# Fine dust measurement in ducts of balanced ventilation systems

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**ABSTRACT**

The measurement of particulate matter (PM) in rooms has gained interest in the last decade. However, the sensors that are currently used are intended for use in still standing air and cannot be applied to ventilation ducts with a typical velocity up to a couple of meters per second. Therefore, a prototype of a measurement module for particulate matter has been developed for use in ducts of ventilation systems. To the author's knowledge, this has not been done before.
The $PM_{2.5}$ values as measured by the prototype in an extract duct, were compared with the values as measured in the room where the air is extracted from. The differences between the measured $PM_{2.5}$ values were 2 to 4%, which was a sufficient accuracy for the prototype.
Three field tests were carried out in three houses with a balanced ventilation system in The Netherlands, with a distance between the houses of 50 km up to 150 km. For each field test, two PM measurement modules were installed near the balanced ventilation unit; one in the extract duct and one in the supply duct. During the measured period in the heating season, the heat recovery ensured similar temperatures in the extract and supply ducts, resulting in $PM_{2.5}$ values that could easily be compared with each other.
The measured $PM_{2.5}$ values in the extract ducts showed typical indoor PM sources like cooking, but also showering and steam ironing because water droplets are also measured by the sensor. In the supply air, peaks caused by incidental recirculation of chimney smoke into the fresh air intake were visible. Moreover, the effect of filter type (fine or coarse) and of filter age (old or new) within the ventilation unit could be found.

**KEYWORDS**

Particulate matter, air duct sensor, balanced ventilation

## 1 INTRODUCTION

Particulate matter in dwellings has gained a lot of interest as buildings are getting airtight and because it is harmful to a person's health. The levels of indoor particulate matter in airtight dwellings depends on indoor sources (kitchen, candles) and outdoor sources (traffic, industry, agriculture). Mechanical ventilation can reduce particulate matter levels from indoor sources and filtering of supply air reduces particulate matter levels from outdoor sources. Simulation studies have shown that penetration of $PM_{2.5}$ outdoor pollutants can be limited by a good $PM_{2.5}$ filter efficiency (Verheyleweghen et al., 2022). Also, in a practical study in occupied dwellings it has been shown that air supply filtration has a real impact on the levels of particles entering the dwelling (Golaz et al., 2022).
Particulate matter can be measured by low-cost sensors, but most of them are used to indicate a level in a room. Sensors for measurement of particulate matter in ducts would help to indicate the average levels of the indoor air as well as the levels of the supply air of the ventilation system.
This study aims to develop a PM sensor prototype for application in air ducts. In a test room, the PM sensor prototype in ducts is evaluated against measurement by a sensor component in a

room. After this, the PM sensor prototype is used to indicate PM levels in extract air and in supply air of a balanced ventilation system.

## 2 DEVELOPMENT OF A PM SENSOR FOR MEASUREMENT IN DUCTS

Commercially available low-cost PM sensor components are mostly suitable for implementation into sensors that can be placed in a room. The velocity of the air that is sampled cannot be higher than 1 m/s. This makes the components not suitable for measurement of particulate matter in ducts of ventilation systems with typical air velocity up to a couple of meters per second.

In order to measure the particulate matter in ducts, a prototype of a PM sensor for ducts has been developed. Schematically, the prototype consists of an inlet cone in which the air from the duct is drawn into the prototype in an isokinetic way (air velocity in inlet cone is equal to the air velocity in the duct). The air is directed in a direction perpendicular to the main air direction in the duct and it is slowed down to an air velocity lower than 1 m/s. This air is led over the PM sensor component after which it is directed to an outlet in the downstream direction of the air duct.

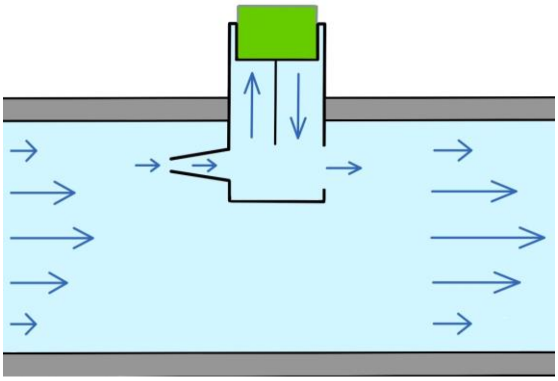


Figure 1: Schematic principle of PM measurement in a duct (blue). Blue arrows indicate air direction in the PM sensor prototype and the PM sensor component is indicated in green.

The prototype (dimensions 10 x 10 x 2 cm) was built with 3D printing. In figure 2, the prototype is shown with the inlet cone on the left. In the top, the PM sensor component (Sensirion SPS30) can be inserted into an opening in such a way that the sampled air is led via the measuring side of the sensor.

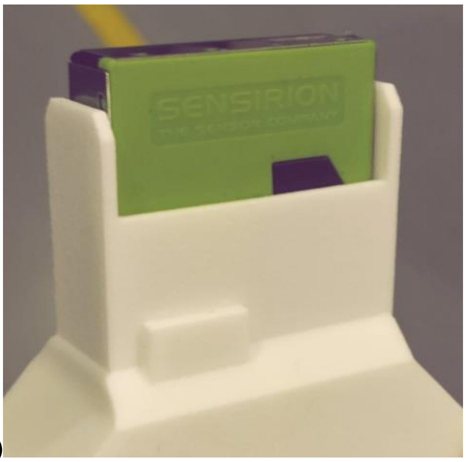
a)  b) 


Figure 2: a) 3D printed PM sensor prototype, b) close-up of upper part of the prototype with the green PM sensor component inserted

In order to get an idea of the measured values of the prototype, an experimental set-up has been made as shown in figure 3. A test chamber (volume 19.5 $m^3$) was provided with a PM sensor component (Sensirion SPS30). Air from the test chamber was extracted via ducts from Expanded Polypropylene (EPP) with an inner duct diameter of 160 mm. The air was extracted by a balanced ventilation unit. The supply air from the balanced ventilation unit was led back into the test chamber.
The PM sensor prototype was placed just upstream of the balanced ventilation unit, in the duct. Particulate matter was introduced in the test chamber by burning incense sticks prior to the measurement, as this is producing mainly $PM_{2.5}$ according to literature (Goel et al., 2017).
The ventilation flow rate was varied during the 20 minute experiment. This resulted in an increasing trend of average air velocity through the duct that was 1.2 m/s (0-3 min), 2.1 m/s (3-8 min), 3.5 m/s (8-13 min) and 4.8 m/s (13-20 min).
The measured $PM_{2.5}$ values from the sensor in the test chamber and the sensor in the PM sensor prototype were compared with each other. Figure 4 shows the decay of PM values in time. Although the experimental set-up resulted in a closed system, the $PM_{2.5}$ values showed a decay because the test chamber was not fully airtight.

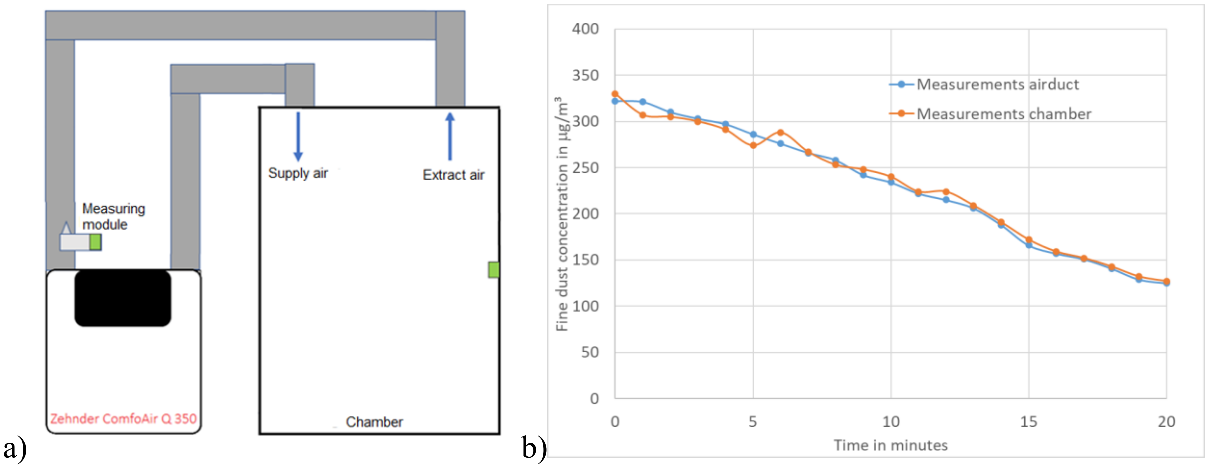



Figure 3: a) Experimental set-up of validation measurement for the PM sensor prototype and b) measured PM2.5 values (sensor values in test chamber in orange and PM sensor protype values in blue)

## 3 DESCRIPTION OF FIELD TESTS

In order to test the PM sensor prototype in real life ventilation systems in houses, a field test was conducted. Three houses with balanced ventilation units, located in The Netherlands, were selected. They were situated in Helmond, Lettele and Zwartsluis. The distance between these houses was between 50 km and 150 km. The balanced ventilation units were provided with an EPP module and connected on top of the unit. On top of the EPP module the extract duct and the supply ducts were installed. The EPP module contained two PM sensor prototypes, one in the extract duct and one in the supply duct (see figure 4).
Placement of the PM sensor prototype in the supply duct has two advantages over placement outdoors. First, the supply duct contains air that is already filtered by the ventilation unit. This means that it is actually reflecting the PM values that are supplied to the rooms in the house. Second, measurement of particulate matter is sensitive to variations in operating temperature (Liu, 2019). Because of the heat recovery, the supply air temperature is close to the extract air temperature and therefore the PM values can better be compared with each other (as opposed to measurement in cold or warm outdoor air).

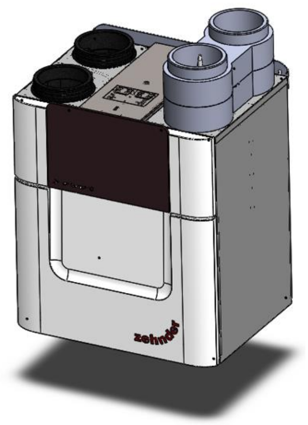


Figure 4: Schematic principle balanced ventilation system with PM measurement in extract and in supply air

# 4 RESULTS

## 4.1 Measured $PM_{2.5}$ values in three field tests

Figure 5 shows a week of the $PM_{2.5}$ values in the ventilation system in Helmond. The extracted air shows distinct peaks that were caused by cooking. The peak values ranged between 30 and 200 μg/m$^3$, depending on the prepared meal, with the exception of a peak value of 400 μg/m$^3$ when something had burned in the oven. There were also numerous smaller peaks that were caused by showering, and by steam-ironing.
The larger peaks of $PM_{2.5}$ took about 3 to 4 hours before they were ventilated out of the house. The $PM_{2.5}$ values in the supplied (filtered) air were below 12 μg/m$^3$ for the whole week.

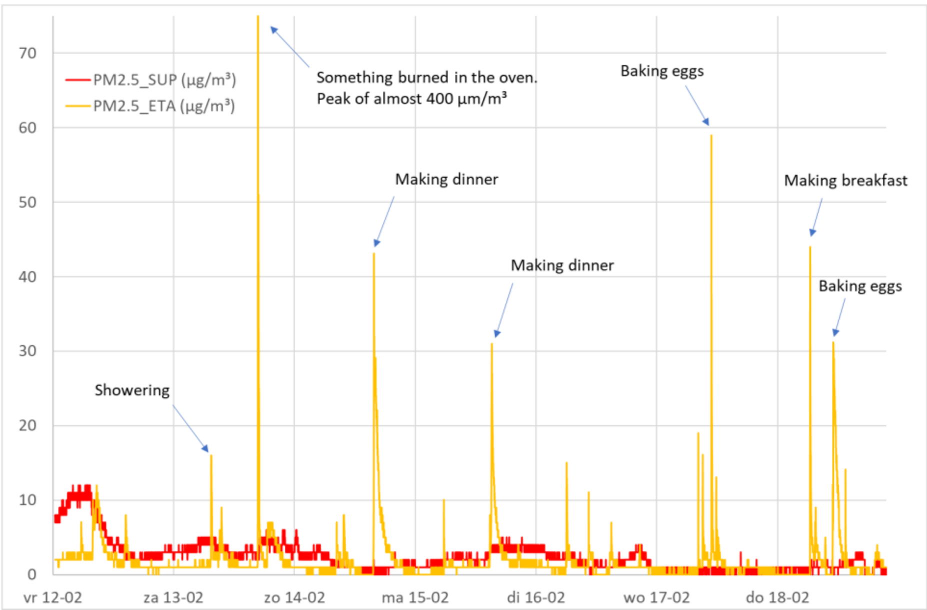



Figure 5: $PM_{2.5}$ values in extract air (yellow) and in supply air (red) in Helmond.

Figure 6 shows a week of the $PM_{2.5}$ values in the ventilation system in Lettele. The extracted air shows distinct peaks that were caused by cooking. The peak values ranged between 100 and 600 μg/m$^3$.
The larger peaks of $PM_{2.5}$ took about 1 hour before they were ventilated from the house.
The $PM_{2.5}$ values in the supplied (filtered) air were mostly below 30 μg/m$^3$ for the whole week except for a number of peaks in the supply air. The peaks in the supply air were thought to be

originating from exhaust air from a wood stove that was recirculating back into the fresh air intake on the roof.
On Feb 6th it seems that a high $PM_{2.5}$ value in the supplied air also leads to higher values of the internal $PM_{2.5}$ values, as reflected by the higher values in the extract.

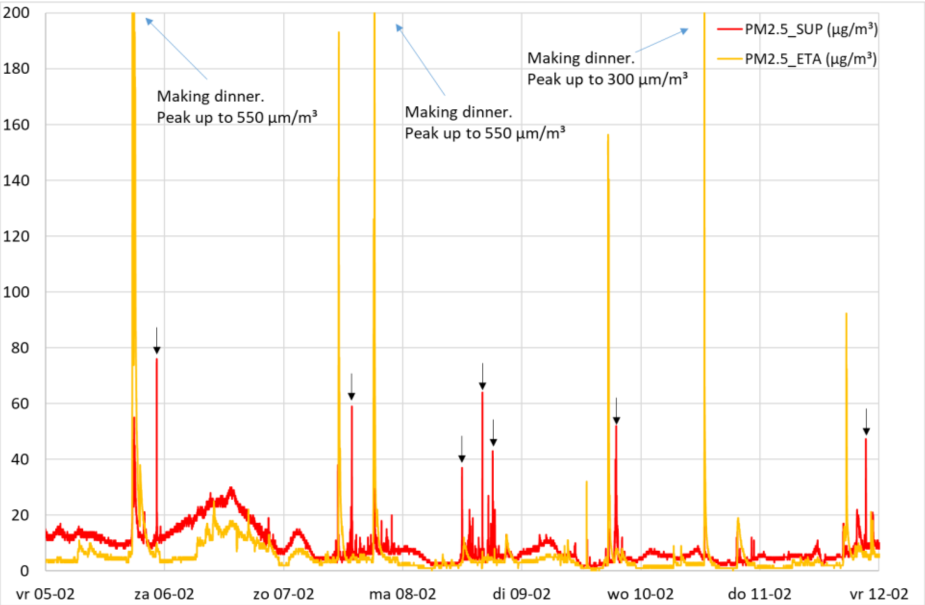



Figure 6: $PM_{2.5}$ values in extract air (yellow) and in supply air (red) in Lettele.

Figure 7 shows a week of $PM_{2.5}$ values in Zwartsluis. The peaks in the extract $PM_{2.5}$ values are lower than in the other houses. This is believed to be the result of a good function cooker hood, which is working separately from the residential ventilation system. Therefore, the $PM_{2.5}$ resulting from cooking is directly extracted by the cooker hood and brought out of the house. There is one exception with a peak value of 85 $\mu g/m^3$, originating from the opening of a wood stove.
The $PM_{2.5}$ values in the supplied air seem on average a higher value than the houses in Helmond and Lettele.

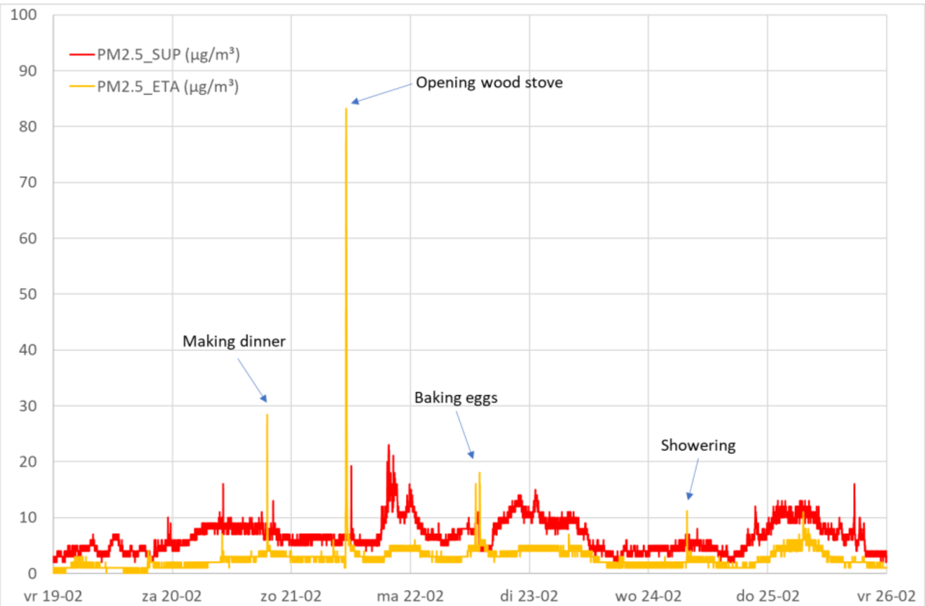



Figure 7: $PM_{2.5}$ values in extract air (yellow) and in supply air (red) in Zwartsluis.

## 4.2 Comparison of $PM_{2.5}$ values in supply air of all field tests

Interesting is the $PM_{2.5}$ values in the supplied air during the same period in the three houses. Figure 8 shows nearly two months of $PM_{2.5}$ values in the (filtered) supply air. It also shows the filters that are used: a new ePM1/F7 filter in Helmond and a new Coarse/G4 filter in Zwartsluis. The ventilation system in Lettele had a 3-month-old ePM1/F7 filter which was replaced by a clean ePM1/F7 filter on Feb 27$^{th}$.
The results show that the trend of the $PM_{2.5}$ values in the supply air are similar for the Coarse/G4 filter and the old ePM1/F7 filter (except for the peaks resulting from re-intake of exhaust air from a wood stove chimney). Despite the 50 km distance between the field test locations, the external $PM_{2.5}$ values and the filter efficiency lead to a similar daily trend. Only the larger filtration efficiency of the new ePM1/F7 filter leads to low $PM_{2.5}$ values in the supply air. After Feb 27$^{th}$, when the 3 month old ePM1/F7 filter is replaced with a clean ePM1/F7 filter, the $PM_{2.5}$ values in the supply air are suddenly getting low. After a week, the lower filtration efficiency of the Coarse/G4 filter leads to higher supply PM2.5 values again.

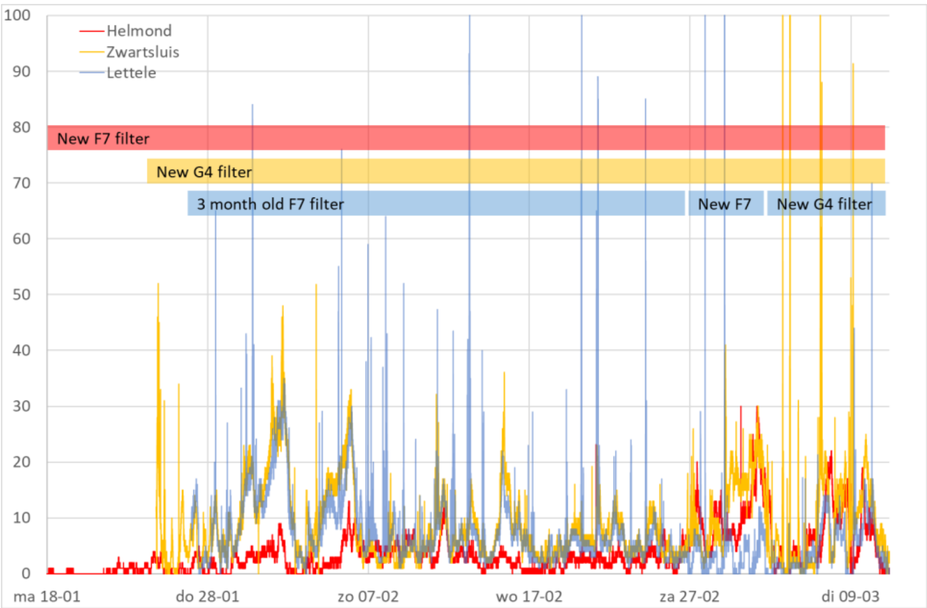



Figure 8: $PM_{2.5}$ values in supply air in Helmond (red), in Zwartsluis (yellow) and in Lettele (blue).

# 5 DISCUSSION

The measurement of particulate matter in ducts proved to be a difficult task. In order to measure the right values of the PM concentration, the air as to be sampled in an isokinetic way and the air has to be slowed down before it is reaching the PM sensor component. This development has led to the application of a patent.
With the available equipment, the measurement accuracy of the PM sensor prototype could only be assessed relative to the measurement values of the PM sensor component in still standing air. The decaying $PM_{2.5}$ signal of the PM sensor component in the room was closely followed by the $PM_{2.5}$ signal of the PM sensor prototype. The difference between the two signals stayed within 4%. There was no clear dependency of the relative difference between the signals with the air velocity through the duct.
The measured $PM_{2.5}$ values in balanced ventilation systems installed in three Dutch houses have been investigated.

The $PM_{2.5}$ values in the extract air showed peaks when typical indoor sources like cooking, showering, or steam-ironing occurred. An increasing trend of the $PM_{2.5}$ signal in the supply air (originating from increasing trend outdoors), led to an increasing trend of the $PM_{2.5}$ signal in the extract. This indicates that the $PM_{2.5}$ level indoors is the result of a combination of indoor sources and outdoor sources.
The $PM_{2.5}$ values in the supply air show a trend that is largely dominated by the outdoor PM concentration. All three locations of the investigated houses, although distance between houses ranged from 50 km to 150 km, seem to be influenced by the same outdoor trend.
The exact values in the supply air are also influenced by filter efficiency. It can be seen that an ePM1/F7 filter leads to lower $PM_{2.5}$ values in the supply air than a Coarse G4 filter. There is also the observation that the new ePM1/F7 filter leads to lower $PM_{2.5}$ values in the supply air than a 3-month-old ePM1/F7 filter.

## 6 CONCLUSIONS

For measurement of particulate matter in air ducts, a PM sensor prototype has been developed. The prototype has been validated against values of a commercial sensor in still standing air and leads to good agreement.
The developed PM sensor prototype has been used to measure $PM_{2.5}$ values in the extract air and the supply air of a balanced ventilation system. In three Dutch houses, the prototype showed values that indicate indoor sources of $PM_{2.5}$ and outdoor sources of $PM_{2.5}$.
Furthermore, the measured $PM_{2.5}$ values in the supply air seem to be dependent on the filter type and the filter age.

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