million particles/m^3 (sizes 0.3-0.5 µm). Highest levels were measured when the Opakfil F7 was installed (date?). Lowest levels in the outdoor air were measured when the City Carb filter was installed 18/3.

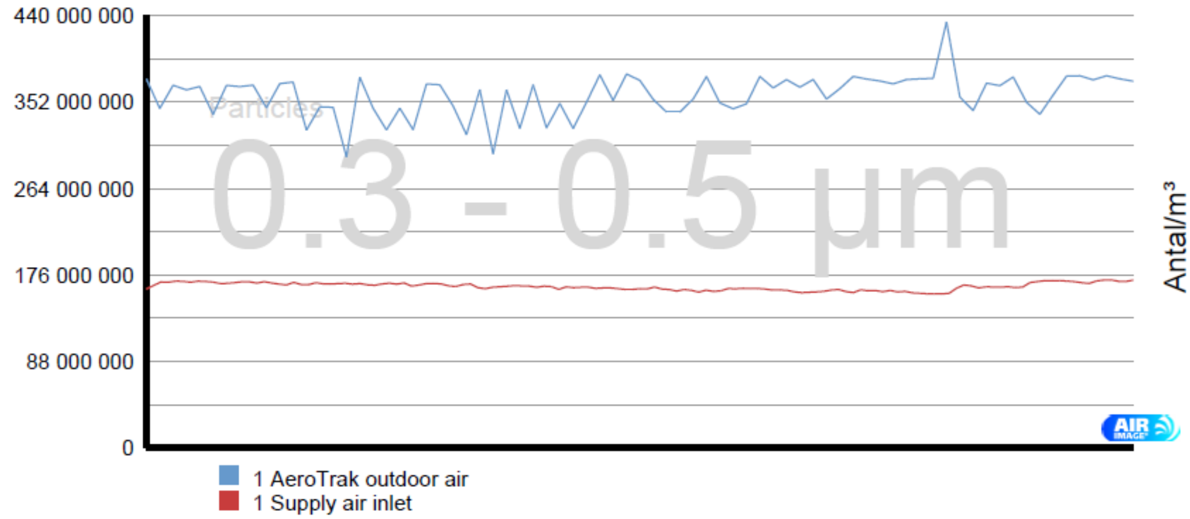

Figure 3. Filter No 1 City Flo XL F7

City Flo XL F7 filter was installed as reference, measurement as the normal filter the client uses, was done 17/3. The difference between supply air and outdoor air was around 50-56% at the time of measuring. The filter has both molecular filter layer and particle filtration. The blue graph (outdoor air level) at a high level. Ref Air Image database and red graph (indoor air level) is constant at a lower steady state.

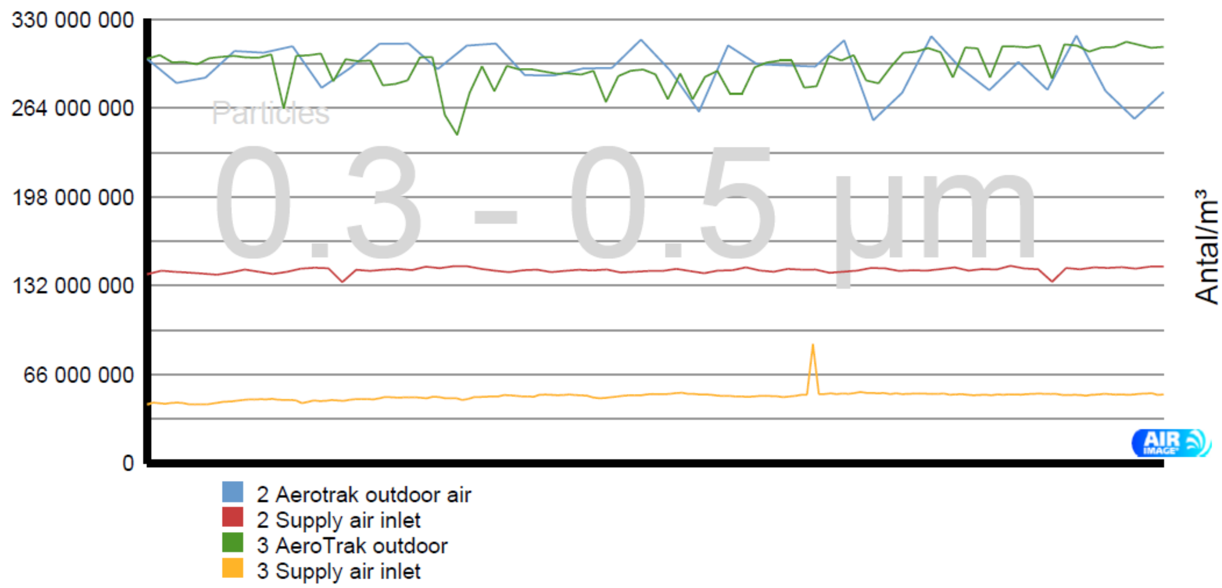

Figure 4. Filter no 3 HiFlo F9 against Hi Flo F7

Diagram above (Figure 4) shows the difference between F7 (red graph) and F9 (yellow graph) filter class with similar levels of outdoor air (red and green air graph at the same level) particle concentration. Still the particle concentration to the incoming air was significant lower with the F9 filter. According to the EN779 standard F7 should have a minimum of 35% and F9 70%. However this in situ test shows that the efficiency is higher. Even laboratory test have higher initial efficiency than the EN779:2012 requirement.

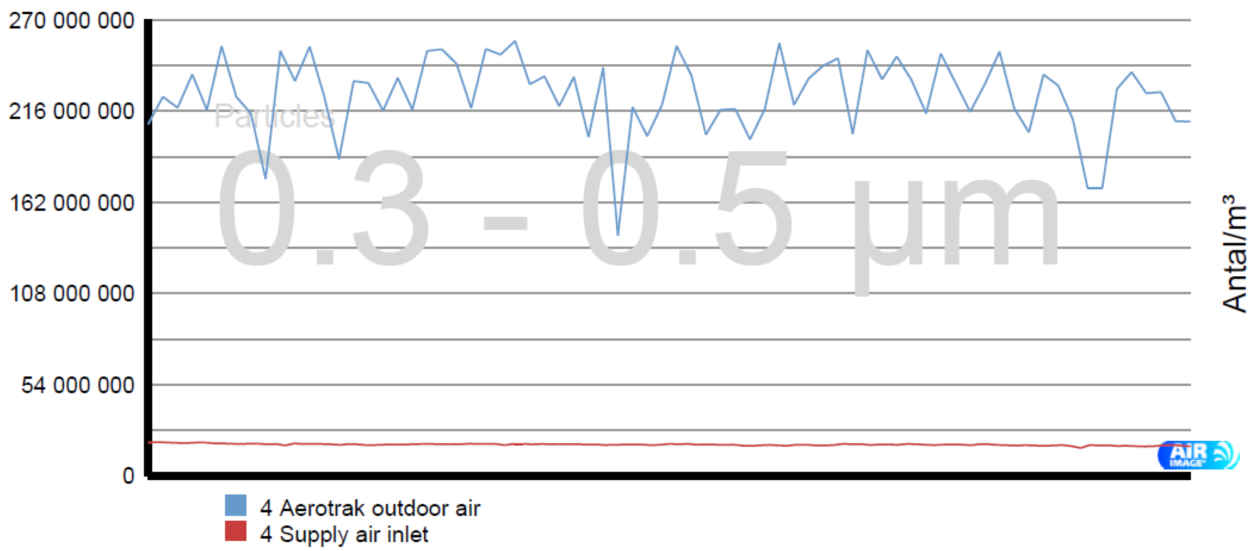

Figure 5. Filter no 4 CityCarb F7

The efficiency in this test is higher than tests done under laboratory conditions (80% versus 93% efficiency). Blue graph outdoor air and red graph supply air inlet.

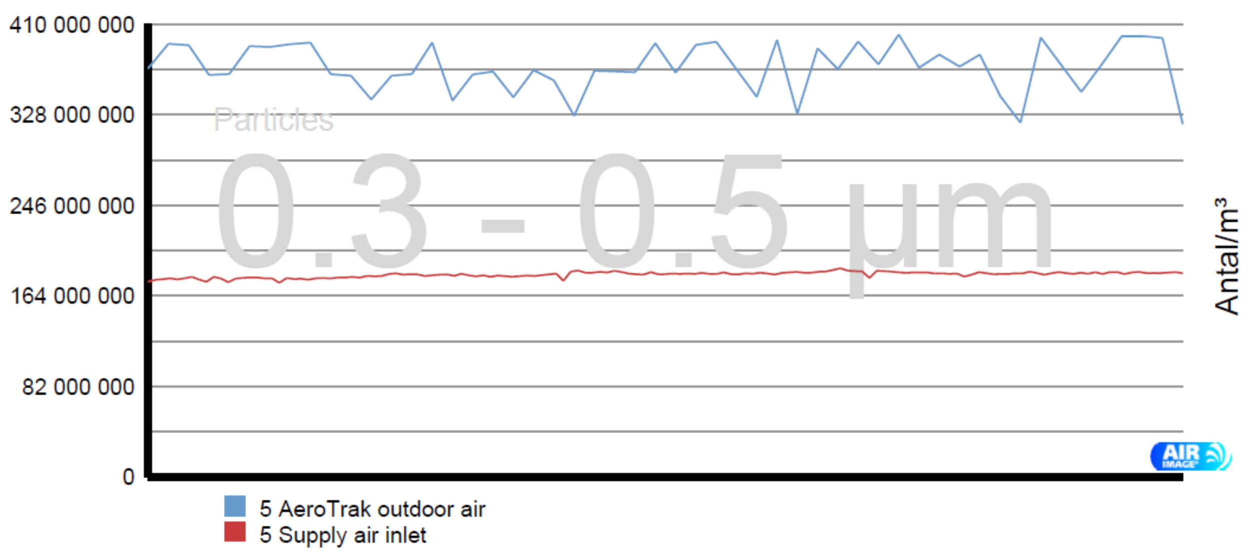

Figure 6. Filter no 5 Opakfil F7

The diagram show the effect when the highest levels of particles were measured outdoors (blue graph) during this day 17/3. Supply air inlet (red graph) had 170 000 000/m^3.

356 000 000 particles /m^3 of 0.3-0.5 µm and 390 µg/m^3 in mass weight PM2.5.

346µg/m^3 of PM2.5 was measured 18/7, which is very high levels concerning the WHO target for yearly average, 25µg/m^3. The value of numbers of particles the actual day was 300- 400 000 000 /m^3 of 0.3µm-0.5µm which is also high. It is even over the limits for our instruments to work properly. Ref, Air Image system, A Hedström and Ref.GMSE, Global Monitoring for Environment and Security) program and funded by the European Commission.

Test against outdoor air and with F7 City Flo installed in the AHU

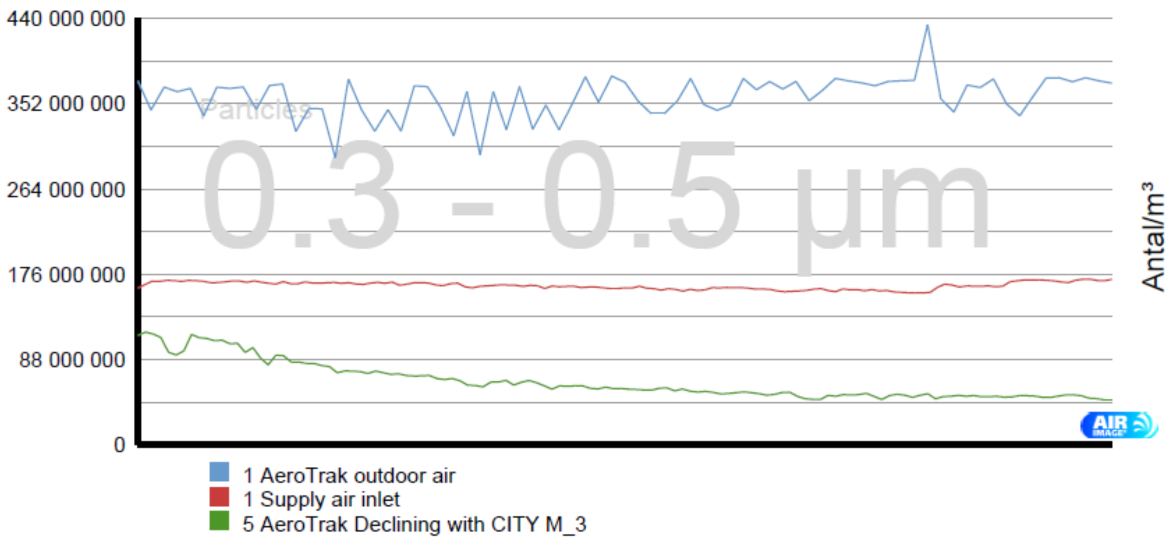

Figure 7. Using Filter Nr 1 City Flo XL F7 in the AHU and CityM declining test

Air cleaners installed with a standard filter of F7 installed in the AHU. Measurements where done during 30 minutes and the green curve shows that the particle concentration declines over time. During the time of measurement the outdoor concentration where higher than the average concentrations measured during this week.

This diagram (Figure 7) shows time on the x-axis and starts with the three air cleaners being turned on. A decreasing level of particles may be seen until a steady state at 40 000 000/m3 of 0.3µm-0.5µm inside the room was reached. Time frame before steady state was reached where 30 minutes. 352 000 000 particles outside, in the supply there was 165 000 000 and in the room there were a final level at 40 000 000. This was close to 90% cleaner air inside the room than without the Air Cleaners.

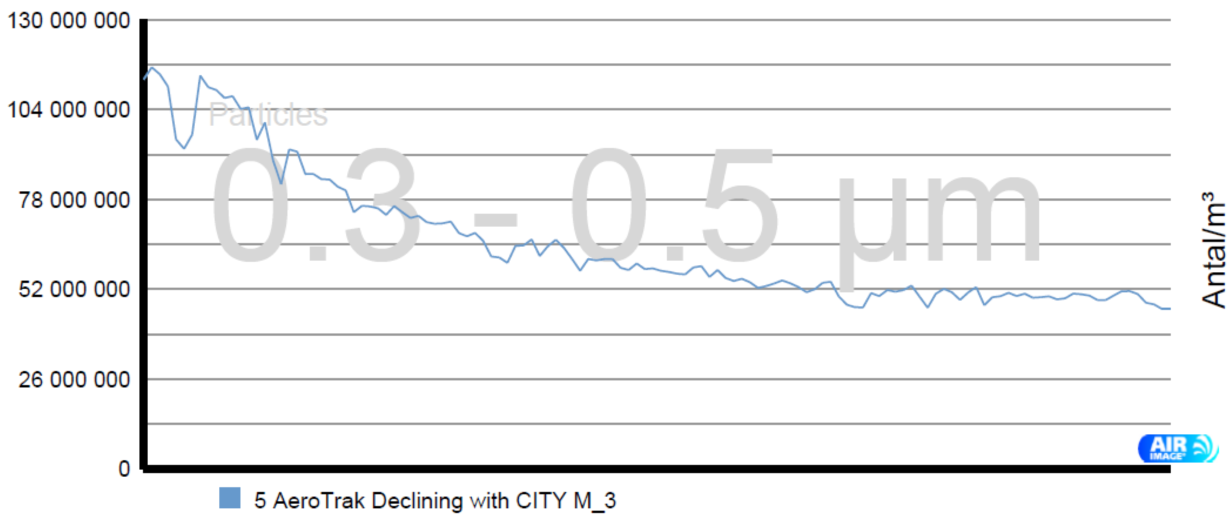

Figure 8. City M declining test

This diagram shows the declining test with City M Air Cleaner and CityFlo F7 filter installed.

The Comparison between all filters, outdoor air vs supply inlet air

1= City FloF7   2=HiFloF7   3=HiFlo F9   4=CityCarb F7   5=Opakfil F7 and CityM

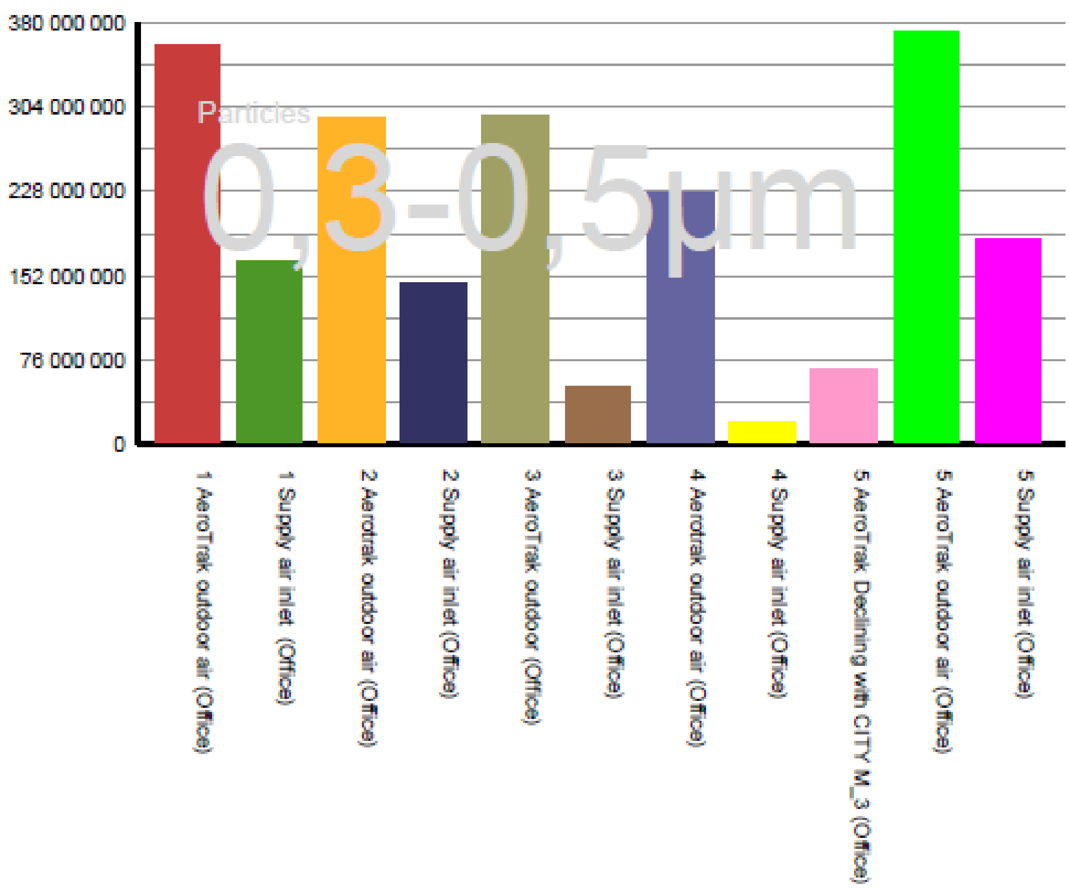

Fig 10. Outdoor air vs supply air in the inlet for each filter

Summary regarding outdoor air and supply air inlet for each filter and CityM installed.

City M was installed together with CityFlo F7.

Other test results.

The SEM analysis shows the distribution of particles over the surface of the membrane media. The test outdoors showed that there is a high amount of big particles at the size 1 µm and larger, these particles were mainly minerals and sand which is very common in outdoor air. There is also different kind of iron oxides found in the sample and some agglomerate of combustion particles. The smaller particles are assessed to be in high levels; the majority of these particles come from combustion processes. The combustion particles are generated by most combustion process, a common source is anthropogenic such as exhaust air from cars and from heating. The small combustion particles have also formed larger groups of agglomerates also referred to as clusters.

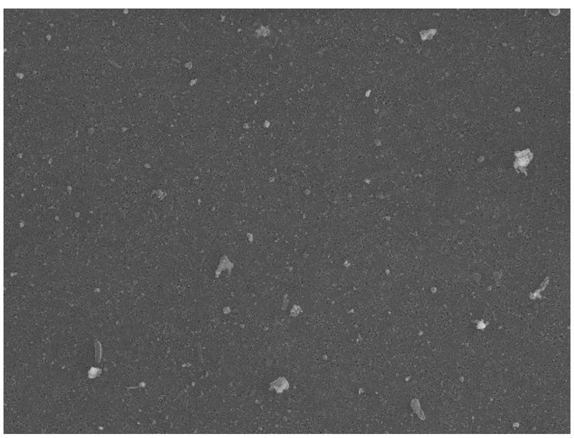

Figure 9. Magnification 250X show the structure of the larger particles in the sample. The particles seen is mainly minerals and sand.

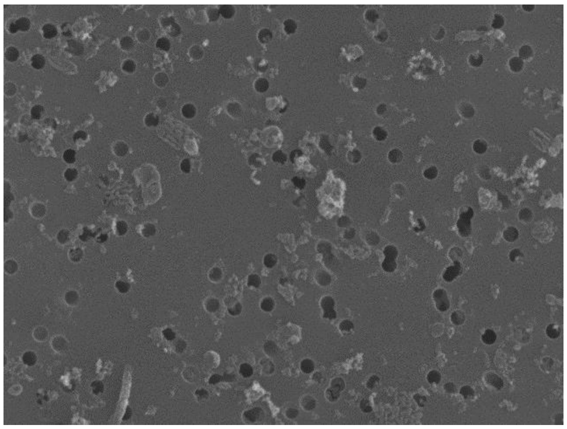

Figure 10. Magnification 10000X show the distribution of small particles in the sample. The particles seen is mainly combustion particles which can be seen as spherical small particles which are grouped together into aglomerates.

2-5um	5-10um	10-20um	20um+	Total	Explanation
48	2			*50*	Combustion particles
26	11			*37*	Corrosion particles or iron rich minerals
14	17	5		*36*	Different types of minerals
10	9	2		*21*	Gypsum, cement or similar
5	11			*16*	-
	1			*1*	Metal particles or aluminum rich minerals
			1	*1*	-
137	48	8	1	*194*	Maximum 300 particles are analyzed
240	99	15	2	*356*	

Table above shows the different types of particles in varying particle sizes. There was no deviating type of particle from what is normally occurring in the outdoor air.

Lab results for emissions in the indoor air

Sample point	SO2	O3	NO2	Toluene	Benzene
outdoor	1,0	32	46,2	1,6	1,2
indoor	<1,2	30	20,6	1,8	0,73
EN13779:2007	ODA 1		ODA 3		

ODA (outdoor air) can be used to set the required IDA (indoor air). For an ODA 3 the recommendation is to use pre filters even for the poorest indoor air quality.

Discussions

Outdoor air and traffic related pollutants were officially classified as carcinogenic by the World Health Organization in 2013. Particle levels and distribution could be a risk factor which may negatively impact on our health. As we live 90% of our time indoors it is important to investigate if we can protect ourselves against air pollution coming indoors with standard AHU filters in a city like London.

Often the concentration of ultrafine particles and Nano particles is related to the distance from a busy highway, but in a city narrow streets will often have more impact on a local environment. A lot of studies have been made into the movement of particles in ambient air however we are still discovering the huge impact small particles and also larger infective particles have on our health. Therefore we should make every effort to minimize exposure to air pollution when inside buildings. We have more complex indoor environment than outdoors because of all emissions and other indoor sources mixed with incoming air. This investigation was made to find if standard filter products and also AHU products could protect us against City pollution as in London.

Dr. Cheol-Heon Jeong and Jon Wang have linked some emission factors to different vehicle sources. Specifically, cars showed higher levels of carbon monoxide (CO) and aromatic volatile organic carbon (VOC); while trucks show higher levels of nitrogen dioxide (NOx), black carbon, and ultrafine particles. Dr Cheol-Heon Jeong and Jong Wang et. Al. *"The particle size is very important because the deposition rate of particles in the lung increases as the size of the particles decreases and people living, working, or travelling within 20 meters from major roads could be exposed to significant amounts of traffic related volatile ultrafine particles below 20 nanometers."*

Filters tested at this site were CityFlo F7, HiFlo F7, HiFlo F9, CityCarb and Air Cleaner City M with CityFloF7. During the week of testing, the particle level was high with readings during the test period of 350 µg/m^3 of PM2.5 and particle counts ranging 200 000 000 to 400 000 000/m^3 by number (0.4 micron).

In the WHO guideline the annual mean is recommended to be below 10µg/m^3 and a 24 hour mean below 25µg/m^3. Outdoor levels taken during the days of these tests were 14 times higher than the recommended 24hour mean.

Based on the EN13779:2007 the recommended filter configuration is to use a three stage system (G4+F7+F9) in order to achieve the highest indoor air quality by removing particles. An alternative to this is to use a higher filter class in the incoming AHU air and install standalone air purifiers within the room. This approach also solves also the particles/emission generated indoors at the same time.

Pre filters can be used in order to prolong the life time of the high efficiency particle filters (F7 to F9) and minimum F7 to protect carbon filters such as City Carb since airborne dust can block the pores in the carbon and minimize optimal uptake of contaminant gases.

The outcome was very clear that CityCarb and Hi Flo F9, had the best particle removal efficiency not only in EN 779 test but also outdoor and indoor simultaneously particle measurements.

The overall result covering particulates and gases indicates that the combination of CityFlo F7 in combination with Air Cleaners gives the best level of clean indoor air quality.

The overall particle level outdoors during the week we tested was high and the smallest PM matter showed indications that the distribution of all particulates outdoors is not normal. The discussion about Cerium Oxidative in diesel combustion could perhaps contribute to increase particles by number and even smaller. Prof. Brett Gantt EPA has informed us that Cerium containing particles do increase numbers as an additive in the diesel. Ref. list. “Near Road Modeling and Measurements of Cerium – Containing Particles Generated By nanoparticles Diesel Fuel Additive use”. We don’t have any evidence for that Cerium Oxidative was present during our test.

Conclusions

Project I A Q London has shown that normal filters for ventilation systems even in an urban area such as London can remove a significant proportion of air pollutants. Effective air filtration can clean and purify indoor air quality and protect people in buildings. It has shown that normal comfort filters for ventilation systems in an urban area, highly polluted, such as London can be sufficient . However for extremely high air pollution events or air pollution hotspots in buildings it may be necessary to consider to need for additional standalone air purifiers to be installed at point of need.

When evaluating the type of air filters needed, it is fairly obvious that we need a high efficiency filter ideally F9 for particulates and preferably in a combination with gas phase molecular filtration in order to remove odours and gas contaminants thus achieving substantially improved indoor air quality. The combination protects us as humans from molecules and particles coming indoors. The lifetime of a filter and also the Energy rating is important with A+ rated filters now available but the most important issue for health remains that fine particles and gaseous emissions are removed.

Since many emissions are generated also indoors along with many bioparticles there is only one energy efficient solution in this situation and that is to use Air purifiers with carbon filters. Air Purifiers in combination with F7-F9 filters in the AHU can decrease particle levels by 90% after only 30 minutes.

These tests show that when using Air Purifiers the total concentration of VOC may be decreased with **50%** for benzene in the office space. The reduction value was **67%** lower when using a CityFlo and Air Purifier in combination rather than just using a CityFlo filter alone.

Acknowledgment

Special thanks is given to Patrick Pihl from the Swedish Property Board and Fredrik Häggström from Business of Sweden who let us perform our tests in their facility. We would also like to thank David Taylor and Chris O Neil for assisting us and helping out with allowances and other testing. Finally I would like to thank my team who performed the tests and dealt with all the different and sometimes difficult issues that occur in field measurements.

Anders Hedström Global IAQ Manager Camfil AB

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Attachments

Common air quality index calculation grid, EU

Index Class	Grid	ROADSIDE INDEX						BACKGROUND INDEX							
		Mandatory pollutant			Auxiliary pollutant			Mandatory pollutant				Auxiliary pollutant			
		NO2	PM10		PM2.5		CO	NO2	PM10		O3	PM2.5		CO	SO2
			1 hour	24 hours	1 hour	24 hours			1 hour	24 hours		1 hour	24 hours		
Very High	>100	>400	>180	>100	>110	>60	>20000	>400	>180	>100	>240	>110	>60	>20000	>500
High	100	400	180	100	110	60	20000	400	180	100	240	110	60	20000	500
	75	200	90	50	55	30	10000	200	90	50	180	55	30	10000	350
Medium	75	200	90	50	55	30	10000	200	90	50	180	55	30	10000	350
	50	100	50	30	30	20	7500	100	50	30	120	30	20	7500	100
Low	50	100	50	30	30	20	7500	100	50	30	120	30	20	7500	100
	25	50	25	15	15	10	5000	50	25	15	60	15	10	5000	50
Very Low	25	50	25	15	15	10	5000	50	25	15	60	15	10	5000	50
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Abbreviation list

AHU Air handling unit

ACH Air Changes rate per hour

PM Particle mass

EN779 standard

VOC Volatile Organic Compounds

MVOC Microbial volatile organic compounds

CO_2 Carbon dioxide

IAQ Indoor air quality

SEM Scanning Electron Microscope