Filtering ultrafine particles and gases – targeted clean air

Väkevä Minna, Timo Jalonen and Kimmo Haapalainen

Lifa Air, Ltd., Hameentie 103 D, FIN-00550 Helsinki, Finland

Corresponding email: minna.vakeva@lifa.net

SUMMARY

We have performed studies onboard cruise ship to study the particle number concentrations, the commonly used filters and the utilization of novel filtration technologies. We observed that the majority of particles in the indoor air of a ship - and this applies when the ship was sailing in clean or polluted outdoor air - are smaller than 1 micron, and mostly of the of the sizes of combustion particles (ultrafine particles). We also observed that the commonly used filters mainly filtered particles larger than 1 micron. Thus we were able to improve the indoor air quality dramatically by introducing a new filtration technology that filters efficiently not only particles but also gas/vapour phase impurities. The same technology was further applied in an urban office to generate a clean breathing zone, and the results were promising: The breathing zone air was cleaned with up to an efficiency of 73,6%. Also subjective results from the people involved in the test were positive

INTRODUCTION

Indoor particulate and gaseous pollutants cause health problems and make living or working uncomfortable. Recently researchers have shown that there is a direct relationship between the productivity of employees and the indoor climate. Even though studies of outdoor pollutant concentrations and their drifting to indoor environment are abundant, and the awareness of the adverse health effects increase, the utilization of efficient filtration does not.

Ambient particle concentrations and their health effects

Studies of aerosol number size distributions show that the majority of the particles are in the so-called ultrafine mode, i.e. their diameter is less than, or of the order of, 100 nm [1,2]. E.g. Car engines and burning processes emit small particles. Especially the diesel exhaust particles have been shown to cause health problems: the ultrafine diesel particles increase response to allergens and have been proven to be carcinogenic [3,4]. Filtration classes better than EU 7, rather even HEPA class, should be used to efficiently remove the ultrafine particles.

Gaseous phase pollutants

Gas and vapor pollutants are in most buildings not filtrated at all, and thus compounds originating outdoors or emitted indoors are carried around the premises through the HVAC system. Compounds that have recently been studied are e.g. ozone and volatile organic compounds (VOC). Ozone episodes are regular in European cities and VOCs are emitted when e.g. fossil fuels are burned. There are also several indoor sources of VOCs. Much studied VOCs are the benzenes, which are known carcinogens – exposure to benzene is e.g. related to the development of leukaemia and lymphoma.

Re-circulation

In many locations circulation of air is considered the most energy efficient method. Re-circulation, however, also circulates the impurities emitted indoors. By filtering air at the return air units or in a Fan Coil Unit (FCU) it possible to increase the level of comfort and to protect the HVAC system. We have studied different levels of return air filtration and the consequent effect on particle concentration and e.g. sensed odours.

Studies in real environment

Researchers have reported high particle numbers (Aitken and Accumulation mode) measured indoors in urban environment. Several studies also report that these are the most abundant modes in marine air. Thus we saw a need to study indoor air of a cruiser ship. In a cruiser ship the ratio of re-circulated air is usually high – the objective of our study was to determine whether there are significant indoor sources and to what extent are the ambient particles transported indoors. And further to study the effect of different filters in reducing the particle concentrations.

The marine studies also offered us a kind of a micro-environment whose results can directly be applied to land applications and especially to cases where re-circulation of air is used: In some buildings it is not possible to increase the power of the HVAC system to meet the clean air requirements of e.g. people with allergies. For example in a premise with a suspected mould problem, where the actual source of the spores has not been located, clean air should be supplied to the person's breathing zone without a need to increase general air supply. Such an approach has also been studied in an office with good results. We wanted to study the actual particle concentrations, but also the sensed effect of the improved indoor air: does the decrease in indoor pollutants affect the subjective results i.e. make the test persons feel well in their current workplace/station.

METHODS

Ship measurements

The ship study was conducted on a large cruiser ship operating on the Caribbean seas. The trial project phases:
1.) Pre-study and installation of the filters and sampling lines: a) the pre-existing situation was studied through measuring the particle concentrations in airflows of four fan coil units. For this sampling lines were installed into the fan coil units; b) improved particle and gas filters were installed into two of the selected fan coil units; c) the aerosol particle measurements were repeated for each of the four fan coil units to define the short-term effect of the filters.
2.) The concentration of aerosol particles was measured every 1-3 weeks by the ship personnel for a period of six months.

Four sampling lines were installed into each fan coil unit: 1) air that was returned from the cabin to the fan coil unit, 2) return air after the filter in the fan coil unit; 3) the air coming from the main air handling unit (AHU); 4) air mixed of the filtered return air and the air from the air handling unit (supply air to the cabin).

The advanced filter technology was a filter bag that consisted of filter media for both particles and gases. The particle filter media is pre-charged, and thus capable of collecting also submicron particles. The gas (and vapour) media is based on activated carbon. Both filter medias are manufactured in a way that enables a very low pressure drop (filtration efficiency EU7). In one of the cabins also a particle charger was used to gain an even higher filtration efficiency; a particle charger in front of the filter bag results in a HEPA-class efficiency.

Aerosol particle number concentrations were measured with an optical particle counter. The device calculates the number of 0.3, 0.5, 0.7, 1.0, 2.0 and 5.0 mm particles per a litre of sample air, it also measures the relative humidity and temperature. The main focus of the trial was, on sub-micron particles that penetrate traditional filters. Such particles are most abundant in all environments and have been proven to cause adverse health effects.

Measurements in an office

Measurements of the effect of a local clean air breathing zone were conducted in an office in Helsinki, Finland. The office is going to be renovated in the near future, due to suspected mould problems. The office room is used by 4-5 people, out of whom two have asthma and one allergies.

A office desk, with an integrated air filter system, was installed into the office room for the duration of the tests (5 weeks). The filtration system re-circulated air, ths acting as a local air cleaner. The desk had two clean air nozzles leading air from the filter unit to the breathing zone of the worker using the desk. The distance between the nozzles was 120 cm, and they were situated at even distances on both sides of the computer keyboard (which was considered the centre point of the desk).

The effect of using the filter unit was measured using an optical aerosol particle counter, with main focus on 0,3 μm particles. Measurements were performed above the keyboard at the height of the face of the person using the desk. Effect of different flow velocities through the filter system were studied.

During the study the users of the desk was interviewed weekly to find out the subjective response to the filtering of air.

RESULTS

Ship measurements

The installation took place during a dry dock of the cruise ship. The shipyard is located in the vicinity of a European city. During dry dock the measurements the median ratio of the concentration of 0.3 micrometer particles of the supply air to the cabin (“to the cabin” = filtered + air from AHU) compared to the concentration of the particles in the air from the AHU was 0.90 for cabin A (min 0.81, max 4.14), 0.41 for cabin D after installation of the filter (min 0.21, max 0.51), 0.71 for cabin B (min 0.50, max 0.88), and 0.46 for cabin C after the deployment of the filter (min 0.36, max 0.58). This shows that at the dry dock the air from the AHU was usually the biggest source of small aerosol particles. It also shows that even though the filtration efficiency of the advanced filters was on the average 95% for the filter bag, and 97% for the filter bag & charger, the air entering the cabin can only be filtered up to

the ratio defined by the air flows: the amount of air from the AHU with respect to the amount of circulated air from the cabin.
Already during the pre-measurement phase few occasions with very high emissions of particles within the cabins were observed. They were related to people getting ready to go ashore: Perfumes, hairspray, fixing of clothes and similar sources are the likely causes of the detected high particle numbers. Similar events occurred occasionally through out the study period, but mostly the particles of the air from AHU outnumbered the indoor emissions.

We observed that at all times the number of the particles increases dramatically with decreasing particle size. This is true for all measured samples: air that enters the FCU from the cabin, air that has been filtered in the FCU, the so called fresh air that comes from the main AHU and the air supplied to the cabin (mixed of filtered air and fresh air). Fluctuations in the particle numbers are due to the different environments the ship has sailed at: the number of 0.3 micron particles in the fresh air (i.e. the air that came from the AHU) ranged from 2 000 particles per litre up to more than 250 000 particles per litre. During the trial the AHU contained filters that are comparable to the standard filters used in the fan coil units. Examples of the measured particle number concentrations are shown in Figures 1 and 2.

Filtration efficiencies for the studied filters are shown in Table 1. The median is used due to the few occasion when the filters seemed to emit particles – such data points would affect the calculation of averages to an unrealistic level: e.g. for the standard filters in cabin A, the median filtration efficiency for 5 um particles was 67%, but the average only 42%. For the advanced filters the average and the median did not differ remarkably.
Please note that the calculated filtration efficiencies for the largest particle sizes (1, 2 and 5 micrometers) were not representative at all times: occasionally the sample air only contained very few of these particles and thus the statistics during such times is very poor. The largest particles might also in some cases deposit on the surfaces of the FCU and then the observed particles are rather due to re-suspension than penetration through the filter at the measurement time.

Table 1. Median filtration efficiencies for the filters in the fan coil units

Cabin & filter	0.3 μm	0.5 μm	0.7 μm	1.0 μm	2.0 μm	5.0 μm
A, Standard	2%	2%	5%	12%	20%	67%
B, Standard	1%	2%	5%	9%	17%	50%
C, Advanced filter bag	91%	95%	96%	97%	98%	100%
D, Advanced filter bag &Charger	97%	97%	98%	98%	99%	100%

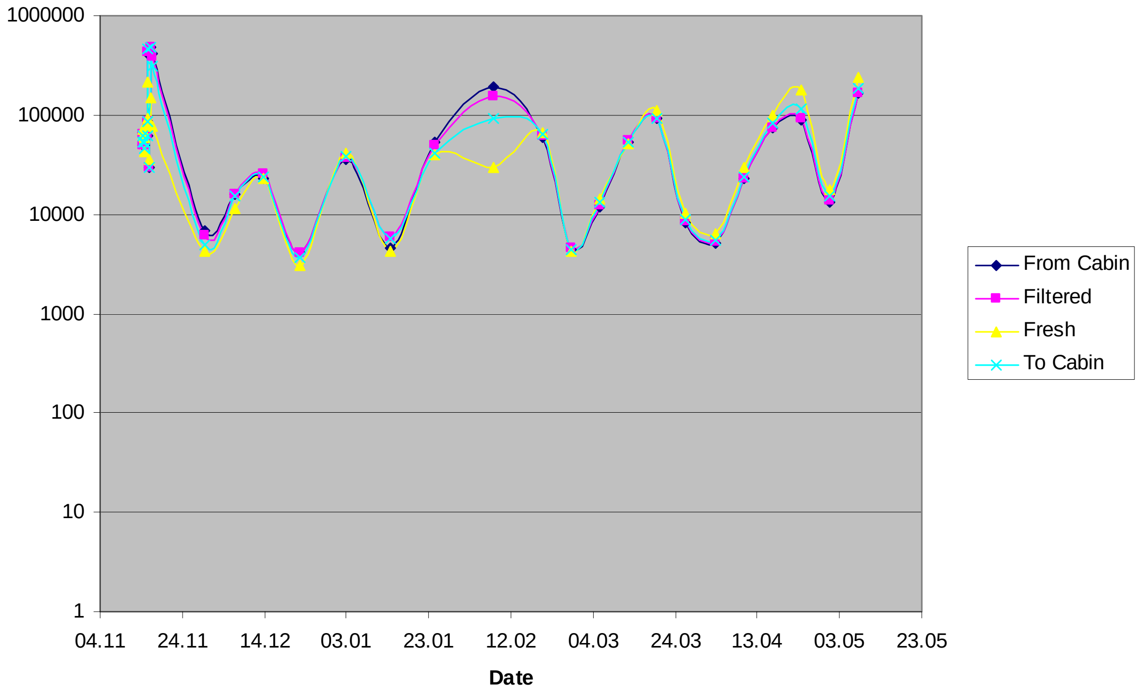

Figure 1. Measured concentrations of cabin A (with standard filter): on vertical axis the number concentration of 0,3 µm particles in a litre of air, on the vertical axis the measurement time.

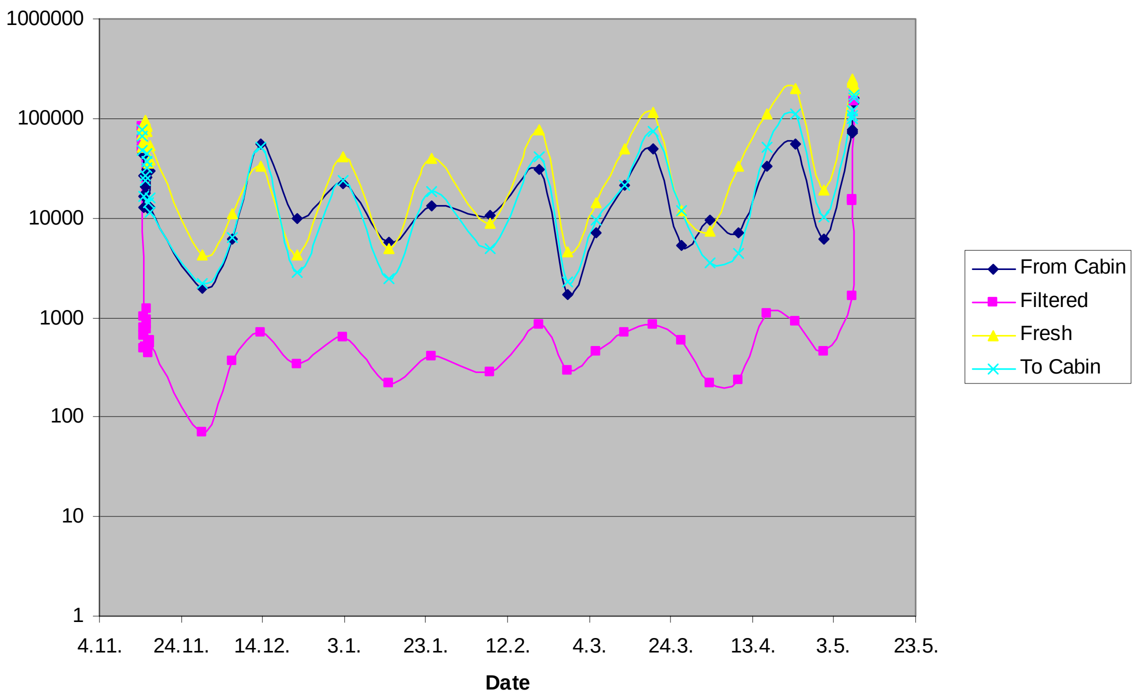

Figure 2. Measured concentrations of cabin D (with advanced filter and the particle charger): on vertical axis the number concentration of 0,3 µm particles in a litre of air, on the vertical axis the measurement time.

Measurements in an office

The effect of the air filtering desk was remarkable. The highest cleaning efficiency (for 0,3 μm particles) within the breathing zone was 73.6% when the system was running on maximum air volume. The cleaning efficiency is defined as the ratio of particles in the breathing zone when the filter system is running compared to the number concentration of particles in the breathing zone when the system is switched of.

Table 2. Average cleaning efficiency of the filter unit integrated to the office desk.

	Cleaning efficiency	Filtration efficiency of the filter unit
Lowest volume flow through the filter	52.1 %	99.55%
Highest volume flow through the filter	73.6%	99.45%

The interviews revealed that during the trial period while working by the desk the symptoms the worker suffered from occurred less frequently or vanished completely.

DISCUSSION AND CONCLUSION

All the studies showed that the effect of using good air filters is dramatic. In the ship, especially when the ship visited urban harbours, ambient pollution is remarkable and thus good filtration should be placed on both the main air handling unit and in to e.g. fan coil units. Filters in the fan coil units reduce the negative effects of recycled air (i.e. removes the indoor emissions)

The office study showed that air in challenging indoor air environments (with respect to particle sources that can not be located & removed) a local clean air zone drastically improves the air quality. The breathing zone air was cleaned with up to an efficiency of 73,6%. Also subjective results from the people involved in the test were positive: they had less symptoms and hence less sick-leaves even though they continued to work in an environment that earlier caused the symptoms to occur. Whether the positive subjective results are due to the reduced air impurities or the psychological effect of the efforts to improve the situation, can not be determined based on the short study. However, if the intention is to minimize the amount of particles in the breathing zone of the work place and hence improve the well being of an employee, then the results are conclusive both based on measurement data and subjectively.

ACKNOWLEDGEMENT

The authors want to acknowledge all partners and parties involved in the studies.

REFERENCES

1. Hussein et al. Urban aerosol number size distributions. 2004. Atmos. Chem. Phys., 4
2. Ketzel, M. Dispersion and Transformation of Traffic Exhaust Particles in the Urban Atmosphere, PhD Thesis
3. Obersdörster, G. 2001. Pulmonary effects of ultrafine particles. Int Arch Occup Environ Health;74

4. Pekkanen, J., Kulmala, M., Exposure assesment of ultrafine particles in epidemiological time series studies. Scand J Work Environ Health 2004