# POSSIBILITIES AND LIMITATIONS OF LOW-COST PM SENSORS

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## RESUME

Depuis quelques années, des micro-capteurs d'aérosols dits « à bas coût » ont fait leur apparition sur le marché. Ceux-ci sont devenus très populaires dans la communauté scientifique des aérosols mais aussi auprès des citoyens. Leurs prix varient d'environ 20 à 500 €. Leurs prix offrent évidemment de nouvelles possibilités, comme par exemple la mise en place de réseaux intégrant de nombreux capteurs permettant de surveiller la qualité de l'air, en atmosphère générale ou à l'intérieur de locaux de travail. Toutefois, il existe plusieurs limites à leurs utilisations, notamment lorsque les taux d'humidité dans l'air sont élevés. Dans ce contexte, un sécheur de faible coût a été mis au point permettant de pallier l'effet de l'humidité. Ce dispositif a été testé durant plusieurs semaines avec le micro-capteur NovaFitness SDS011 dans le cadre d'une campagne de mesure des concentrations PM10 en extérieur. Les résultats obtenus montrent une très bonne concordance avec la méthode de référence gravimétrique. En outre, les concentrations PM2.5 sont également très bien corrélée (R2 > 0.96) à celles obtenues à l'aide d'un dispositif de prélèvement à point fixe MPGII (fraction alvéolaire). Cette corrélation est quasiment identique pour six aérosols d'essais de nature, forme et distribution granulométrique différentes. Un facteur de correction unique a donc été déterminé pour l'ensemble des micro-capteurs et aérosol d'essais faisant concorder à ±30% près les concentrations PM2.5 aux données de référence.

## ABSTRACT

Low-cost PM sensors have entered the market a few years ago and have become very popular among aerosol as well as citizen scientists. Their prices range from approximately 20 € to 500 €. Due to the low costs, they offer new possibilites, like setting up dense networks to monitor air quality, e.g. in the atmosphere or in workplaces. However, several limitations apply, particularly, when measuring at high humidity levels. A low-cost aerosol dryer has been developed that overcomes this shortcoming. It has been used in an atmospheric field measurement over several weeks and the resulting daily mean $PM_{10}$ concentrations measured with a NovaFitness SDS011 sensor were shown to agree well with those of a gravimetric reference method. The $PM_{2.5}$ concentrations of the same sensor type further showed a very high correlation ($R^2$ >0.96) with gravimetric reference data for the respirable dust concentrations, collected with an MPG II sampler. The correlation was nearly identical for six test aerosols with very different particle size distributions, materials and shapes. By using a single correction factor for all sensors and test aerosols, the $PM_{2.5}$ data agreed mostly within ±30% with the reference data.

**MOTS-CLÉS :** capteur de particules à faible coût, air ambiant, poussière respirable, réseau de mesures /
**KEYWORDS:** low-cost PM sensor, ambient air, respirable dust, network

## 1. INTRODUCTION

The development of low-cost PM-sensors started several years ago, when simple photometric particle sensors from smoke detectors were first used to control indoor air purifiers. Since these sensors are mass-produced they can be offered at much lower prices than high-class scientific instruments. Subsequently, they have raised a lot of attention over the recent years in the fields of air quality control and aerosol science. Due to the low costs, they have also become popular among citizen science initiatives that aim at monitoring ambient air quality with high spatio-temporal resolution. The OK Lab initiative for example provides information on their website on how to assemble a simple monitor for $PM_{2.5}$ and $PM_{10}$ based on the low-cost (~20 €) Nova Fitness SDS011 sensor (Budde, et al., 2018). Their monitor is equipped with a microcontroller and a WLAN chip that connects the sensor to the user's WiFi network to upload the measured data to a website (https://luftdaten.info/), where it gets displayed on a map at the location where the sensor is installed. The entire monitor, including the sensor, its electronic periphery and housing in total amounts to approximately 50 €. The initiative started in Stuttgart, one of Germany's most polluted cities, a few years ago but has meanwhile spread all over Europe and beyond.

Due to their low cost, PM sensors are ideal for setting up dense air quality networks that provide information on PM concentrations with high spatio-temporal resolution, not only in ambient air quality monitoring (Badura, et al., 2018; Gao, et al., 2015; Liu, et al., 2019; Tagle, et al., 2020), but e.g. also in workplace exposure assessment (Thomas, et al., 2018; Jones, et al., 2016; Sousan, et al., 2016). Due to their light weight, they have also become popular for the use on drones to obtain 3D, altitude-resolved information on PM concentrations (Yadav, et al., 2020; Bezantakos, et al., 2018). Other applications include the surveillance of filter performance (Bächler, et al., 2020) or the sensor-controlled operation of ventilation systems in smart homes (Salimifard, et al., 2020; Kumar, et al., 2016).

However, the low cost comes at a price and several limitations apply (Budde, et al., 2018; Asbach, et al., 2018). These limitations include reduced accuracy, repeatability and comparability as well the detection limits of the sensors regarding minimum and maximum particle size, minimum and maximum particle concentrations and

particle materials (refractive index) (Kuula, et al., 2020). Furthermore, it has been shown that the sensors are prone to cross-sensitivities, particularly against (high) relative humidity (Crilley, et al., 2018).
This article is intended to provide an overview of the possibilities and limitations of available low-cost PM sensors. It provides a mixture of a literature review and own data.

## 2. MEASUREMENT PRINCIPLE OF LOW COST PM-SENSORS

All available low-cost PM-sensors are based on the measurement of the light scattered by particles inside an optical measurement volume. Most sensors use a (red) laser as light source. Table 1 provides an overview of the most commonly used low-cost sensors and their specifications. In general, three different types of devices can be distinguished: 1) photometers, 2) "advanced" photometers and 3) spectrometers. Photometers, sometimes also called nephelometers, are the simplest devices in which the light scattered by all particles in the optical measurement volume is measured as an integral value. In order to deduce the mass concentration from this, the particle size distribution, particle density, particle shape and refractive index must be assumed. Accordingly, a pure photometer can only be calibrated for one metric (e.g. $PM_{2.5}$). Of the sensors shown in Table 1, only the devices from Omron, Sharp and Shiniyei belong to this sensor category. The majority of the devices is based on the principle of the "advanced" photometer (Wang, et al., 2009). Here, in addition to the total scattered light intensity, the temporal course of the intensity, which is influenced by individual particles, is also evaluated. This allows conclusions to be drawn about the particle sizes, so that several metrics can be determined simultaneously. The advanced photometers listed in the table determine at least the mass concentrations of the fine dust fractions $PM_{2.5}$ and $PM_{10}$, in some cases also other fractions, e.g. $PM_4$ or $PM_1$. The Sensirion SPS030, as well as the Groupe Tera Next PM CR also give values for the number concentration in different size ranges. Whereas the Sensirion sensor is designed for ambient measurements, the Groupe Tera sensor is intended to be used in cleanrooms and thus at much lower concentrations.
The most complex devices are the spectrometers, in which the particles are passed singly through the measurement volume in order to measure the scattered light pulses caused by individual particles. For this, considerably more sensitive photodetectors are required than for integral measurement with photometers. However, measuring the scattered light from individual particles allows the size of the measured particles to be determined. By counting the scattered light pulses, the number concentration can be determined as a function of the particle diameter and thus the number size distribution of the particles in the aerosol. Of the sensors listed, only the two devices from Alphasense belong to the category of spectrometers. The OPC-R1 determines the number size distribution in 16 and the OPC-N3 in 24 size classes. Both devices also calculate the fine dust mass concentrations of the fractions $PM_1$, $PM_{2.5}$ and $PM_{10}$ from this. The OPC-N3 is the successor of the model OPC-N2 and covers a slightly broader particle size range than its predecessor but has otherwise very similar specifications. The OPC-N2 can still be found in several studies in the literature.
While the spectrometers and advanced photometers listed in Table 1 use a simple fan to draw air through the measurement volume, the photometers do not use an active flow, but only exploit the natural aerosol exchange with external air currents. The sensors from Omron and Shinyei support the natural exchange with a heating resistor that provides thermal air movement.

## 3. USE OF PM SENSORS IN VARIOUS APPLICATIONS

### 3.1. Sensors for outdoor applications

Most studies found in the literature on the use of low-cost PM sensors deal with ambient measurements. Figure 1 shows an example of an air quality map, resulting from the citizen science initiative OK Lab. Each honeycomb-shaped field provides the mean particle concentration (here: $PM_{2.5}$) as the average of all sensors within the covered area. The initiative uses NovaFitness SDS011 sensors. The same type of sensor has been studied by Liu et al. in ambient measurements in Oslo, Norway for a four-month period (Liu, et al., 2019). In their study, they used three identical sensors and compared their $PM_{2.5}$ output with the data from a co-located official atmospheric measurement station, equipped with a TEOM 1405 FDMS (Thermo Fisher). They found that the results from the three individual sensors agreed very well each other and demonstrated a high linearity to the officially measured $PM_{2.5}$ concentrations. However, they also showed that the sensor tended to overestimate the particle concentrations when the relative humidity was high. Tagle et al. also used the NovaFitness SDS011 sensor to monitor the $PM_{2.5}$ and $PM_{10}$ concentrations at three monitoring sites in Santiago, Chile (Tagle, et al., 2020) and compared the results with the data from a co-located beta attenuation monitor (MetOne, model BAM 1020) and a TEOM (Thermo Fisher, model 1400) as well as filter based, gravimetric data. In total, they used seven specimens of the SDS011 sensor and like Liu et al. also report about a good agreement among the data from the seven sensors. The correlations of the measured 1 h-average $PM_{2.5}$ concentrations and the reference $PM_{2.5}$ data were higher than for the corresponding $PM_{10}$ concentrations. This result is not surprising, since the sensor was originally designed for monitoring $PM_{2.5}$ only and the $PM_{10}$ measurement has been added later on.

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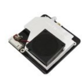
Table 1: Overview of commonly used low-cost PM sensors and their specifications (manufacturer information)

| Manufacturer | Model | Metrics | Size range | Concentration range | Measurem. principle | Price | Photo |
|---|---|---|---|---|---|---|---|
| Omron | B5W-LD0101-1 | MC | >0.5 µm | not specified | Photometer | ~15 € |  |
| Sharp | GP2Y1010AU0F | MC $PM_{2,5}$ | not specified | 25 - 500 µg/m³ | Photometer | ~5 € |  |
| Shinyei | PPD42NJ | MC | > 1 µm | 0 - 1,400 µg/m³ | Photometer | ~5 € |  |
| Amphenol Advanced Sensors | SM-UART-04L | MC $PM_{2,5}$, $PM_{10}$ | 0.3 - 10 µm | 1 - 999 µg/m³ | Advanced Photometer | ~25 € |  |
| Audiowell | DL0001 | MC $PM_1$, $PM_{2,5}$, $PM_{10}$ | 0.3 - 10 µm | 0 - 500 µg/m³ | Advanced Photometer | ~25 € |  |
| Audiowell | DL0003 | MC $PM_1$, $PM_{2,5}$, $PM_{10}$ | 0.3 - 10 µm | 0 - 500 µg/m³ | Advanced Photometer | ~25 € |  |
| DFRobot | Sen0177 | MC $PM_1$, $PM_{2,5}$, $PM_{10}$ | 0.3 - 10 µm | 0 - 500 µg/m³ | Advanced Photometer | ~45 € |  |
| Groupe Tera | Next PM | MC $PM_1$, $PM_{2,5}$, $PM_{10}$ | 0.3 - 10 µm | 0 - 1,000 µg/m³ | Advanced Photometer | ~65 € |  |
| Groupe Tera | Next PM CR | NC, >0.3 µm, >0.5 µm, >1.0 µm, >2.5 µm, >5.0 µm | 0.3 - 10 µm | <$10^7$ 1/m³ | Advanced Photometer | ~150 € |  |
| Honeywell | HPMA115SO | MC $PM_{2,5}$, $PM_{10}$ | 0.3 - 10 µm | 0 - 1,000 µg/m³ | Advanced Photometer | ~20 € |  |
| Nova Fitness | SDS011 | MC $PM_{2,5}$, $PM_{10}$ | 0.3 - 10 µm | 0 - 999.9 µg/m³ | Advanced Photometer | ~25 € |  |
| Panasonic | SN-GCJA5 | MC $PM_{2,5}$, $PM_{10}$ | >0.3 µm | 0 - 2,000 µg/m³ | Advanced Photometer | ~25 € |  |
| Plantower | PMS7003 | MC $PM_1$, $PM_{2,5}$, $PM_{10}$ NC >0,3, >0,5, >1, >2,5, >5, >10 µm | 0.3 - 10 µm | 0 - 500 µg/m³ | Advanced Photometer | ~20 € |  |
| Plantower | PMS5003 | MC $PM_1$, $PM_{2,5}$, $PM_{10}$ NC >0,3, >0,5, >1, >2,5, >5, >10 µm | 0.3 - 10 µm | 0 - 500 µg/m³ | Advanced Photometer | ~15 € |  |
| Sensirion | SDS030 | NC, MC $PM_1$, $PM_{2,5}$, $PM_4$, $PM_{10}$ | 0.3 - 10 µm | 0 - 1,000 µg/m³ 0 - 3 * $10^9$ 1/m³ | Advanced Photometer | ~25 € |  |
| Winsen | ZH03A | MC $PM_1$, $PM_{2,5}$, $PM_{10}$ | not specified | 0 - 1,000 µg/m³ | Advanced Photometer | ~15 US$ |  |
| Alphasense | OPC-R1 | AGV, MC $PM_1$, $PM_{2,5}$, $PM_{10}$ | 0.35 - 12.4 µm | 10,000 1/s 0.7% coinc. at $10^9$ 1/m³ | Spektro-meter | ~150 € |  |
| Alphasense | OPC-N3 | AGV, MC $PM_1$, $PM_{2,5}$, $PM_{10}$ | 0.35 - 40 µm | 10,000 1/s 0.84% coinc. at $10^9$ 1/m³ | Spektro-meter | ~450 € |  |

Bulot et al. studied the performance of four different low-cost PM sensors at two locations in Southampton, UK, over a nearly one-year period (Bulot, et al., 2019). The sensors studied are Alphasense OPC-N2, Plantower PMS 5003 and PMS 7003 as well as the Honeywell HPMA115S0 (see Table 1). They found that the two different Plantower sensors agreed very well with each other, whereas the correlation of both Plantower sensors with the ones from Honeywell and Alphasense was significantly worse. They conclude that the sensor performance varies more with PM sources and background concentration than with relative humidity. They found that the $PM_{2.5}$ data from both Plantower sensors correlated better with the reference $PM_{2.5}$ data than the data from the Alphasense OPC-N2. It should, however, be noted that the reference data were obtained from a measurement station in Portsmouth, approximately 40 km away from Southampton. The Honeywell sensors delivered no meaningful data due to a sensor failure.

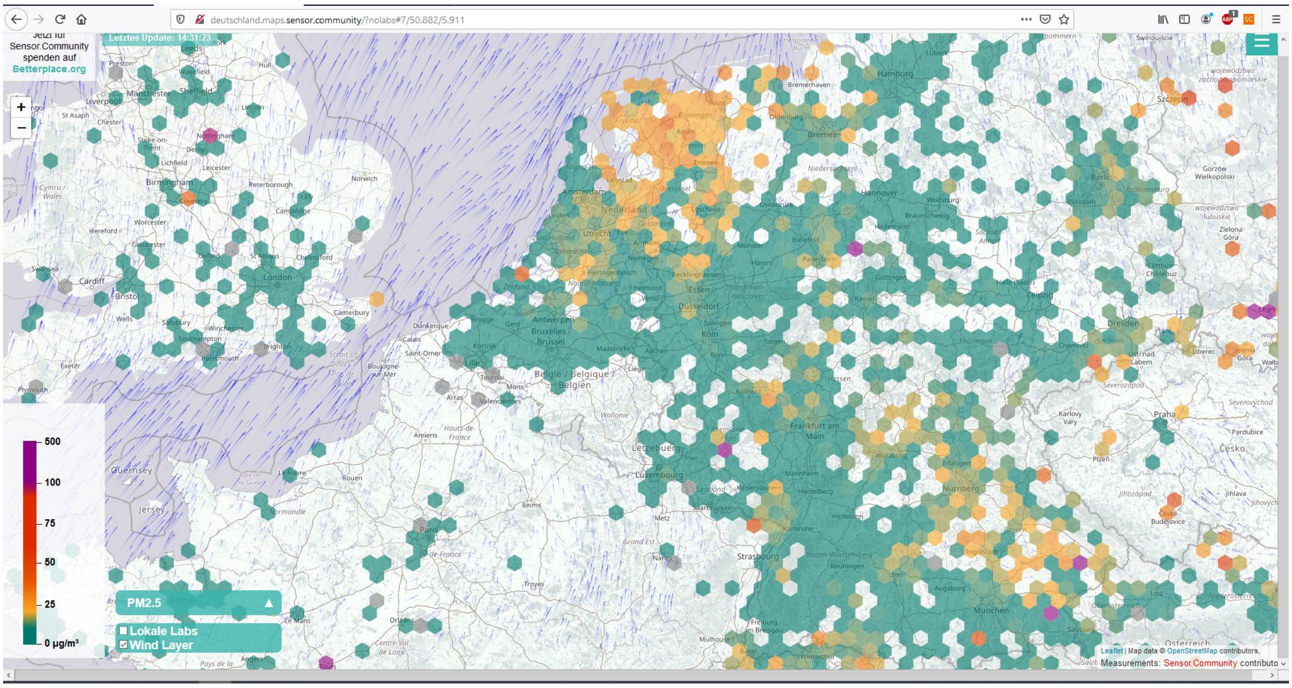



Figure 1: Air quality ($PM_{2.5}$) map, based on low-cost PM sensor NovaFitness SDS011 (source: https://luftdaten.info/, acessed Dec. 15th, 14:30)

At the Institute of Energy and Environmental Technology (IUTA), we also conducted several measurement campaigns to measure ambient $PM_{2.5}$ and $PM_{10}$ concentrations on the institute's parking lot with low-cost sensors. We employed NovaFitness SDS011 sensors and compare the time-resolved data to those from two co-located TEOM instruments (Thermo Fisher, model 1400 ab), one equipped with a $PM_{10}$ and the other with a $PM_{2.5}$ inlet. The measurement station is further equipped with a $PM_{10}$ filter sampler for gravimetric analysis according to EN 12341 and a weather station to monitor the temperature, relative humidity, wind speed and wind direction. The left graph in Figure 2 shows the time series of the $PM_{10}$ concentrations measured during an approximately 3-month period. It can be clearly seen that the agreement between the sensor data and the reference data is good only on a few days, whereas on some days the sensors underestimate and on other days oversetimate the $PM_{10}$ concentrations. The right graph in Figure 2 shows the ratio of the hourly $PM_{10}$ concentrations measured with the SDS011 sensors and the TEOM, plotted versus the relative humidity. While the right graph shows a rather large scatter of the ratio, i.e. a large discrepancy between the hourly data from the sensors and the TEOM, it also clearly shows a trend from ratios <1 for low relative humidity to >1 for high relative humidity. While the ratio >1 for high humidity levels was expected due to water uptake and growth of hygroscopic particles (Köhler, 1936), the ratio <1 for low humidity levels was rather surprising.

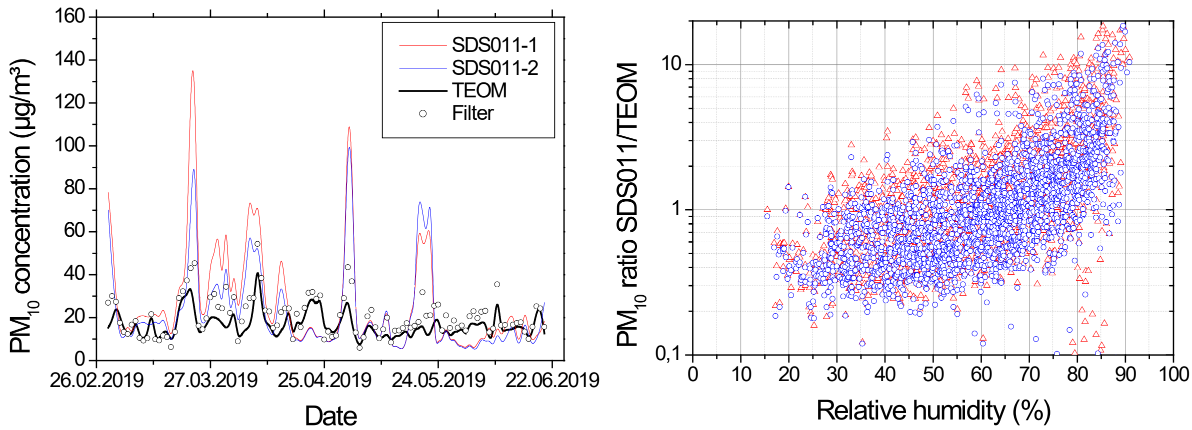



Figure 2: 24 h average $PM_{10}$ concentrations measured on the parking lot of IUTA with two NovaFitness SDS011 sensors, one TEOM and a filter sampler (left) and ratio of $PM_{10}$ data measured with SDS011 sensors to TEOM, based on hourly data vs. relative humidity (right)

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Triggered by these results, a low-cost aerosol dryer was developed that heats the aerosol to approximately 20°C above ambient temperature before the aerosol is drawn into the sensor. The dryer consists of a copper tube, surrounded by a heating sleeve. Two sensors with and two without dryer were installed on the roof of the measurement container for approximately seven weeks. The resulting ratios of the hourly mean $PM_{10}$ concentrations measured with the sensors and the TEOM are shown in Figure 3. The right graph shows the ratios without dryer upstream of the sensors. The same trend as before can be observed, i.e. the ratio increases to values well above one for high humidity levels whereas it is mostly below one at low humidity. The measurements were conducted during spring 2020, which was a very dry period in Duisburg with almost no rain. This may explain, why the highest ratios were lower than in the previous measurement campaign (see Figure 2). Nevertheless, the right figure shows no strong humidity dependent trend. Almost all ratios are below one, which indicated that the dryer effectively reduced the relative humidity in the aerosol.

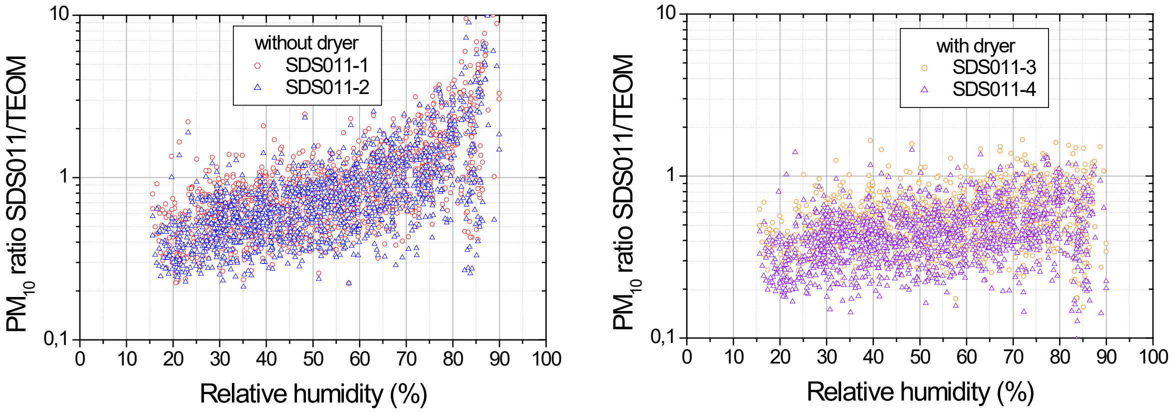


Figure 3: Ratios of the hourly average $PM_{10}$ concentrations measured with SDS011 sensors and TEOM, left: sensors without dryer, right: sensors with dryer

Based on sensor and the filter data for $PM_{10}$, a correction factor was determined to correct for the underestimation of the sensors with dryer at the now continuously low humidity. Figure 4 shows that the the agreement between the corrected sensor data and the TEOM and Filter data is very good. The SDS011 data shown is the average of the two sensors applied with and two sensors without dryer, respectivley. The agreement between the data from the sensors without and the TEOM and filter data is worse and does not show a clear trend. It can be seen that the daily average on some days is higehr and on other days lower than the reference data, depending on the average humidity during this day. This shows that the concept of first reducing the relative humidity to a low level and then applying a correction factor seems to be appropriate.

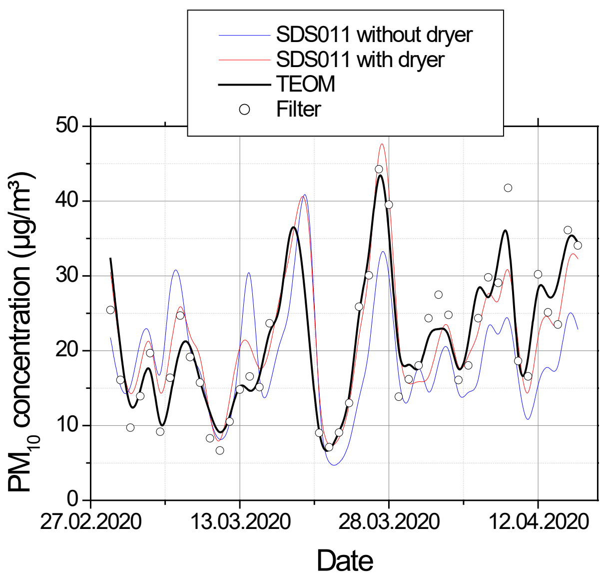


Figure 4: Time series of daily average $PM_{10}$ concentration measured with SDS011 sensors with and without dryer (each one average of two individual sensors), TEOM and gravimetric filter analysis

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### 3.2. Sensors for workplace applications

Due to their low costs, PM sensors offer new possibilities to permanently monitor airborne dust concentrations. They can for example be used to set up dense networks to obtain particle concentrations with high spatio-temporal resolution (Thomas, et al., 2018). Jones et al. used low cost sensors to monitor exposure in a swine building under relatively harsh concentration. In any case, prior to using low-cost sensors in workplaces, they need to be calibrated for the expected dust in the workplace (Asbach, et al., 2018). Sousan et al. carried out such calibration tests for the Alphasense OPC-N2 and found the performance of the sensor to strongly depend on particle size (Sousan, et al., 2016). At IUTA, we also carried out calibration measurements for the use of low-cost PM sensors for the measurement of respirable dust concentrations in workplaces. We produced a variety of test aerosols with different particle size distributions and concentration levels, particle shapes and refractive indices (Asbach, et al., 2018). The test aerosols used are listed in Table 2 along with their main properties. Eskal (KSL Staubtechnik GmbH) was used as it is available with different size distributions and dyed in different colours, i.e. with different refractive indices, but identical material, i.e. calcium carbonate, $CaCO_3$. In addition, spheriglass particles (Potters Ballotini) were chosen due to their spherical shape and milled slate (Bassermann Specialties) because of their platelet shape. The powders were dispersed using a homemade powder disperser and fed into a 20 m long wind tunnel, where the particles were mixed with clean dilution air. The wind tunnel feeds into a 23 m³ chamber, in which the particles get homogenously dispersed, so that all measurement instruments located inside the chamber sample identical aerosol. To adjust the particle concentration in the chamber, the powder was mixed with different amounts of clean sand. During the transport of the dispersed dust through the wind tunnel, the large sand particles settled to the bottom of the tunnel and thus only the aerosolized powder remained airborne.

Table 2: Test aerosols used for testing low-cost PM sensors for measuring respirable dust concentrations in workplaces

| Nr. | Name | Material | Modal diameter[1] | Density | Comment |
|---|---|---|---|---|---|
| **1** | Eskal 300 pure | $CaCO_3$ | Number: ~1.7 µm<br>Mass: ~4.5 µm | 2.71 g/cm³ | |
| **2** | Eskal 300 red | $CaCO_3$ | Number: ~1.7 µm<br>Mass: ~4.5 µm | 2.71 g/cm³ | Dyed red |
| **3** | Eskal 300 black | $CaCO_3$ | Number: ~1.7 µm<br>Mass: ~4.5 µm | 2.71 g/cm³ | Dyed black |
| **4** | Eskal 500 pure | $CaCO_3$ | Number: ~2 µm<br>Mass: ~10 µm | 2.71 g/cm³ | Same material as eskal 300, but larger particles |
| **5** | Spheriglass 5000 | $SiO_2$ | Number: ~1.3 µm<br>Mass: >17 µm | 2.5 g/cm³ | Spherical glass beads |
| **6** | Milled slate PNPOU | Slate | Number: ~2 µm<br>Mass: >17 µm | 2.8 g/cm³ | Platelets |

[1]measured with welas

In these measurements, three Alphasense OPC-N2 and up to five NovaFitness SDS011 sensors were used and their results compared with gravimetric data, obtained from a reference filter sampler MPG II for respirable dust (Mattenklott, et al., 2011). The size distributions measured with the Alphasense OPC-N2 were in addition weighted with the size selection curve for respirable dust with a $d_{ae,50}$ at 4 µm according to EN 481 and compared to an optical aerosol spectrometer (Palas, model welas 2500). The resulting mass size distributions are shown for four exemplary test aerosols in Figure 5. It can be seen that the sizing agreement of the Alphasense sensors is rather good, whereas the determination of the particle concentration is less accurate and differed from sensor specimen to specimen. This would mean that every individual sensor would require an individual calibration for each workplace, which requires a lot of effort. It should, however, be noted that the sensors were not new, when they were used in these tests and the discrepancies observed may stem from different aging or soiling of the individual sensors.

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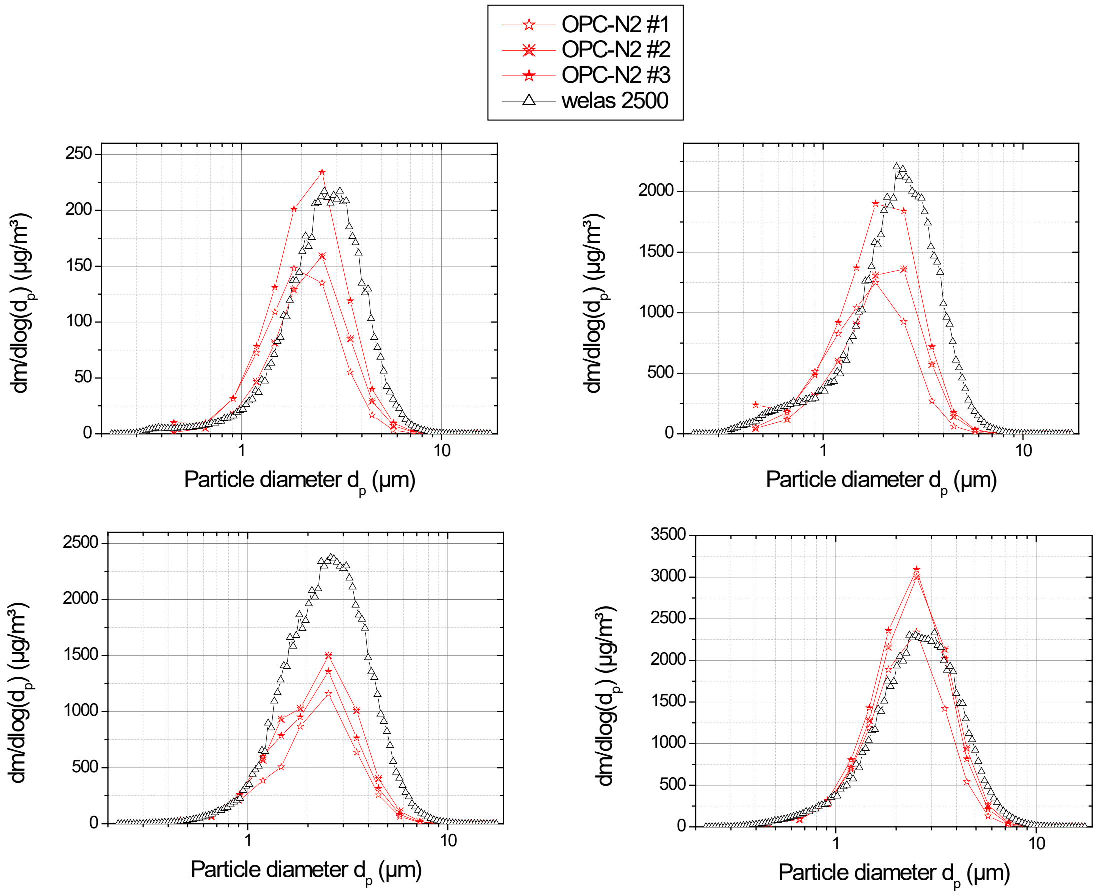


Figure 5: Respirable dust mass size distributions, measured with three specimens of the Alphasense OPC-N2 sensor and an optical aerosol spectrometer welas 2500 (Palas)

The results of the NovaFitness sensors were surprising, as especially the $PM_{2.5}$ concentration delivered by the sensors were highly correlated ($R^2$ = 0.963) with the reference respirable dust concentrations. The correlations were nearly identical for all investigated test aerosols, listed in Table 2. The inter-sensor variability was very low. The concentration values reported by the sensors were well below the reference data. However, due to the high correlation, the data can simply be corrected by applying a correction factor. Since the slopes of the correlations was nearly identical for all test aerosols and sensors, a single correction factor was sufficient. The correlation of the $PM_{10}$ data delivered by the sensors was also high ($R^2$ = 0.839), but not as good as for the $PM_{2.5}$ concentrations. It was further shown that the linear relationship between the $PM_{10}$ concentration reported by the SDS011 sensors and the reference respirable dust concentrations was only valid up to approximately 1.5 mg/m³ and reached saturation for higher concentrations. For $PM_{2.5}$ the linear relationship was still applicable to respirable dust concentration of approximately 5 mg/m³. Two different correction factors were determined, one based on the average ratio of the concentrations measured with the sensors and the reference concentrations. The second correction factor was the reciprocal slope of the linear correlation of the sensor data versus the reference concentrations. The results of these two approaches are shown in Figure 6 for both $PM_{2.5}$ and $PM_{10}$. The figure shows that both approaches deliver good results, particularly for $PM_{2.5}$, where most values agree within ±30% with the reference data. The mismatch is higher for the $PM_{10}$ data. It should be noted that the data stem from two different measurement campaigns and only the data from three sensors that were applied in both campaigns are shown.

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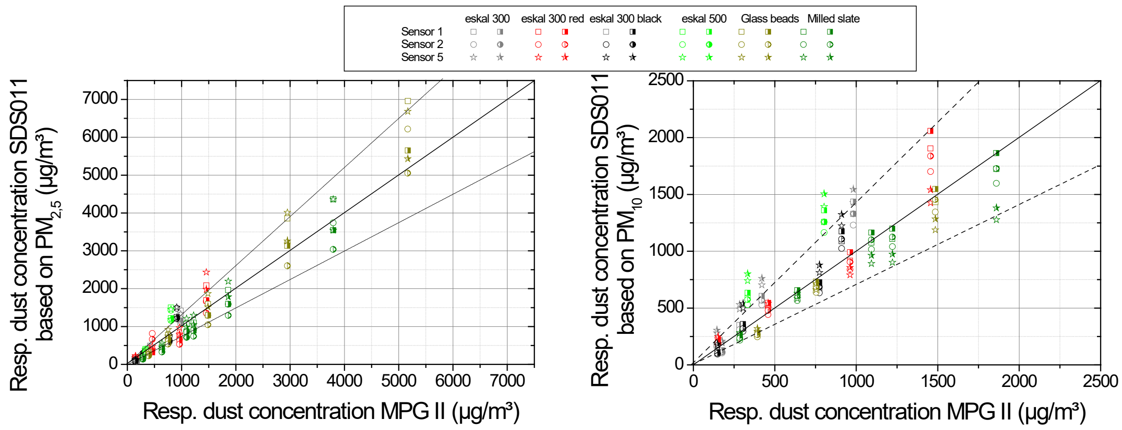


Figure 6: Correlations of the $PM_{2.5}$ and $PM_{10}$ concentrations from teh SDS011 sensors and the respirable dust concentrations measured gravimetrically with the MPG II for six different test aerosols; sensor data were corrected based on two different approaches (1) correction factor = average ratio of sensors and MPGII (open symbols) and (2) correction factor = reciprocal slope of linear regression curve (semi-closed symbols); the straight line is for 1:1 agreement, the dotted lines indicate ±30% deviation.

## 4. CONCLUSIONS

Low-cost PM sensors have become very popular in many fields of aerosol science and for citizen science projects. Due to their low costs, they allow for setting up dense networks for monitoring of air quality with high spatio-temporal resolution, e.g. in the atmosphere or at workplaces, among others. However, several limitations to their applications apply. The sensors are mostly based on photometric measurement of the light scattered by a cloud of particles. Consequently, several assumptions regarding the particle sizes, shapes and materials need to be made in order to translate the measured light intensity to a particle mass concentration. Only if these assumptions are met, the results can be accurate. It was furthermore shown that high humidity levels can lead to a strong overestimation of the particle mass concentration due to hygroscopic particle growth. This problem was effectively overcome by a low-cost aerosol dryer that has been developed. It was furthermore shown that the $PM_{2.5}$ concentration measured with NovaFitness SDS011 sensors in a laboratory experiment showed a very high correlation with the respirable mass concentration determined gravimetrically from filters, sampled using the MPG II reference sampler. A simple correction factor could be derived that is independent of the particle size, shape or material and identical for all sensors tested. With this correction, the $PM_{2.5}$ data from the sensors agreed mostly within ±30% with the reference data, even up to a mass concentration of approximately 5 mg/m³. The sensor is thus a promising candidate for measuring respirable dust concentrations in workplaces.

## 5. LITERATURE

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