WHAT PM LEVEL DO YOU HAVE IN YOUR INDOOR ENVIRONMENT?

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ABSTRACT

High concentrations of particulate matter (PM) have become a big concern around the globe. The high concentration levels of particles have a big impact on our indoor air quality (IAQ) and health. There are many reports stating how hazardous the PM levels are for our health. There was a study in Europe [1] 2013 regarding PM concentrations impact on public health. In this study involving 3 121 944 people, they made the conclusion that an increase of the PM_{10} concentration with 10 µg/m^3 will the lung cancer rate increase with 22 %. The $PM_{2.5}$ was even more dangerous, with an increase of 10 µg/m^3 the lung cancer increase with 36 %. We spend typically 90 % of our time indoors, therefore is this environment very important.

Today we could design the PM levels in our indoor environment in the same way as we design the indoor temperature. To design for a comfortable indoor temperature we use local data for the outdoor temperature. With this data as an input we could design our HVAC system so the temperature will become comfortable year round. In a similar way we could design the PM level indoors. Every city has data about the local PM levels. We could also find data for removal of PM from the HVAC filters, by combining the outdoor PM levels and the filter data we could get a good prediction of the IAQ regarding PM.

However there is one very important parameter that we need to consider when designing PM levels and that is the air bypassing the filter. The air bypassing the supply air filter is caused by:

- Temperature difference over the building envelope (air entering the building envelope via leakages)
- Wind forces (creating overpressure on side of the building and under pressure on the other side)
- The air tightness of the building (define the magnitude of air entering via leakages)
- Leakages in the filter installation
- In some cases surplus air of exhaust air to establish under pressure in the building will contribute to unfiltered air

All these parameters will have an impact on the IAQ due to the fact that the air that is not passing the supply air filter will not be filtered. This paper will show how the IAQ is affected and present a calculation method for the IAQ quality based on filtration efficiency and air leakage. It also contains results from two different In Situ measurements to validate the theoretic approach.

Keywords: HVAC, ISO16890, PM efficiency, Air quality, Infiltration

1. Objective

The objective with this paper is to show the influence from different filter classes and unfiltered air on IAQ. This is done both with a theoretical study and calculation of how the air flow and building air tightness affects the IAQ. We have also done In-Situ measurements with different filter classes in two locations. One location with low PM_x values and one with high values.

2. Introduction

During 2016 a new ISO standard [2] for HVAC filters will come. Classification will be based on PM_x removal for the filter. By means of the new standard the PM_x value could be calculated downstream the filter element. The distribution of particles in outdoor air is assumed to be known in accordance with [7], the local concentration for PM_x is known and the PM_x removal efficiency is known for the actual filter element (measurements based on ISO standard [2]).

As an example: $PM_{2.5}$ is measured locally to 21 µg/m^3. The $PM_{2.5}$ removal efficiency has been measured to 70% for a specific filter element. The downstream concentration for this example will then be 21 µg/m^3 * (1-0,7) = 6,3 µg/m^3. Data for PM removal for PM_1, $PM_{2.5}$ and PM_{10} could be found at http://www.vokesair.com/ .

A patent has been granted in the same area, “Method for filter selecting” [6]. The method comprising the steps of: measuring a pollution level present in the air, determining a filter parameter based on a combination of the measures pollution level and the requested IAQ downstream, providing the filter system with a filter having a filter parameter matching the requested IAQ; measuring a pollution level of the air provided by the filter system in which the selected filter is arranged. The “Method for filter selecting” has been applied for the measuring results in this paper.

3. Theoretical study: How much of the air entering a building is unfiltered?

The Indoor air quality is not just depending on supply air quality and particles generated inside the building. Due to air infiltration/exfiltration caused by weather conditions and unbalanced ventilation systems, all air entering the building will not be filtered. The unfiltered air flow to a building depends on following

- Air tightness of building
- Pressure drop over building envelope (caused by temperature and wind load)
- Eventual surplus exhaust air

The surplus exhaust air for the Nordic countries is very common +10% of the supply air. In southern part of Europe the AHU is normally balanced or adjusted to achieve an overpressure in the building. The reason for this difference is the climate and the need to prevent condensation in the building envelope.

The air tightness of a building is normally measured by a blower door [3]. The method is to seal all ventilation openings to the building. Then the house is put under pressure via a fan. Typically the flow rate is measured at pressure drop of 50 Pa over the building envelope and reported as Ach_{50} value. This means the number of air changes per hour at pressure difference of 50 Pa.

The relationship between Ach_{50} value and the yearly average infiltration value has been examined in an article [4]. In the article they assume a pressure drop over the building of 4 Pa (as an average over a year). A formula for the Ach_4 correlating with the Ach_{50} has been found, the formula is

$Ach_4 = 0{,}1983 * Ach_{50}^{1{,}04}$. [Equation 1]

In another article [5] the number of Ach_{50} values in accordance with the building code for different European countries has been compared. For an office following values was reported.

Country	**Maximum allowed, Ach_{50}**
UK	3,7
Finland	4,0
Norway	1,5
France	7
Belgium	3
Germany	1,5
Italy	4,4
Netherlands	4,2
Spain	6,3
Sweden	2,1

Table1: Maximum allowed number of Ach_{50} values for offices in accordance with the national building code

The air change rate for office buildings around the world differs a lot depending on national regulations and age of the ventilation system. An investigation [10] done by REHVA with support from the European commission showed that the air flow rate/person in office buildings is in the range from 4,2 to 12 l/s/person in the 16 different European countries. If the value is recalculated to air change rate/hour it corresponds to 0,45 to 1,28 air changes/hour.

For new installations general guidelines [11, 12] recommends 3-6 air changes/hour. The air change rate and the amount of unfiltered air will affect the IAQ and will affect the recommendation of filtration efficiency for the supply air.

In best case we assume the following conditions:

- Office fulfill national building code regarding air tightness
- Yearly average annual pressure drop over building envelope is 4 Pa
- Fresh air to the office is 5 Ach
- The ventilation is balanced or with positive pressure = no surplus exhaust air
- Total air change = Fresh air + unfiltered air

Country	*)Ach, due to infiltration	Ach due to surplus air	**Total amount of unfiltered air (Ach)**	**Percentage of unfiltered air**
UK	0,8	0,0	**0,8**	**14%**
Finland	0,8	0,0	**0,8**	**14%**
Norway	0,3	0,0	**0,3**	**6%**
France	1,5	0,0	**1,5**	**23%**
Belgium	0,6	0,0	**0,6**	**11%**
Germany	0,3	0,0	**0,3**	**6%**
Italy	0,9	0,0	**0,9**	**15%**
Netherlands	0,9	0,0	**0,9**	**15%**
Spain	1,3	0,0	**1,3**	**21%**
Sweden	0,4	0,0	**0,4**	**7%**

Table 2: *) Calculated by using values from table 1, and equation [1]

In worst case we assume the following conditions:

- Office fulfill national building code regarding air tightness
- Fresh air to the office is 0,5 Ach
- Surplus air is 10 % of fresh air (0,05 Ach)
- Total air change = Fresh air + unfiltered air

Country	*)Ach, due to infiltration	Ach due to surplus air	**Total amount of unfiltered air (Ach)**	**Percentage of unfiltered air**
UK	0,8	0,05	**0,85**	**63%**
Finland	0,8	0,05	**0,85**	**63%**
Norway	0,3	0,05	**0,35**	**41%**
France	1,5	0,05	**1,55**	**76%**
Belgium	0,6	0,05	**0,65**	**56%**
Germany	0,3	0,05	**0,35**	**41%**
Italy	0,9	0,05	**0,95**	**65%**
Netherlands	0,9	0,05	**0,95**	**65%**
Spain	1,3	0,05	**1,35**	**73%**
Sweden	0,4	0,05	**0,45**	**47%**

Table 3: *) Calculated by using values from table 1, and equation [1]

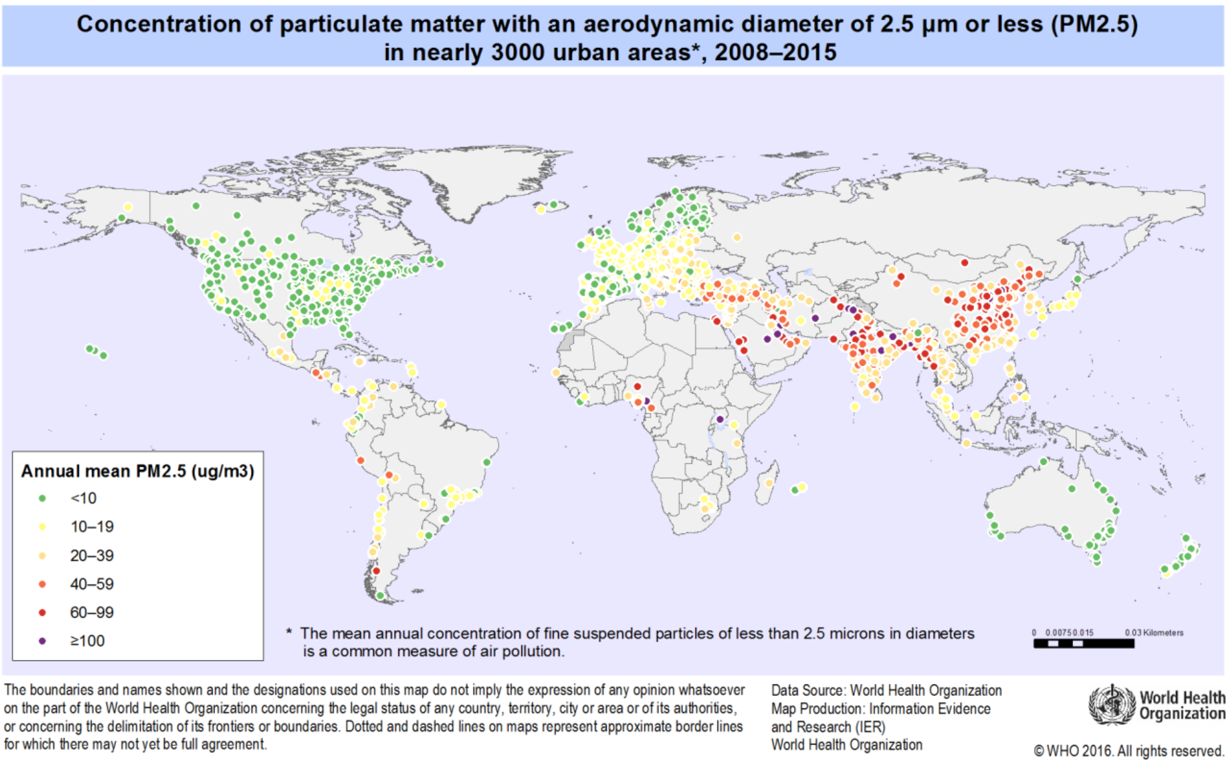
The conclusion from the calculation above is that the amount of unfiltered air can vary between 6 % up to 76 % depending of the Ach and the building air tightness. This clearly shows the importance to take the leakage in the building envelope into account when calculating the IAQ.

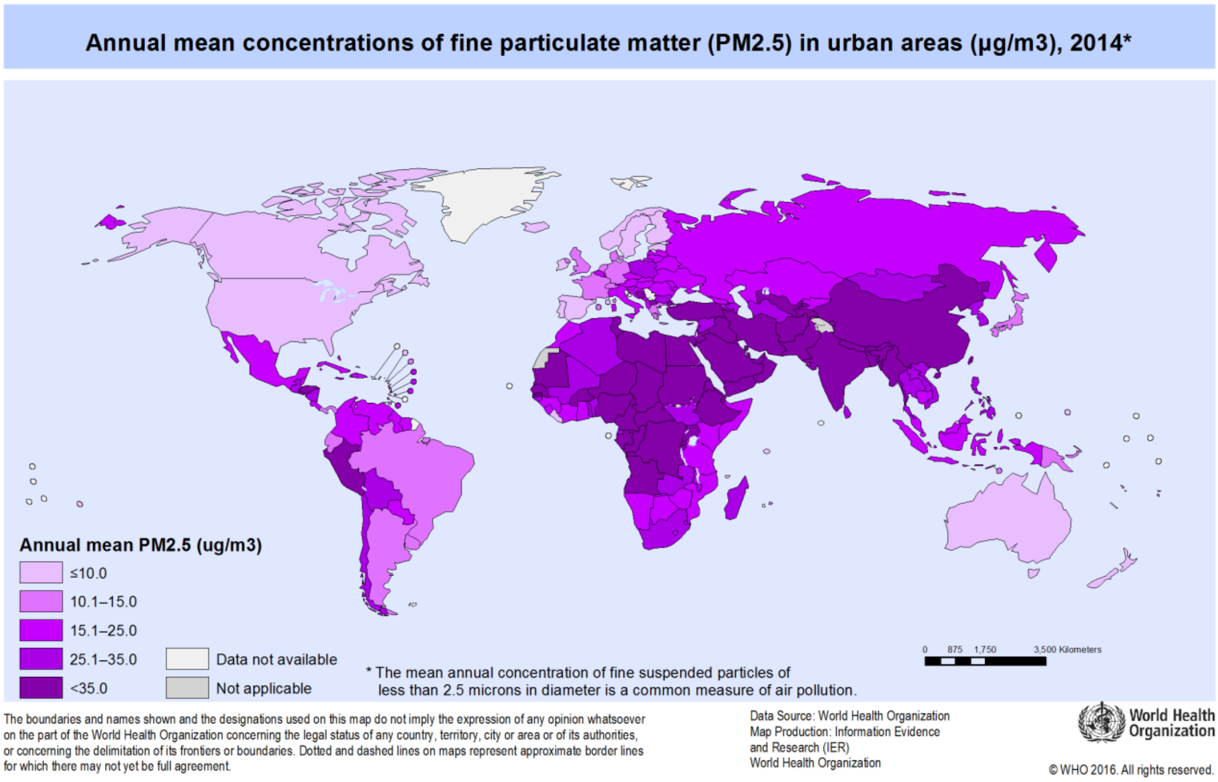
The new ISO 16890 standard test results can be used for calculation of the PMx concentration downstream the filter [ISO]:

$$C_{down}(PM_x) = C_{up}(PM_x) \cdot (1 - E(PM_x)) \text{ [Equation 2]}$$

According to WHO guidelines [8], the outdoor air concentration for PM_{10} should be <20 µg/m^3, and $PM_{2.5}$ should be <10 µg/m^3. The steering committee for this guide line has concluded “that there is no convincing evidence of a difference in the hazardous nature of particulate matter from indoor sources as compared with those from outdoors” [9]. Therefore is the particulate matter recommended for outdoor air applicable for indoor air.

The air pollution level is today well known in many cities around the world and the data could be found on public web sites. According to the pictures below from Global health observatory (GHO) the annual PM2.5 level in American and European cities is up 19 µg/m^3 in the heavy polluted areas. In Asia, the pollution level is up to 100 µg/m^3 and in some cases even higher [18, 19].





By using equation [2] we get the following PM2.5 concentration downstream a PM2.5 50 % efficiency filter:

	Outdoor concentration (C_{up}) $\mu g/m^3$	*)Downstream concentration (C_{down}), $\mu g/m^3$
USA	8,5	4,3
Germany	14,5	7,3
France	12,7	6,4
China	61,8	30,9
India	73,6	36,8

Table 4: *) Calculated by using Equation [2]

Filtration efficiency needed to meet WHO recommendation (<10 µm/m³ for PM2.5):

	Outdoor concentration (C_{up}) $\mu g/m^3$	Downstream concentration (C_{down}), $\mu g/m^3$	Required PM2.5 efficiency
USA	8,5	<10	0 %
Germany	14,5	<10	32 %
France	12,7	<10	22%
China	61,8	<10	84 %
India	73,6	<10	87 %

Table 5:

With the impact from infiltration/exfiltration in buildings the choice of filtration efficiency is affected. Based on the facts found earlier in the paper (6 to 76% of the air entering a building with HVAC unit is unfiltered) we can do the following calculation:

$$PM\ level\ for\ air\ entering\ the\ building = Part\ of\ filtered\ air * filtration\ efficiency * PM\ conc.\ Outdoor\ air + Part\ of\ unfiltered\ air * PM\ Outdoor\ air \quad \text{[Equation 3]}$$

In the table below equation 3 has been used to show what the IAQ will be with different percentage of leakage air:

	Outdoor conc. PM2.5 (C_{up}) µg/m³	Required PM2.5 efficiency, calculated	Downstream concentration (C_{down}), µg/m³	*)Achieved PM2.5 level with calculated efficiency 6% unfiltered air	*)Achieved PM2.5 level with calculated efficiency. 76% unfiltered air
USA	8,5	0 %	10	8,5	8,5
Germany	14,5	32 %	10	10,1	13,4
France	12,7	22%	10	10,1	12,0
China	61,8	84 %	10	13,0	49,3
India	73,6	87 %	10	13,4	58,2

Table 6: *) Calculated by using equation 3

If we rewrite the formula we can solve the equation for which filtration efficiency that is needed to achieve a certain IAQ:

$$Filtration\ efficiency = 1 - \left(\frac{\frac{PM\ level\ for\ air\ entering\ the\ building}{PM\ conc.\ Outdoor\ air} - Part\ of\ unfiltered\ air}{Part\ of\ filtered\ air} \right) \quad \text{[Equation 4]}$$

	Outdoor conc. PM2.5 (C_{up}) µg/m³	Downstream conc. target (C_{down}), µg/m³	*)Required PM2.5 efficiency. 6% unfiltered air	*)Required PM2.5 efficiency. 50% unfiltered air	*)Required PM2.5 efficiency. 76% unfiltered air
USA	8,5	10	0%	0%	0%
Germany	14,5	10	33%	44%	129% x)
France	12,7	10	23%	30%	89%
China	61,8	10	89%	120%x)	349% x)
India	73,6	10	92%	123% x)	360% x)

Table 7: *) Calculated by using equation 4

x) Impossible to meet required efficiency regardless of filter class, too much air bypassing filter.

4. In situ measurements

During 2015 measurements were done in two different locations, Gothenburg and Shanghai.

Gothenburgh:

- Gothenburg is located at the Swedish West Coast and have 550 000 inhabitants
- Measurements were done in an office building with a floor space of 17 000 m^2
- The average value in outdoor air of $PM_{2.5}$ year 2013 was 6,5 µg/m^3 [13]

Shanghai:

- Shanghai is located at the Chinese east Coast and have 24 000 000 inhabitants
- Measurements were done in a building that hostess both manufacturing and offices, the floor space is 33 800 m^2
- The average value in outdoor air of $PM_{2.5}$ year 2013 was 61 µg/m^3 [14]

5. Measurement Method

For the Swedish office building in Gothenburg the measurements of PM_x were done in the general ventilation systems (figure 2). The filtration efficiency was measured for the supply air filters with a Palas Fidas Mobile [15] by measurements upstream and downstream the filter. Further on, the PM concentration was logged in the outdoor air and in the exhaust air. The PM_x value in exhaust air is assumed to be an average value for IAQ. The logging procedure was done in intervals of 30 minutes with continuously switch between outdoor air and exhaust air.

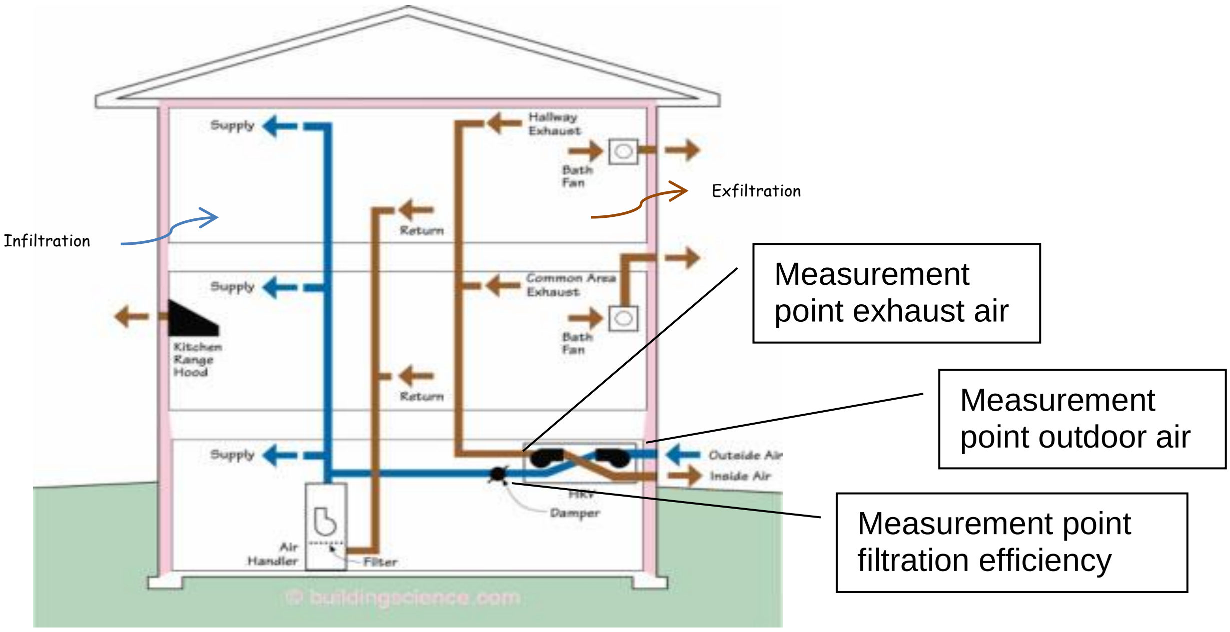


Figure 2 – Description of measuring point's office Gothenburg [16]

The PM_x removal over the filter element was measured on site. The PM_x value in the supply air was calculated based on measured PM_x concentration in outdoor air at the building and the PM_x removal efficiency for the actual filter element in the air handling unit (AHU).

Filter class PM2.5 85% (former F9) was installed in the AHU and the measurement time for each filter class was at least 24 hours. The result for a complete working day has been analyzed for each filter class. The following factors have been analyzed:

- Filtration efficiency regarding PM_x, measured in AHU on site
- PM_x concentration outdoor air
- Calculated supply air PMx concentration (based on measurements on site)
- PM_x concentration exhaust air (IAQ)
- Ratio between PM_x concentration, exhaust air/outdoor air

For the Shanghai office building the measurements of PM_x was done in the general ventilation systems (figure 3). The filtration efficiency was measured for the supply air filters with a *Dylos DC1700* by measurements upstream and downstream the filter.

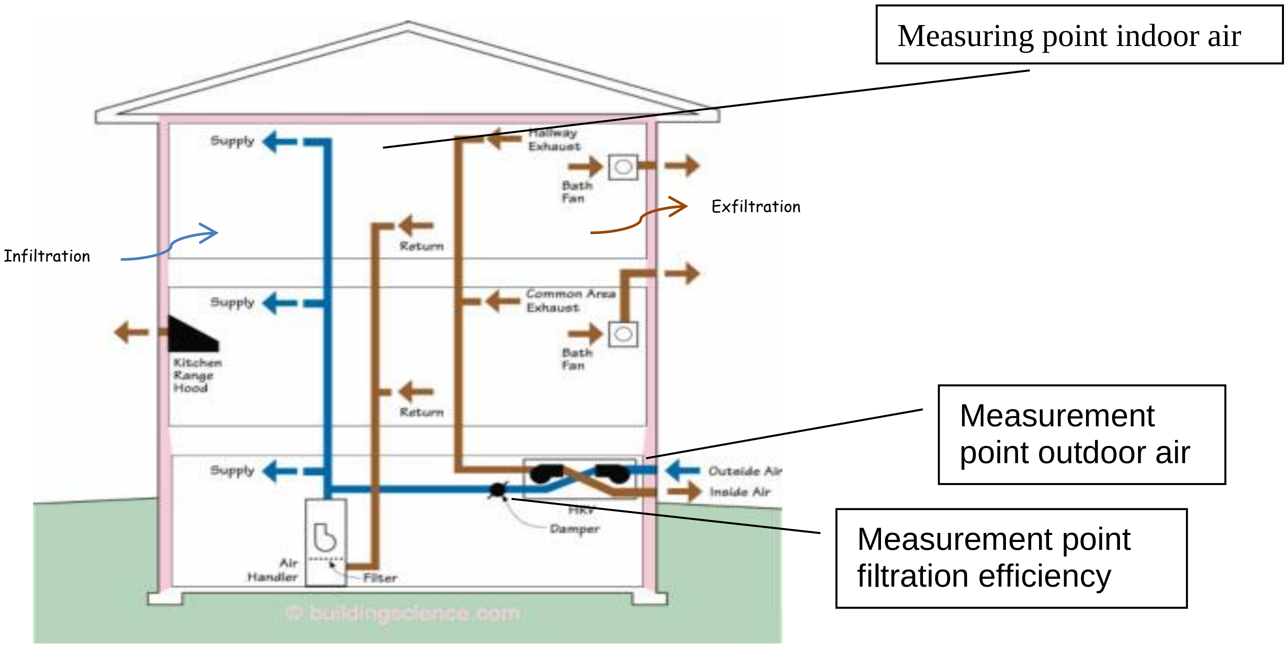


Figure [3] – Description of measuring points Shanghai

Filter class PM2.5 85% (former F9) was installed in the AHU. The measurements were done instantaneous during working hours, following measurements were done

- Filtration efficiency regarding PM_x, measured in AHU on site
- Outdoor PMx concentration
- Calculated supply air PMx concentration (based on measurements on site)
- Measured PMx concentration in room

6. Results

At both locations the $PM_{2.5}$ removal in the actual Air handling unit for the PM2.5 85% filters was measured.

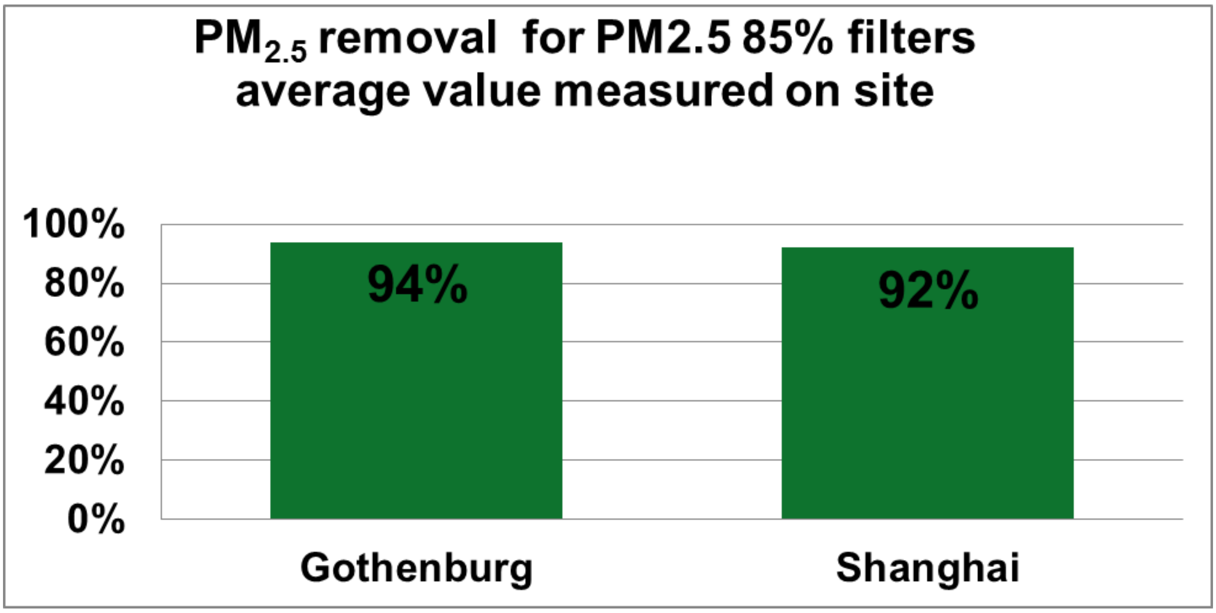


Figure 4

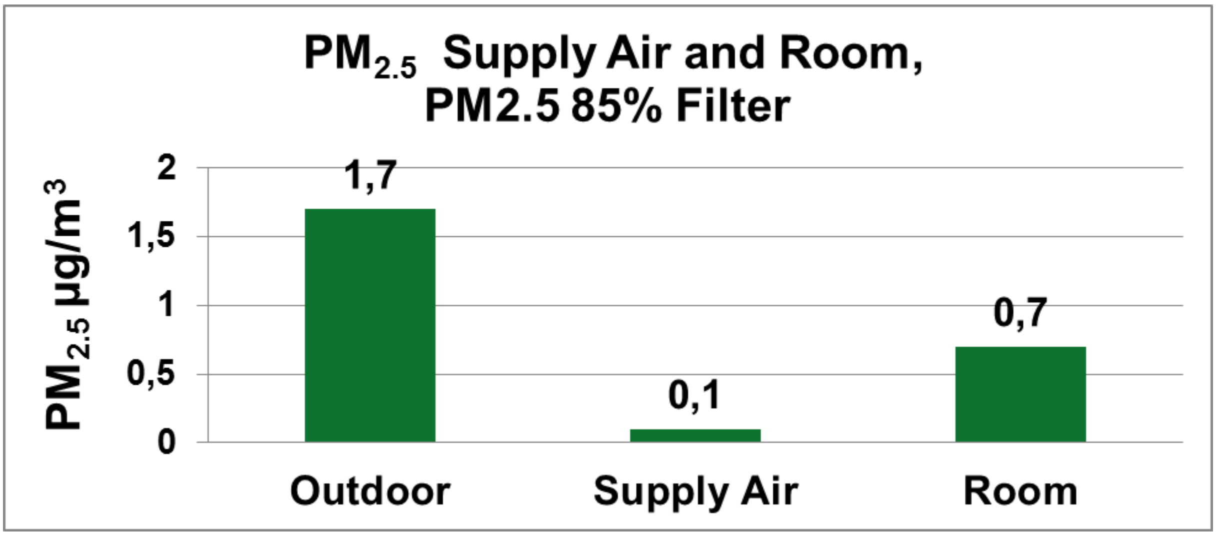


Figure 5: Air quality in office with PM2.5 85% filters in Gothenburg

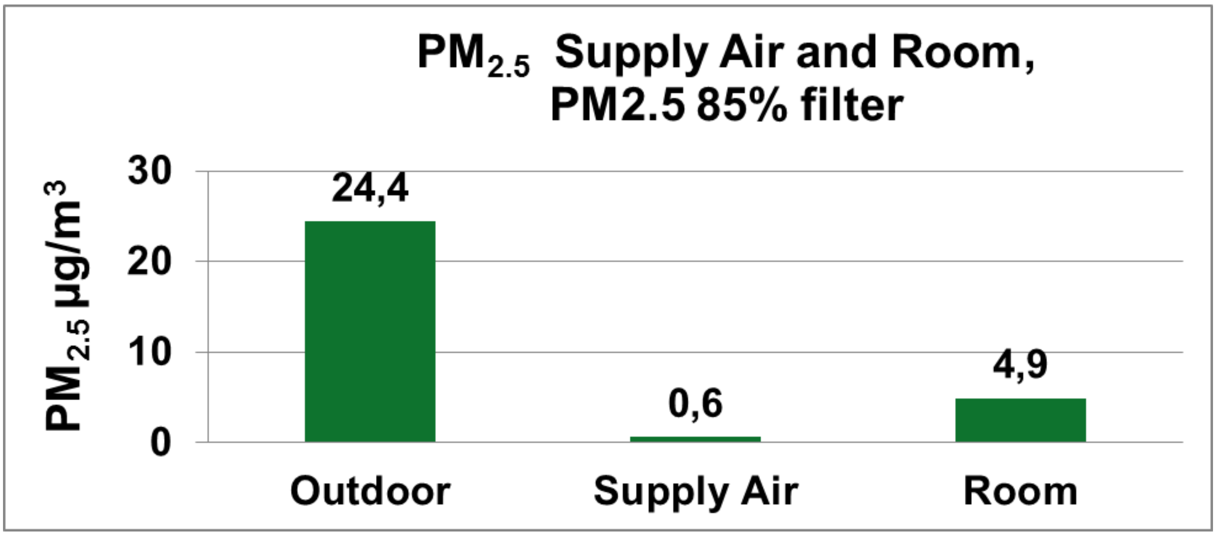


Figure 6: Shanghai Office during working hours

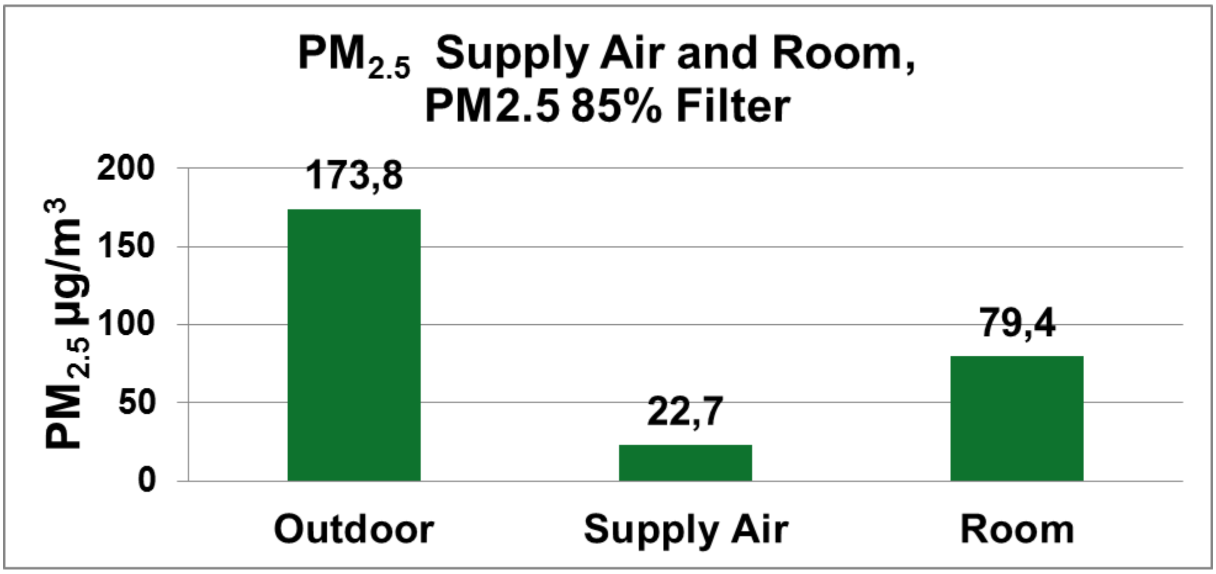


Figure 7: Shanghai Office during working hours, day with poor outdoor air quality

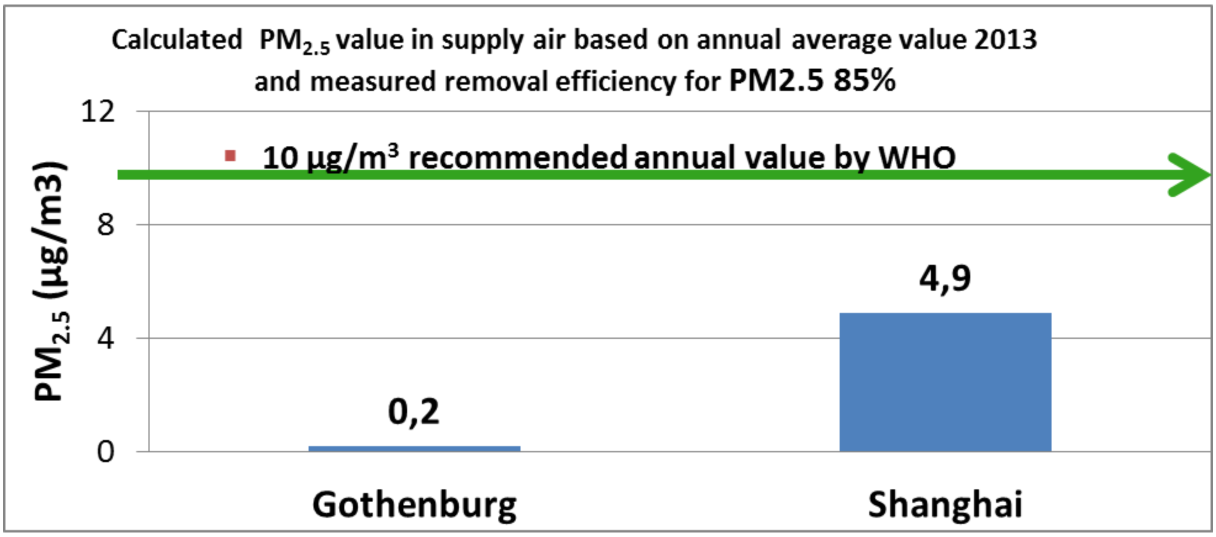


Figure 8: Calculated annual PM2.5 average value in supply air for Gothenburg (6,5 µg/m^3) and Shanghai (61 µg/m^3)

7. Conclusions

- In this project we have shown that health risks from high indoor PM values caused by high outdoor values could be solved by HVAC filters, figure 8.

- A formula for calculation of amount of unfiltered air depending on air tightness of building envelope and climate conditions is shown under chapter 3

- The unfiltered air can vary between 6 % up to 76 % depending of the Ach and the building air tightness, table 3 and table 4

- To poor air tightness of building envelope, will create poor IAQ, despite of which filter class is used.

- The filtration efficiency for the same type of filter in different environments is in the same range for PM2.5 85%, Shanghai in Gothenburg (figure 4)

Reference list

[1] Air pollution and lung cancer incidence in 17 European cohorts:……,The Lancet Oncology, 2013 volume 14 no.9 p813–822
[2] ISO/DIS 16890-,Air filters for general ventilation — Part 1: Technical
[3] ASTM E1827 - 11
Standard Test Methods for Determining Airtightness of Buildings Using an Orifice Blower Door
[4] ACH and Airtightness test results….., Dr Laszlo Fulöp, György Polics
[5] ETHICS WP 1: Air-tightness of buildings, 2008
[6] Patent, Method for filter selecting EP 2105677 A1, Thomas C, Magnus J
[7] Seinfeld J.H., Pandis S.N., *Atmospheric chemistry and physics*. Wiley Inter science Publications, John Wiley & Sons, New York, USA, 2006
[8]WHO, Air quality guidelines, Global update 2005, Particulate matter, ozone, nitrogen dioxide and sulfur dioxide
[9]WHO Guidelines for indoor air quality, Selected Pollutants", 2010
[10] http://www.rehva.eu/fileadmin/Old_website_content/technology-and-research-committee/aivc-paper---ventilation-rates-and-iaq-in-eu.pdf
[11] http://www.engineeringtoolbox.com/air-change-rate-room-d_867.html
[12] http://www.nuaire.co.uk/media/79314/nuaire_commercial_useful_info.pdf
[13] http://goteborg.se/wps/portal/invanare/miljo/goteborgs-miljomal/frisk-luft/partiklar
[14] Shanghai Daily, January 13th 2014
[15] http://www.palas.de/en/product/fidasmobile
[16] http://buildingscience.com/documents/information-sheets/info-611-balanced-ventilation-systems
[17] Measurements conducted by MANN+HUMMEL Shanghai, Mr. Rex Chen