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Comparison of Methods for Converting Dylos Particle Number Concentrations to PM2.5 Mass Concentrations

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Abstract

The aim of this study was 1) develop a method for converting particle number concentrations (PNC) obtained by Dylos to PM2.5 mass concentrations, 2) compare this conversion with similar methods available in the literature and 3) compare Dylos PM2.5 obtained using all available conversion methods with gravimetric samples.

Data were collected in multiple residences in three European countries using the Dylos and an Aerodynamic Particle Sizer (APS, TSI) in the Netherlands or an Optical Particle Counter (OPC, GRIMM) in Greece. Two statistical fitted curves were developed based on Dylos PNC and either an APS or an OPC particle mass concentrations (PMC). In addition, at the homes of 16 volunteers (UK and Netherlands), Dylos measurements were collected along with gravimetric samples. The Dylos PNC were transformed to PMC using all the fitted curves obtained during this study (and three found in the literature), and were compared with gravimetric samples.

The method developed in the present study using an OPC showed the highest correlation (Pearson (R)=0.63, Concordance (ρ_c)=0.61) with gravimetric data. The other methods resulted in an underestimation of PMC compared to gravimetric measurements (R=0.65 – 0.55, ρ_c=0.51-0.24).

In conclusion, estimation of PM2.5 concentrations using the Dylos is acceptable for indicative purposes.

KEYWORDS: Dylos, particle number concentration, mass concentration, conversion, APS, OPC

Practical implications

Low-cost real-time particle counters are becoming more available. Most of these particle counters express their output in particle number concentrations, while the majority of health risk studies are based on health effects of particulate matter as mass concentrations. This study suggests that a conversion formula can be derived to estimate PMC from PNC data, but indicates that this method is uncertain and is currently only useful for indicative purposes.

Introduction

Particulate matter (PM) exposure is associated with adverse health effects including respiratory symptoms, lung function decline as well as cardiovascular and respiratory related hospital admissions and mortality.[1-3] Epidemiological evidence and subsequent legislation relating to PM air pollutant exposure is generally based upon ambient outdoor concentrations,[4] due to the limited availability of indoor PM exposure data and difficulty in assessing indoor PM levels comprehensively. However, adults spend 80 to 90% of their time indoors.[4-6] Ambient air has an impact on the quality of the indoor environment, [2 7] but there are additional indoor sources including combustion, building materials, household cleaning products as well as movements of inhabitants. [8 9] Several studies highlighted cooking as one of the most significant pollutant generating activities indoors in non-smoking residences with indoor PM concentrations that can far exceed outdoor PM concentrations.[4 9-11]

Recent technological developments have led to the availability of relatively low cost PM sensors, usually based on the use of light scattering to count particles. Due to the low cost of these devices, they have the potential to be more widely used in exposure assessment and epidemiological studies to provide insights in indoor PM exposure levels, indoor PM sources and associations with health effects. Nevertheless, the performance of these sensors has not been thoroughly tested and there is still room for improvements. One of these low cost PM sensors is the Dylos DC1700™ which has been investigated in several studies and expresses particle number concentrations (PNC) in two size bins (>0.5μm and >2.5μm). [12-17]

Health risk studies show an increasing understanding of the importance of PNC in addition to particle mass concentrations (PMC).[18] However, the majority of studies on health effects have assessed PM as mass concentrations, underlining the need to be able to convert PNC to PMC. The availability of Dylos particle counts in only two, relatively large, size bins limits the application of a conversion between the PNC and PMC based on particle size, particle density and number concentrations by size bin.[19] As a result, some studies have converted Dylos PM counts to PMC for PM2.5 by fitting a curve between PNC obtained by the Dylos and PMC obtained by a conventional high cost reference instrument during side by side measurements. While these studies provide a calibration method for the Dylos to predict mass concentrations based on Dylos PNC, none of these studies have compared this ‘curve fitting approach’ with the ‘Gold standard’ gravimetric filter-based methods. Furthermore, most of the fitted curves are based on experiments in which only one known PM source is present. Since particle size distributions and densities are expected to vary with different sources, studies conducted in real-life home settings are useful to explore if a ‘one-size fits all’ statistical conversion method is feasible in real-life home conditions.

As part of the Health and Environment-wide Associations based on Large population Surveys (HEALS) study, a pilot project was conducted to evaluate the possibility of using sensor technology in exposome studies.[20] One of the technologies evaluated was the low-cost sensor Dylos DC1700™ to assess indoor PM exposure. The aim of this study was to compare different fit curves that predict PM2.5 mass based on Dylos PNC. We developed two statistical fitted curves based on data obtained under real-life in-home conditions and compared these to the curves reported in the literature, which were mostly obtained under experimental conditions using a similar approach to develop these fit curves as reported in these studies. We evaluated the performance of each curve (including the curves reported in the literature) by comparing the PMC results obtained by applying these curves to Dylos data with 24h time weighted average gravimetric measurements obtained from co-locating gravimetric samplers with the Dylos.

Methods

The HEALS sensor pilot studies were conducted in three countries: The Netherlands, The UK and Greece. For the current study, data collected during this pilot study were supplemented with additional surveys where conventional monitors and gravimetrical equipment were used.

Study design and data collection

Data was collected for 1) developing ‘fit’ curves for converting Dylos PNC to PMC; 2) and validating these PNC to PMC fit curves and previously reported curves in the literature against gravimetric measurements. An overview of the equipment used and the number of measurements performed are presented by country in Table 1.

Developing fit curves

Data for the calibration of statistical fit curves were collected in two study centers (The Netherlands and Greece) by placing the Dylos side by side with a conventional device in the residences of study participants. An activity diary regarding the possible sources of PM (cooking, vacuum cleaning, cleaning activities) along with a questionnaire concerning the house characteristics were completed by the participants. The sampling equipment was placed in the living room and the duration of the campaign was about 3-7 days in each household. In the Netherlands, data was collected at the homes of three volunteers with an Aerodynamic Particle Sizer (APS, TSI, USA) side-by-side with the Dylos for 10 days in total. In Greece, an OPC 1.108 aerosol spectrometer (GRIMM Aerosol Technik GmbH & Co, Germany) was placed side-by-side with the Dylos at the homes of 7 volunteers of the HEALS pilot study for 48 days in total.

Validation of fit curves

For the external validation of all conversion curves, 24h gravimetric samples were collected side-by-side with the Dylos in The Netherlands and the UK. The samplers were located in the main living area of the family house out of reach of children. The sampling time was approximately 24 hours. In The Netherlands Harvard impactors were used to measure PM2.5 gravimetrically at a sampling rate of 10 l/min in 6 households for 5 consecutive days (n=30). Participants were instructed and trained to change the filters of the Harvard impactor daily, and register the airflow using a rotameter.

In the UK Harvard Personal Environmental Monitors were used to measure PM2.5 gravimetrically in 10 households for one day alongside the Dylos at a sampling rate of 4 liters per minute. The sampling time was limited by the charge of the external battery for the pump.

Instruments

Particle counters

The Dylos (Dylos corporation, USA) is a low cost laser particle counter capable of counting particle numbers in real time (one data point per minute) in two different size bins: 0.5µm and larger and 2.5µm and larger. The upper range of the device is estimated to be close to 20 µm, but this has not been reliably quantified (personal communication, Dylos corporation, 2015). The PNC for PM2.5 from the Dylos were obtained by subtracting the large size bin from the small size bin.

Two conventional research grade particle counters were selected for establishing fit curves: the APS and the OPC optical particle counter.

The APS provides real-time aerodynamic measurements of particle numbers from 0.5 to 20 μm within 52 size bins (PM2.5 in 22 size bins). This device was set to record one data point per minute to match the Dylos. The APS has been validated for an accurate particle size distribution, and is widely used for assessing (occupational) exposure to aerosols, evaluating or designing other aerosol samplers and characterizing ambient particulate matter.[21 22]

The OPC, like the Dylos, uses a light scattering technique to quantify PM concentrations in the range 0.23-20 μm and in 16 size bins (PM2.5 in 10 size bins). The device was set to log one measurement every minute. This instrument can be applied in both environmental and occupational measurements and it has been evaluated in multiple studies for different environments. [26-28]

Conversion of particle counts to mass (APS and OPC)

Data within the PM2.5 range was selected for each device. APS and OPC PNCs were transformed into PMC using the following equation.[19]

$$C_m = 10^{-15} \cdot \rho_p \cdot C_{number} \cdot \pi/6 \cdot d_{m/a}^3 \qquad (1)$$

Equation 1: Particle number concentrations to mass concentrations equation.

Where C_m is mass concentration (μg/m^3), ρ_p is the particle density (g/cm^3), C_{number} the number concentration (particles/cm^3) and $d_{m/a}$ the median particle size in the size bin (nm). The calculated PMC in each size bin were summed to retrieve the total PMC for PM2.5.

To obtain a relevant mass concentration an average density of 1.5 g/cm^3 was used for the mass conversion based on the average particle density for ambient (outdoor) particles found in Europe.[23 24]

Both the OPC and the APS were calibrated annually, as is standard maintenance for these measurement devices. Both the APS and the OPC were calibrated by the manufacturer before the measurement campaign.

Gravimetrical assessment

As far as the sampling methodology in the Netherlands is concerned, gravimetric filter measurements were collected using a Harvard impactor, which is designed to collect particles smaller than 2.5µm at an airflow rate of 10 l/min.[25] Total sampling volume for each filter was calculated based on the total sampling time and the average air flow. The filter weightings were conducted conform the NEN-EN 12341 and NTA 8019. Briefly, Zefluor PTFE filters 47mm – 2.0µg were conditioned for 48 hours in a Weis – Ened conditioner cabinet with a temperature of 20 +/- 1 °C and a relative humidity of 50 +/- 3% during the weighing of the filters before and after the experiment. The filters were weighed in duplicate on a Mettler MX5 scale, with 24 hours between each weighing. The averages of the filter weights were used as the final weight of the filters. For the samples from Scotland, Harvard Personal Exposure Monitors (HPEMs) were used, with 37 mm PTFE filters attached to a BGI personal pump. These were placed in the home next to the Dylos and allowed to run at 4 L/min for the full run-time of the pump which was approximately 24 hours. In the UK, filters were conditioned weighed pre- and post- experiment at the laboratory in a similar matter as was done in the Netherlands. The overall limit of detection was calculated as 3 times the standard deviation of the masses of the blanks and this was divided by a nominal flow rate of 4 L/min to obtain a limit of detection (LOD) of 5.7 µg/m^3. If a positive sample mass was not available after blank correction, a value of the LOD/sqrt(2) was substituted.

Data analysis

Calibration: fit curves

To obtain the PNC to PMC fit curves, the APS, OPC and Dylos data was first log-transformed to correct for the lognormal distribution of the data. Besides the high resolution data (on a data-point per minute scale), all data was also averaged over 10- and 60-minute intervals to reduce the impact of random errors. We then applied mixed effect modeling with the person as random factor for fitting a linear regression model through the log-transformed APS and Dylos data (as collected in the Netherlands) and the log-transformed OPC and Dylos data (as collected in Greece).

The linear regression models were validated by means of a 10-fold cross-validation, in which 10 subsets were created by excluding specific time periods from the full dataset. Analysis of the variability of the fixed effects, random effects and root mean squared error indicated the stability of the model. All analyses were performed in R version 3.4.1 using the base, nlme and ggplot2 packages.

To compare the Dylos fit curves to previously published PNC-PMC conversion equations, the curves from the present study were plotted together with 3 previously obtained curves reported in the literature.[17 26 27]

Gravimetric validation

The fit curves developed in the current study and the ones published in the literature were validated against gravimetric measurements. The Dylos PNC obtained during side by side gravimetric measurements were transformed to PMC using each fit curve (5 in total). These PMC estimates were averaged over the measurement period for which gravimetric measurements were taken, resulting in 40 modelled 24h time weighted average PM2.5 mass concentrations obtained with five fit curves.

Correlation coefficients were calculated to estimate the agreement between the modeled mass and the gravimetric mass concentrations (Pearson correlation coefficient) and take into account the agreement of the actual values of the modeled mass and gravimetric mass (1:1 line) (concordance correlation coefficient), additionally the data were summarized in Bland-Altman plots.

Results

In Figure 1, the Dylos PNC is plotted against the APS mass fitted curves based on 1-minute data and averaged data over 10- and 60-minute intervals (Figures 1a, 1b and 1c, respectively) and against the OPC mass fitted curves based on raw data and averaged data over 10- and 60-minute intervals (Figures 1d, 1e and 1f, respectively) . The individual fits for each volunteer based on raw data and averaged data over 10- and 60-minute intervals are presented in supplemental Figure 1. Figure 2 shows the predicted APS and OPC mass plotted against the observed APS and OPC mass based on the raw data and averaged data over 10- and 60-minute intervals. It can be seen that both models had high Pearson correlation coefficients with values >0.9 for the APS mass and >0.8 for the OPC mass. When using averaged data the Pearson correlation coefficients increase slightly as this approach corrects for extremely high and low values. However, this approach also results in a loss of information, since data is averaged. Since the Pearson correlation coefficients for the averaged data were comparable to the Pearson correlation coefficients for the raw high resolution data we decided to continue with the models based on the raw data.

When exploring the data grouped by volunteer, some patterns can be observed in each household in indoor PM2.5 patterns, suggesting that the relationship between Dylos PNC and measured PMC may vary between households. The patterns are more obvious in the APS dataset obtained in the Netherlands compared to the OPC dataset obtained in Greece in which data from only one home shows a clear deviation. Also, the exposure levels vary among households. The 10-fold cross-validation indicated a great stability of the model, with a maximum variability of 1.7% in the fixed effects and 1.6% in the root mean squared error. This is partially caused by the high number of observations (n = 53,692 for the OPC data and n = 3178 for the APS data). The variability increased only marginally when the data was averaged over 10- and 60-minute intervals, with maximum variabilities of 1.8% and 2.8%, respectively. However, the random effects were relatively large for the APS dataset obtained in the Netherlands (up to 44% of the fixed effect for the intercept (1.82/4.12) and 37% for the slope (0.36/0.97)) possibly due to the limited number of volunteers (N=3). Since the OPC dataset obtained in Greece contained more volunteers (N=7), the random effects were smaller (up to 27% of the fixed effect for the intercept (0.85/3.09) and 21% for the slope (0.17/0.81)), indicating that individual volunteers have less impact on the overall performance of the model.

Figure 3 shows the two fit curves estimated within this current study (APS curve and OPC curve and three curves reported in the literature, presented on the log-scale.[17 26 27]

Table 2 summarizes the fitted relationship, parameter values, and measurement devices used in each study. Three of the five studies used a power law calibration curve to fit the data, one used a 2nd order polynomial model and one study used a linear fit to predict PMC. It has to be noted here that different devices were used for each study.

Figure 4 shows the modelled 24h time weighted average (TWA) PM2.5 mass concentration derived based on the Dylos particle counts with each conversion method against the 24h gravimetric data from 6 volunteers in the Netherlands (5 days per volunteer, n=30) and 10 volunteers in Scotland (1 day per volunteer, n=10). For 1 volunteer in the Netherlands, one gravimetric measurement was excluded due to a loose air hose during the day (total n=39).

Modeled PMC based on all fit curves except for the one developed using the OPC underestimated the 24h PM2.5 mass. The modelled PMC based on the OPC fit curve is distributed around the 1:1 line. However, considerable variability across the 1:1 line can be observed without a clear trend of under-or overestimation. The methods developed based on the APS, both in the current study and the one of Semple et al. (2013) are underestimating less compared to Steinle et al. (2015). The method of Dacunto et al. (2015) underestimates greatly compared to all other methods. For all methods (while slightly less for OPC method), variance within and between volunteers seems to be more pronounced for the gravimetric measurements, and modelled values seem to result in less variability. Figure 5 shows Bland-Altman plots for each method, and gives additional insight in the performance of each model with respect to the gravimetric measurements. When looking at individual correlations between averaged Dylos PNC and filter masses, a negative correlation of -0.4 was observed for two of the six volunteers from the Netherlands. This negative correlation influences the overall performance and correlations of each method, but especially for the APS, OPC and Semple et al. (2013) methods as is presented in Figure S2. The effects of the negative correlation on the performance of each model is also visible in Figure 5, where samples 11 – 15 and 26 – 29 belong to the measurements with the negative correlation, and show the highest underestimation in the Bland-Altman plots.

Overall, the OPC conversion method showed the highest concordance correlation compared to the other fit curves(ρ_c: 0.61 vs 0.18-0.51). The Pearson correlation coefficients for all fit curves were in the same range (R~0.65) with the exception of the fit curve from Dacunto et al. (2015) (R: 0.55).

Discussion

In the present study we developed two fit curves to convert Dylos PNC to PMC using two conventional devices (APS and OPC) in different populations. 10-fold cross-validation showed high stability of the model, which had high Pearson correlations between indirectly measured and predicted PMC for both devices (R>0.81). In a gravimetric validation, we compared the modelled mass concentrations obtained based on Dylos PNC data using these two curves along with fit curves obtained from the literature against gravimetric measurement data in real home settings. The method developed in the present study using an OPC device showed the highest Pearson and concordance correlation (R:0.62, ρ_c:0.59), without systematic under- or overestimation but with considerable variability around the 1:1 line. The other methods all resulted in an underestimation of PM2.5 mass concentrations compared to the gravimetric measurements (R:0.65 – 0.55, ρ_c:0.51-0.24).

The APS and OPC are based on measuring PNC within a range of different size bins. The calculation of the APS and OPC mass within each size bin is based on the assumption that particles are spherical and with a single density. In reality the shapes and composition of the particles are unknown and variable within every aerosol, resulting in a potential inaccuracy of the PMC estimation. Moreover, the APS and OPC use different methods to evaluate the diameter of the particles where the APS uses the aerodynamic diameter and the OPC the optical diameter which also affects how the shape of the particles influence these different devices. Because of these assumptions on density and particle shape, the devices should be calibrated against gravimetric sampling under similar exposure circumstances. Although calibration of these devices may have resulted in less underestimation, it would not have accounted for the variability observed between modelled PMC and gravimetric measured PMC. Peters et al. (2006) compared the performance of these devices for sizing and counting accuracy and found that the APS was more accurate in the sizing of particles due to the larger size resolution (52 size bins compared to 16 size bins). Furthermore, the accuracy of the counting of particles was generally similar with small differences in the lower size range where the APS seemed to be less accurate, and underestimating particles < 0.7µm. Pfeifer et al. (2016) found for the APS that the variability in counting efficiency for particles <0.9 µm is 60% between different tested machines, which underline the findings of Peters et al. (2006).[28] The OPC was less accurate in counting particles > 2.5 µm, however for this study this size range is not investigated.[29] In two additional studies, it was shown that both the APS and the OPC mass concentrations were well in line with gravimetric samples, indicating that these devices are fairly capable of measuring PMC, [30 31] and are usable as a device to evaluate the performance of other real-time instruments.[29]

Dacunto et al. (2015) performed experiments where different types of food were cooked and where a fit-curve was produced for each experiment and for all data together (which was used in the current study). They reported a variance of calibration curve parameters within the different experiments using the same sources and between different sources, suggesting that differences in experimental conditions can produce a wide range of fit curves for conversion of Dylos PNC to PMC, particularly for the higher concentration ranges.[17] This finding is in line with our observations which were obtained under real life circumstances. Clear trends in the calibration curves (PM2.5 measured with an APS or OPC device versus the Dylos counts) can be observed between the situations suggesting the presence of different sources influencing the Dylos measurements in the homes of the different volunteers. These differences might be explained at least in part by the variability in particle density. In the literature, average ambient air particle densities (in Germany) have been reported to be ~1.5 g cm^{-3}, however densities can vary between 0.9 and 2.57 g cm^{-3} [18 32 33] Particle density is dependent on both the shape and the chemical composition of the particle. Therefore, all processes influencing one of these aspects will affect the density of the particles. Particle densities between the different published studies have varied greatly due to the settings. For instance, Steinle et al. (2015) focused on outdoor air quality, comparing the Dylos with an outdoor reference monitor, whilst Dacunto et al. (2015) performed experimental studies with cooking and Semple et al (2013) focused on second-hand smoke in similar indoor settings compared to our study. In the present study we focused on real life indoor situations with PM2.5 from a wide variety of indoor and outdoor sources likely resulting in an even wider range of particle densities. Furthermore, the Dylos' accuracy may explain part of the observed variability, especially in the higher concentration ranges. Semple et al. (2013) reported that Dylos accuracy decreases when PM concentrations are high.[27]

As previously discussed, the real life home situations in the present study have likely resulted in a wide range of particle densities and therefore a larger uncertainty around the fitted curves. This has implications for the application of these fitted curves. Given the uncertainty, this conversion curve approach may be useful when a relatively high contrast in exposure levels is expected to distinguish relatively high from relatively low exposure levels. For instance in situations such as developing countries where both indoor and ambient levels of PM are higher, or in case of high indoor sources in non-developing countries like smoking, indoor fireplaces, etc. However, in case of low level exposures and low contrast in exposure levels caution should be taken when applying this 'one size fits all' method.

The current study adds to existing body of literature on methods for converting Dylos PNC to mass. Several comparably derived curves are described in the literature, but have been developed under (semi)-controlled circumstances such as experimental cooking emissions, secondhand smoking or for outdoor PM. In the present study, curves were established under real life indoor circumstances. Furthermore, the current study is, to our knowledge, the first study to make use of gravimetric measurements to validate the fitted curves and to compare the performance of these curves with the curves found in the literature.

While this study presents valuable insights regarding the application of fitted curves for PNC to PMC conversions, some limitations should also be considered. First, an APS and an OPC were used for calibration of the curves in different populations, while it would be more optimal if identical devices were used for comparability of the results between the populations.

As mentioned before, a negative correlation of -0.4 was observed for two volunteers which significantly influenced the overall performance of each fitted curve. It might be possible that measurement errors occurred when sampling with the Dylos. In previous studies, it was observed that Dylos performance seemed to decrease after being used for a long time. While the Dylos devices were cleaned using compressed air before these measurements, it might be possible that this decrease in performance is responsible for the negative correlation. These measurements were not excluded from the main result. However it is expected that these PNC to PMC conversion methods could perform better than presented in the current study.

Lastly, the current dataset is relatively small. It would have been useful to have a more diverse set of measurements in situations with larger differences in PM levels, since our current dataset consists of generally low levels of PM and therefore the performance of each curve at elevated levels is unknown.

Conclusions

Two fit curves were developed to convert Dylos derived PNC to PMC. These and other previously published fit curves were validated against gravimetric filter measurements under real life indoor circumstances. The OPC method developed in the present study appeared to be the most accurate method under these circumstances. It is recommended to calibrate the measurement device for the specific circumstances in which measurements are being performed. However large variability in PM2.5 mass assessed by either the APS or OPC for a given Dylos derived PNC results in relatively high uncertainty in the fitted curves resulting in a relatively high inaccuracy of this ‘one-size fits all’ approach in complex exposure situations such as the home. Therefore, this conversion curve approach may be most valuable when a relatively high contrast in exposure levels is expected to categorize high versus low exposure levels.

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Figure captions:

Figure 1: Fitted curves between Dylos PNC and (a – c) APS PMC on 1-minute, 10-minute and 1-hour scale and (d – f) OPC PMC on 1-minute, 10-minute and 1-hour scale.

Figure 2: Predicted Dylos PMC and (a – c) observed APS PMC on 1-minute, 10-minute and 1-hour scale and (d – f) observed OPC PMC on 1-minute, 10-minute and 1-hour scale.

Figure 3: Developed fit curves and fit curves found on the literature.

Figure 4: Different fit curves used to predict PMC from Dylos PNC counts compared to gravimetric data. Data presented for 6 persons with multiple measurements and 10 (volunteers 7 – 16) persons with 1 24h measurements.

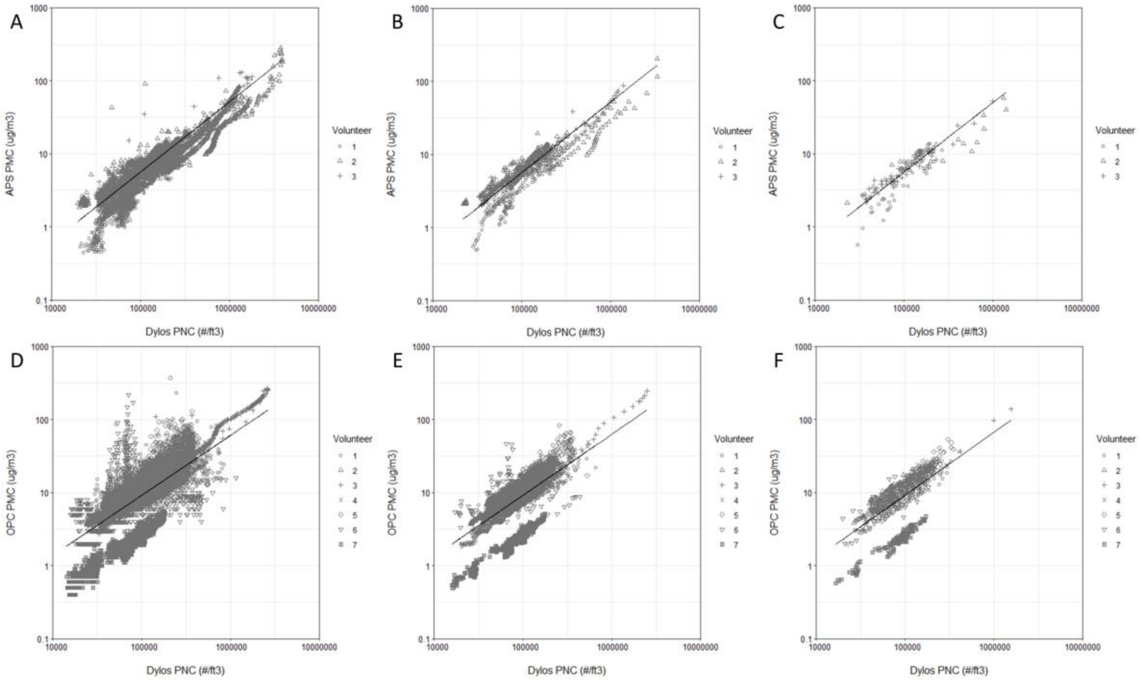
Figure 5: Bland-altman plots for the different fit curves showing differences between filter- and modelled data.

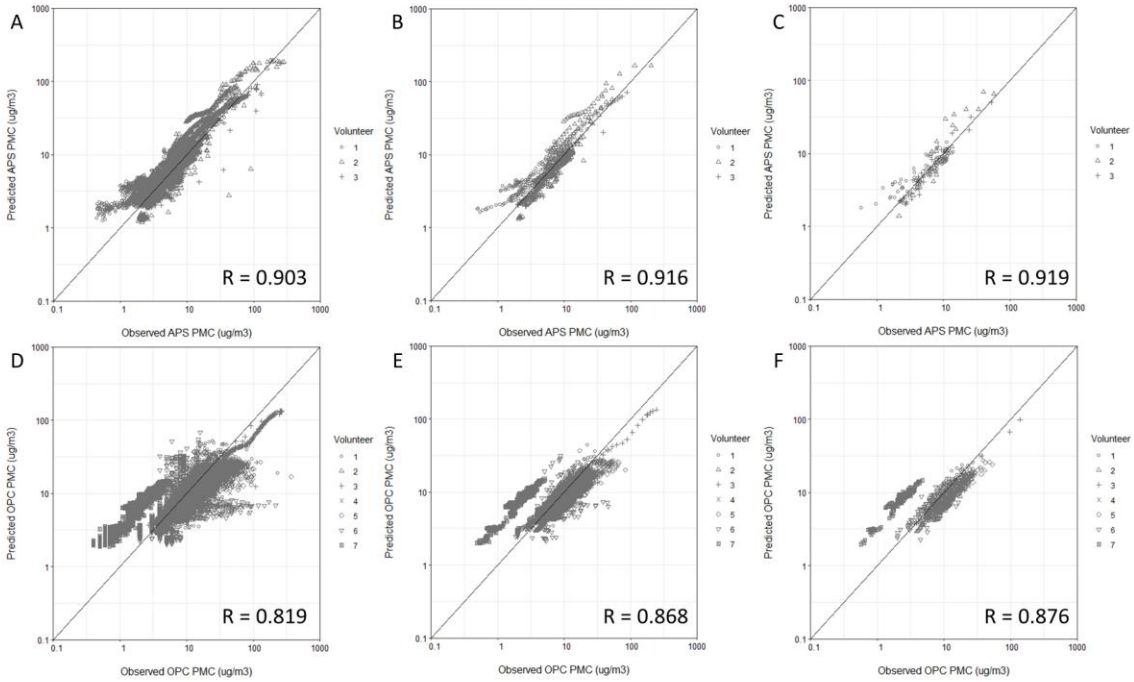
Table 1: Overview of collected data.

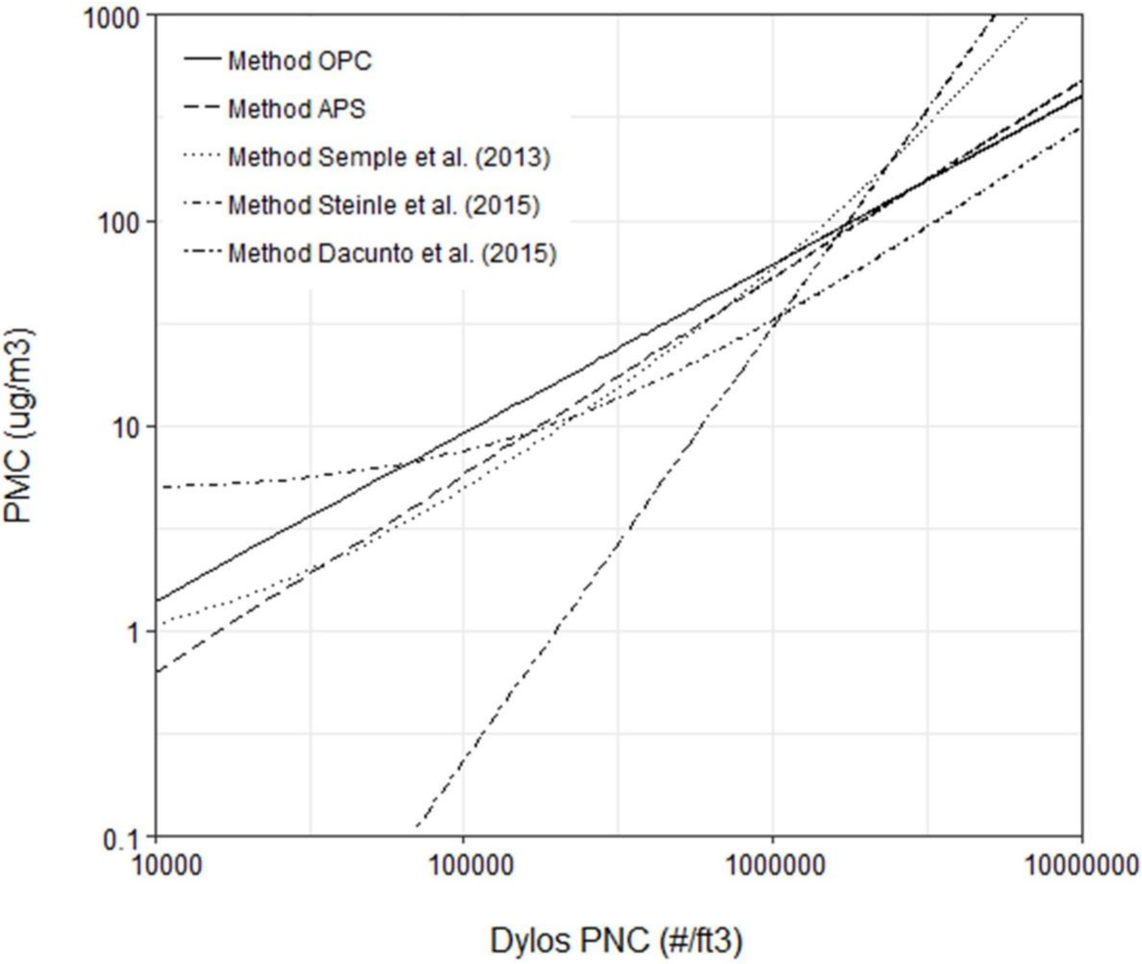
Goal	Study center	Low cost sensor	Reference device	N volunteer	N days total measured
Development of fit curves	The Netherlands	Dylos (counts/min)	APS (counts/min)	3	10 days
	Greece	Dylos (counts/min)	GRIMM (counts/min)	7	48 days
Validation of fit curves	The Netherlands	Dylos (counts/min)	Harvard impactor (mass 24h TWA)	6	30 days
	Scotland	Dylos (counts/min)	Harvard Personal Environmental Monitors (24h TWA)	10	10 days

Table 2: Fitted relationship of all conversion methods applied to Dylos data and their correlations with the corresponding gravimetric measurements.

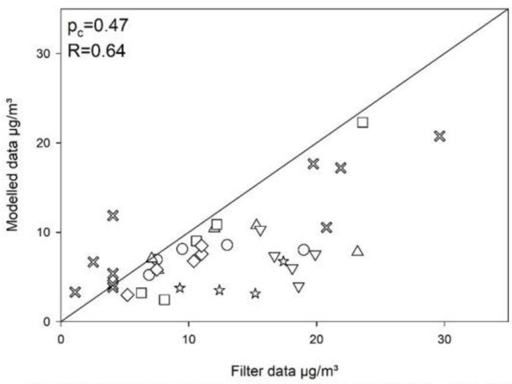
Study	Fitted relationship	Parameter values	Reference device	Study goal
Current study (APS based)	$Y=mx^n$	$m=9.14e^{-5}$ $n=0.96$	APS 3321	Indoor air quality living room
Current study (OPC based)	$Y=mx^n$	$m=7.33e^{-4}$ $n=0.82$	GRIMM	Indoor air quality living room
Semple et al. (2013)	$Y=a_0+a_1x+a_2x^2$	$a_0=0.65$ $a_1=4.16e^{-05}$ $a_2=1.57e^{-11}$	TSI SidePak AM510	Second hand smoke study
Steinle et al. (2015)	$Y=a_0+a_1x$	$a_0=4.75$ $a_1=2.8e^{-05}$	TEOM	Outdoor PM (experimental)
Dacunto, et al. (2015)	$Y=mx^n$	$m=1.09e^{-07}$ $n=2.111$	TSI SidePak AM510	Experimental influence of meat cooking on PM concentrations


A
B
C
D
E
F
APS PMC (ug/m3)
OPC PMC (ug/m3)
Dylos PNC (#/ft3)
Volunteer
1
2
3
4
5
6
7

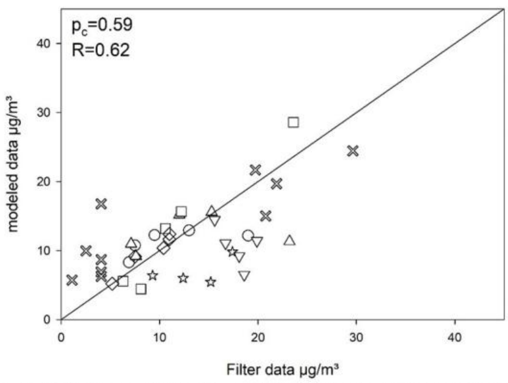

A
B
C
D
E
F
Predicted APS PMC (ug/m3)
Observed APS PMC (ug/m3)
Predicted OPC PMC (ug/m3)
Observed OPC PMC (ug/m3)
Volunteer
R = 0.903
R = 0.916
R = 0.919
R = 0.819
R = 0.868
R = 0.876


1000
100
10
1
0.1
PMC (ug/m3)
Method OPC
Method APS
Method Semple et al. (2013)
Method Steinle et al. (2015)
Method Dacunto et al. (2015)
10000
100000
1000000
10000000
Dylos PNC (#/ft3)

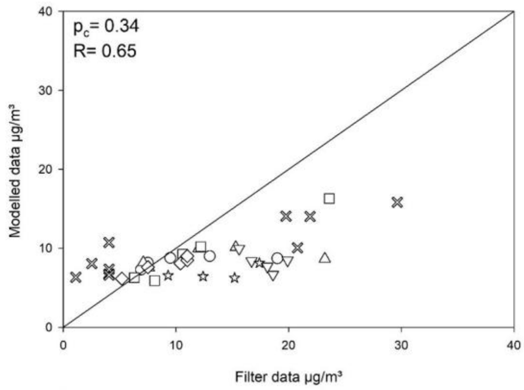
3a :Filter measurements compared to curve APS



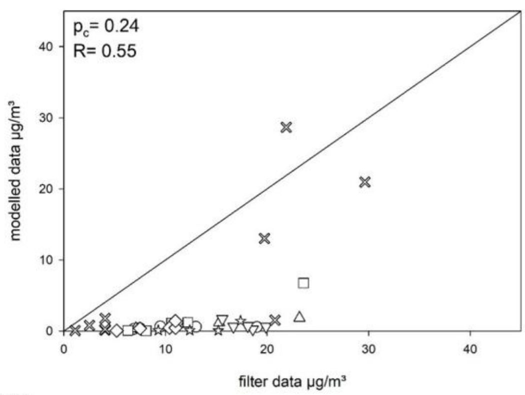
3b: Filter measurements compared to curve OPC



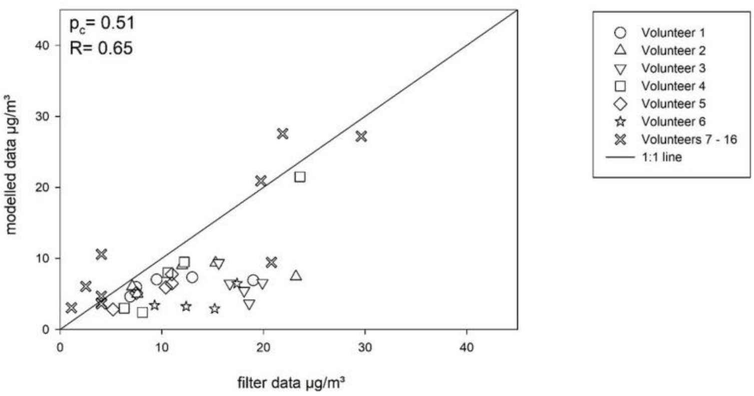
3c: Filter measurements compared to curve Steinle et al. (2015)

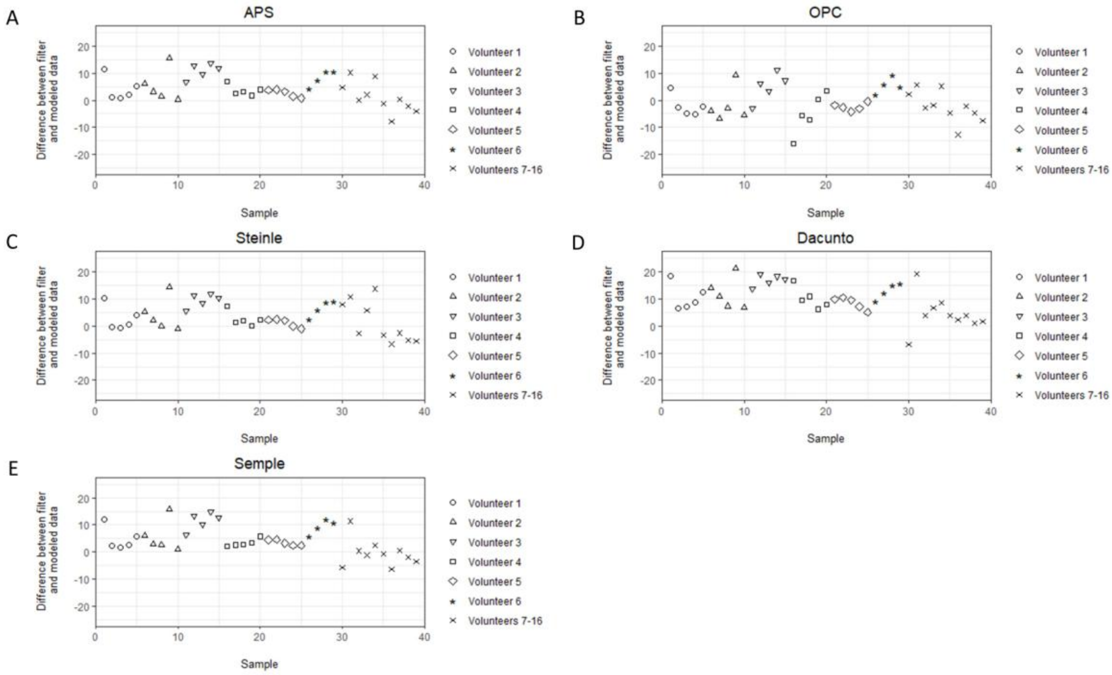


3d: Filter measurements compared to method Dacunto et al.(2015)



3e: Filter measurements compared with method Semple et al.(2013)




A
APS
B
OPC
C
Steinle
D
Dacunto
E
Semple
Difference between filter and modeled data
Sample
Volunteer 1
Volunteer 2
Volunteer 3
Volunteer 4
Volunteer 5
Volunteer 6
Volunteers 7-16