# A TOOL FOR DESIGNING SUPPLY AIR FILTER CLASS FOR HVAC

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## ABSTRACT

Fine filter (F5-F9) rated according to the standard EN779:2002 is classified on the average particle removal efficiency for particle size 0,4 µm, during dust loading of Ashrae test dust. The measured efficiency from an EN779 report will not be possible to use for predicting the particle removal on outdoor air passing the filter due to the artificial dust. Particle matter (PM) is measured locally all over the world, and we can find data for more or less every city in the world. A test method to overcome the problem with dust loading and a calculation procedure has been developed. The calculation procedure is based on data from local measurements of PM and particle removal from filter. The method makes it possible to design the PM removal for $PM_1$ , $PM_{2,5}$ and $PM_{10}$ , for a specific filter. From the calculated values an IAQ could be predicted. The paper will describe the new developed test method for the filter and the procedure for calculation. The paper will also present in situ measurement showing the correlation between the predicted PM values and the actual measured IAQ.

## KEYWORDS

Air Filters, Analyzer for Separation Processes, Air Pollution Samplers, Air Conditioning Plants, Particle Measuring Methods

## BACKGROUND

Clean Air has been an issue for centuries. In the year 1306 King Edward of England made a proclamation banning the burning of coal, due to the heavy smoke this coal caused. One of the first examples of air pollution caused by coal burning comes from King Edwards mother (Queen Eleanor). She became so sick from coal fumes that she had to flee from Nottingham Castle. King Edward imposed a death penalty for burning coal in England.

In USA the first attempt to take control of air pollution was done in Chicago and Cincinnati. In 1881 those cities enacted clean air legalization.

The World Health Organization has published a number of guidelines regarding air quality, the latest version is from 2005 and deals with particle matter (PM), ozone, nitrogen dioxide and sulfur dioxide. PM is measured for different particle sizes where the result is the dust concentration (µg/m³). PM is defined for different particle sizes, i.e. $PM_{10}$, $PM_{2.5}$ and $PM_{1}$. Example: for PM2.5 the index refers to the total dust concentration below the 2,5 µm.

How hazardous are particles compared to other risks in our society? In an investigation [1] done by Department of Health in UK, particle matter, passive smoking and traffic accidents were compared.

*Table 1 Expected gain in life expectancy*

| | Reduction of $PM_{2.5}$ by 10 µg/m$^3$ | Elimination of motor vehicle traffic accidents | Elimination of Passive smoking |
|---|---|---|---|
| Expected gain in life expectancy | 7-8 months | 1-3 months | 2-3 months |

The situation today when designing filter class for HVAC application is that the role of thumb says that on the supply air requires a filter class of F7 in Sweden, F9 in Germany and Coarse filter in USA. But a filter will reduce a certain percentage of the dust concentration. The upstream concentration varies depending on location, which implies that the downstream concentration will vary depending on the location.

*Table 2 Comparison of air quality at different locations with filter class F7*

| Location | [2]$PM_{2.5}$ upstream filter µg/m$^3$ | $PM_{2.5}$ downstream filter µg/m$^3$ (calculated) |
|---|---|---|
| London | 14 | 4,5 |
| Paris | 21 | 6,7 |
| Berlin | 18 | 5,8 |
| Zurich | 15 | 4,8 |
| Copenhagen | 11 | 3,5 |

The difference downstream the filter in Paris and Copenhagen is almost 50 % if F7 is installed at both sites. So to use the roll of thumb is not a good approach.

## HOW TO GET DATA FOR DESIGNING AIR QUALITY

First we need data for PM removal for the filter and secondly we need PM data from the place where the filter is located. Then we are able to propose a filter class to get a sufficient air quality.

*Design data for the filter* In the ISO committee TC142 working group 3 "General Ventilation Filters", a test method is proposed for measuring particle removal efficiency for a filter element in order to generate data for PM removal efficiency.

This method [3] is based on the particle removal on an unloaded filter element. The filter is installed in an EN779 test rig. Flow rate is adjusted to the nominal air flow, the aerosol used is DEHS for particles < 1,0 µm. For larger particles an aerosol with solid particles should be used like KCL or any other aerosol proven to provide the same performance. An initial efficiency curve is measured for particle size 0,2 - 10 µm.

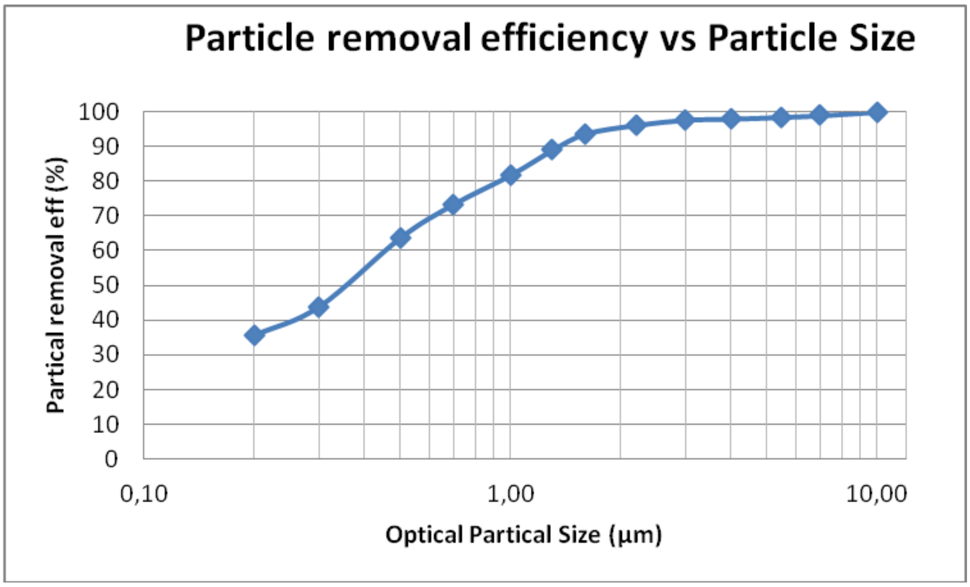


*Figure 1, Filtration efficiency vs. particle size for clean filter of filter class F7*

From this diagram we can use the particle removal efficiency for different particle sizes to calculate the particle concentration downstream the filter.
Many types of air filter rely on the effects of passive static electric charges on the fibers to get a high efficiency. During service time it has been observed that this efficiency can decay. For those type of filters the average value of initial and discharge efficiency shall be used.

*Calculation of PM removal for the filter element:* To make a calculation of the $PM_x$ removal the particle distribution need to be known. The particle distribution depends on the location [4]. In urban areas most particles are generated from transportation and industrial activities with sizes of 0,2 - 0,5 µm and the concentration is high. In rural areas the particles came from the nature which gives coarser particles, typical 6 - 8 µm at lower concentrations.

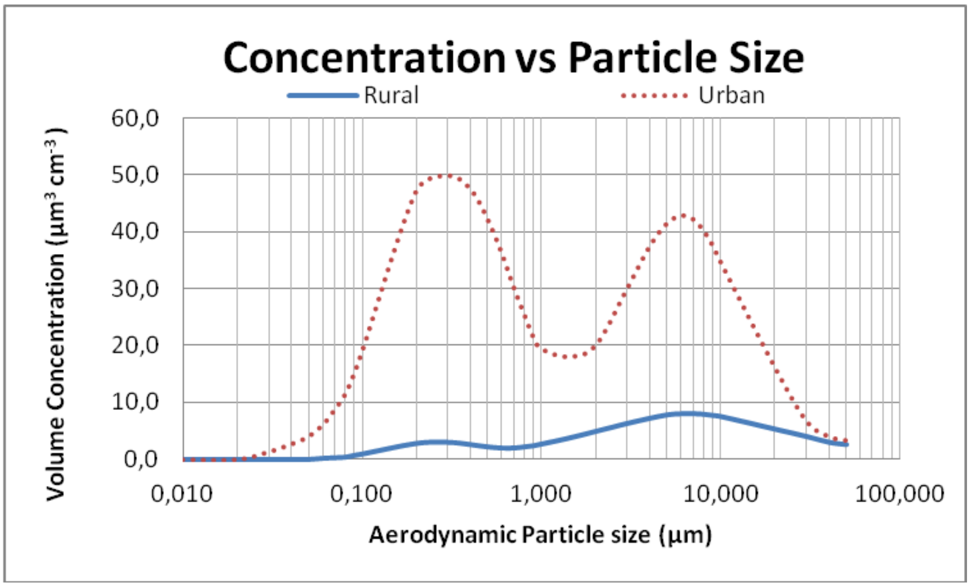


*Figure 2, Particle distribution [4], volume vs particle size for rural and urban location*

The big challenge is the urban area as we can see from figure 2, the concentration is higher and the peak is for the finer particles, which are harder to filter compared to the coarse particles. If we put a filter with the particle efficiency according to Figure 1, we will influence the distribution according to the diagram in Figure 3.

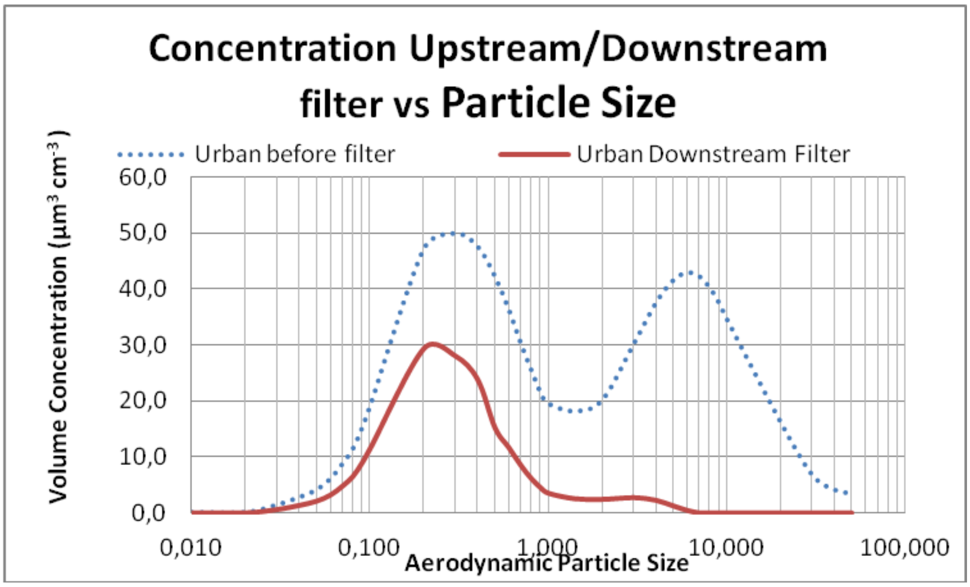


*Figure 3, Particle distribution upstream and downstream a filter of filter class F7*

By using the information from the filtration efficiency curve (fig 1) and particle concentration (figure 2) we can calculate the $PM_x$ value downstream the filter for different particle sizes.

In the diagram below the area under the blue line represent the $PM_{2.5}$ upstream the filter and the red line downstream the filter.

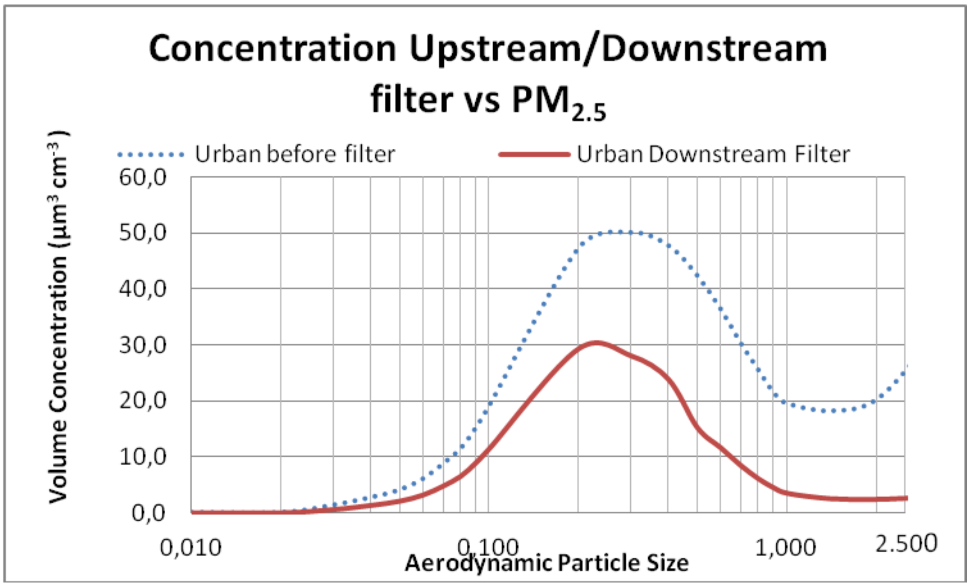


*Figure 4, Volume Concentration in an urban environment vs. aerodynamic particle size between 0,01 µm - 2,5 µm ($PM_{2,5}$)*

The calculation is based on volume and not on mass; we make the assumption that the particles have the same density (1000 kg/m$^3$). Further on the efficiency presented in figure 1, use optical diameter instead of aerodynamic diameter. The difference between optical diameter for DEHS and aerodynamic diameter is approximately 5% [5]. With these assumptions the $PM_{2.5}$ removal and the $PM_{2.5}$ concentration downstream the filter could be calculated from the areas in figure 4.

The calculation could be summarized in a table with the technical specification for the filter.

*Table 3 Filter performance*

| Filter Class EN779 | Pressure drop (Pa) | $PM_{10}$ Removal (%) | $PM_{2.5}$ Removal (%) |
|---|---|---|---|
| M5 | 50 | 80 | 35 |
| M6 | 55 | 85 | 50 |
| F7 | 75 | 90 | 65 |
| F8 | 120 | 95 | 70 |
| F9 | 140 | 97 | 80 |

**WHICH PM VALUE SHOULD WE DESIGN THE FILTER FOR?**

In Europe today we have the EU Directive 2008/50 [6] where we can find the threshold values for $PM_{10}$ and $PM_{2.5}$. According to this directive should the annual average of $PM_{10}$ be < 40 µg/m$^3$ and for $PM_{2.5}$ it should be below 25 µg/m$^3$.
The World Health Organization (WHO) have issued a guideline [7] where the target for the annual mean for PM2.5 is 10 µg/m$^3$ and for PM10 20 µg/m$^3$. Which filter class has to be installed to meet the requirements from WHO (the highest demand) at different locations?

*Table 4 Filter class to meet requirements from WHO [7]*

| Location | Filter class to meet WHO guideline [7] |
|---|---|
| London | F6 |
| Paris | F7 |
| Berlin | F6 |
| Zurich | F5 |

**Outdoor value below threshold value*

From Table 3 we can see that if we shall meet the WHO guideline the filter class varies between F5 (Berlin) up to F7 (Paris). So the values proposed by WHO seems to be achievable values without introducing too high filter classes.

## IN SITU MEASUREMENTS OF PM10 FILTRATION EFFICIENCY

During 2009, 2010 and 2011 measurements of PM10 filtration efficiency has been done in six different locations.

## MEASUREMENT METHOD

The measurements were done in supply air units in residential buildings, office buildings and schools. The gravimetric method that is used consists of sampling heads with an impactor separator and an absolute filter. The air flow is measured with an air flow rate meter. A vacuum pump with adjustment valve is used to get the correct air flow (figure 5). The filters weight is measured before and after the PM measurement and the weight increase is calculated. The method is approved as a Swedish standardized method for PM measurements [9]. The weight of the absolute filters is measured by IVL in climate controlled environment.

Two identical sampling heads are installed upstream and downstream the supply air filters for simultaneous measurement. The airflow for each sampling head is adjusted to 17,8 ± 1 l/min. The total measurement time depends on the operating time of the air handling unit but is typically 20 – 50 hours which gives a total measured air volume in the range of 21 – 53 m³.

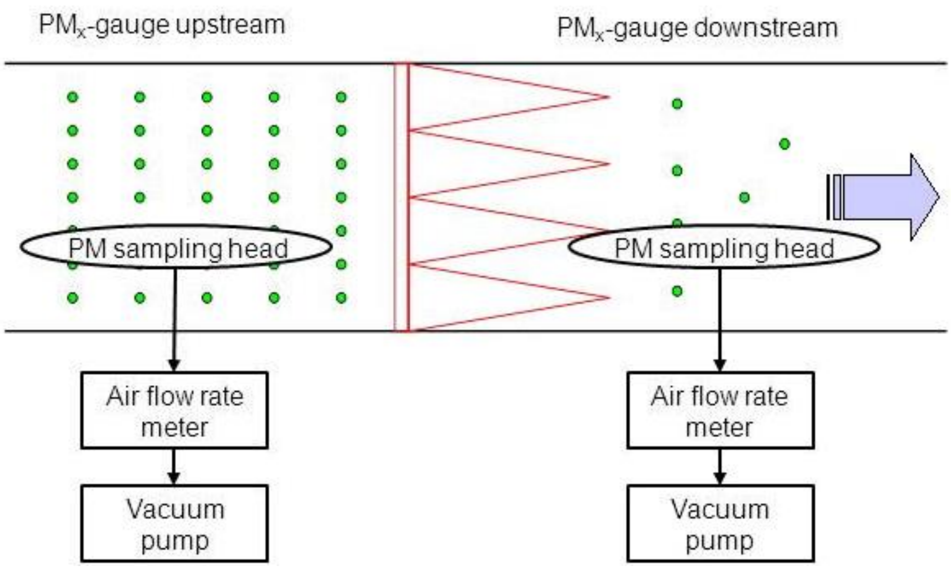


*Figure 5, In situ measurement setup*

**MEASUREMENT LOCATIONS**
Six different places in Sweden have been chosen for PM10 filtration efficiency measurements (Figure 6). The locations are both rural and urban areas and all air handling units has been equipped with bag filter in filter class F7 according to EN779:2002 [10] (Table 4). The cities from north to south are Kiruna, Luleå, Lycksele, Umeå, Stockholm and Svenljunga.

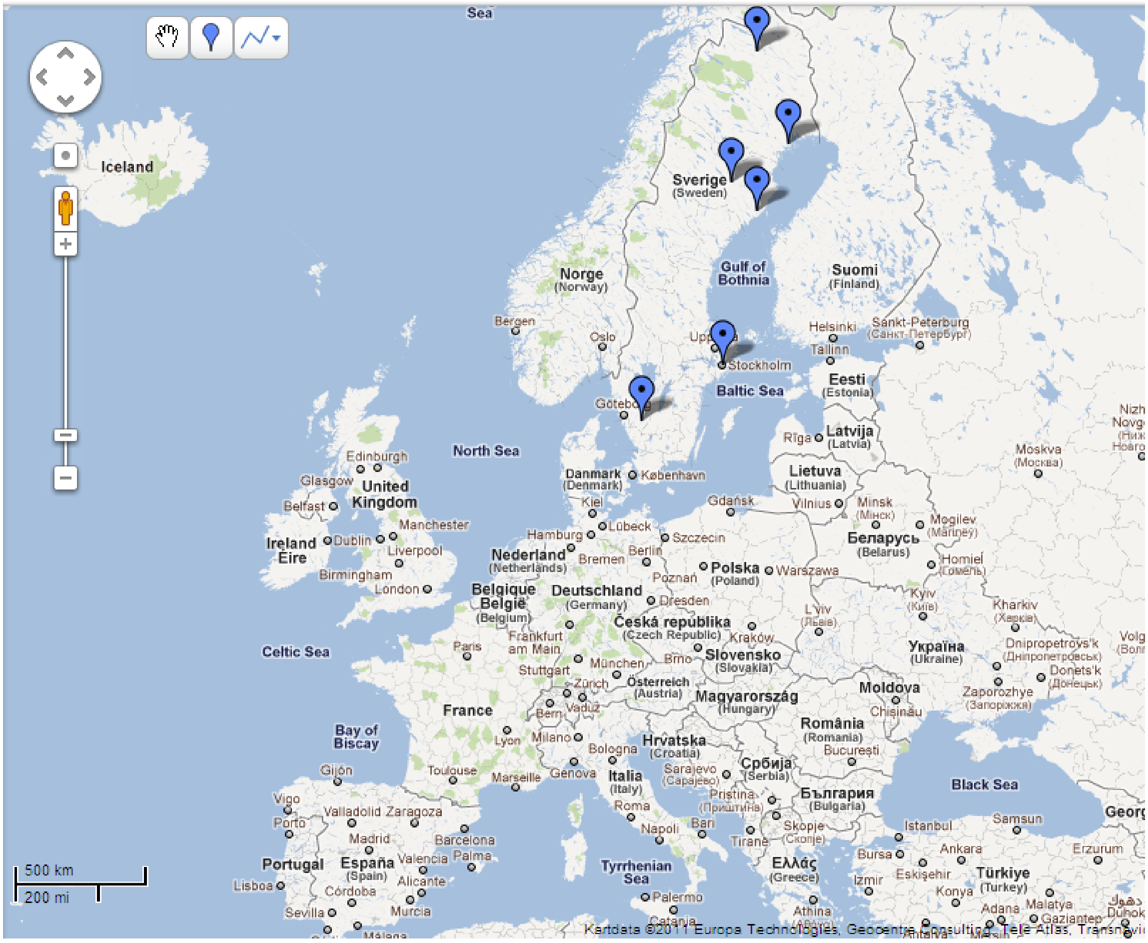

*Figure 6, Locations for In Situ measurements of PM10 removal efficiency*

## MEASUREMENT RESULTS

*Table 5 Results from In Situ PM10 removal efficiency measurements*

| Date | City | Country | Filter class (EN779:2002) | Filter media | Measured PM10 efficiency | Calculated PM10 efficiency* |
|---|---|---|---|---|---|---|
| 2011-02-08 | Kiruna | Sweden | F7 | Glass fiber | 74%± 7% | 97% |
| 2010-12-14 | Umeå | Sweden | F7 | Synthetic fiber | 57%± 6% | 93% |
| 2010-11-23 | Lycksele | Sweden | F7 | Synthetic fiber | 85% ± 9% | 93% |
| 2010-11-09 | Luleå | Sweden | F7 | Glass fiber | 62% ±6% | 97% |
| 2010-09-26 | Umeå | Sweden | F7 | Synthetic fiber | 87% ± 9% | 93% |
| 2010-06-22 | Stockholm | Sweden | F7 | Synthetic fiber | 66% ± 7% | 93% |
| 2009-08-25 | Svenljunga | Sweden | F7 | Synthetic fiber | 75% ± 8 % | 93% |

**The calculated efficiency value was done according to ISO/WD 16890-1 [3].*

Average value for measured PM10 efficiency: 72%

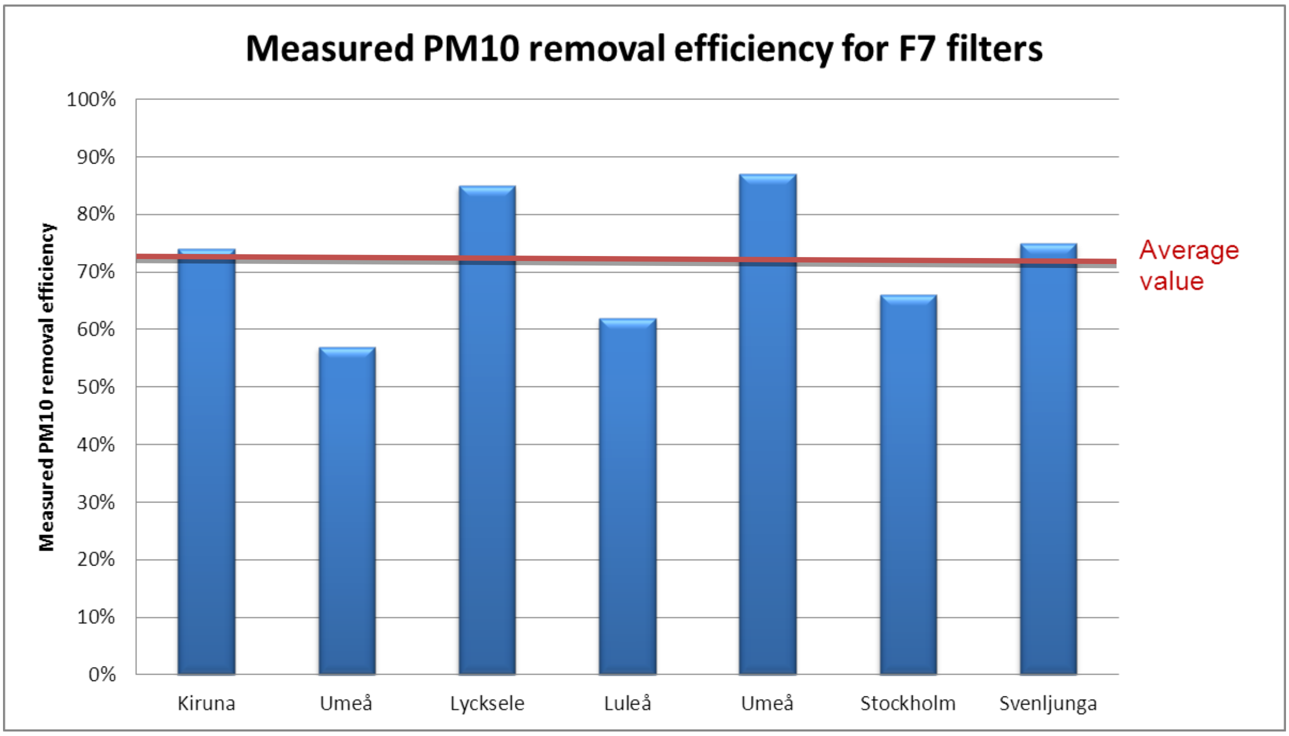


*Figure 7, PM10 removal efficiency measured in different places of Sweden*

## CONCLUSIONS

The paper has clearly shown that it is possible to calculate PM removal based on test data from an EN779 test report.

For big cities in Europe we have shown that required filter class varies between F5-F7 (table 3) to achieve the threshold in the WHO guideline [7]. This paper has also clearly shown that using the role of thumb (F7, F9 or coarse filter on supply air filter) to design filter class is not a good approach. The drawback with using the role of thumb is

- High energy consumption (high energy cost for the consumer due to high filter classes which generates high pressure drop)
- More material used (higher filter class need more filter media)
- Higher $CO_2$ footprint (more energy used during operation and due to more media in the filter)

For example, the energy consumption for one full module F6 running continually one year is 1750 kWh and for a F7 3500 kWh [8]. If we would use the WHO guideline instead of the role of thumb we could save a lot of energy.

Fans in office buildings represent one of the largest parts of the power demand (in Sweden approximately 15 - 20 % [8]). By downgrading from F7 to F6 will in theory reduce power demand in office buildings with 7,5 - 10 %. And this is done without jeopardizing the Indoor Air Quality and we do not need to make any retrofitting.

We have noticed that there is a discrepancy between measured PM removal and calculated values. The PM10 removal efficiency for in situ measurements varies between 57% - 87% with a mean value of 72 %. Deviations may be caused by different particle distribution in different locations but also the fact that Air handling units (AHU) and filter fittings are not leakage free. The bypass air in the AHU will decrease the filtration efficiency.

Further work in this area is required to get a better understanding of which parameters that influence the results. We also need to make in situ measurement with $PM_{2.5}$ .

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