Indoor and Outdoor Ultra-Fine Particulates: A Case Study

CH TECHNOLOGIES (USA)

Rudolph J. Jaeger, Dritan Xhillari, Stella Choi, Dominick J. Carluccio

CH Technologies (USA) Inc., Westwood, NJ

MOTIVATION

Ultrafine particles (UFPs) have been shown to be associated with adverse health effects—e.g. cardiovascular disease, asthma, lung cancer, fatigue, and most recently, dementia. This particle range is a mixed class of substances that, while ill-defined, are not routinely monitored or regulated. Further, while ambient particulate concentrations may translate to outdoor exposure, people spend about 90% of their time indoors where additional sources may exist. As such, this study aims to quantify the indoor/outdoor (I/O) ratio of UFPs in densely populated and high traffic areas.

Due to surface area, studies suggest smaller particles are more biologically active. Thus, we focus on Lung Deposited Surface Area, which is the fraction of the particle size distribution by surface area that is expected to deposit in the alveolar region of the lung.

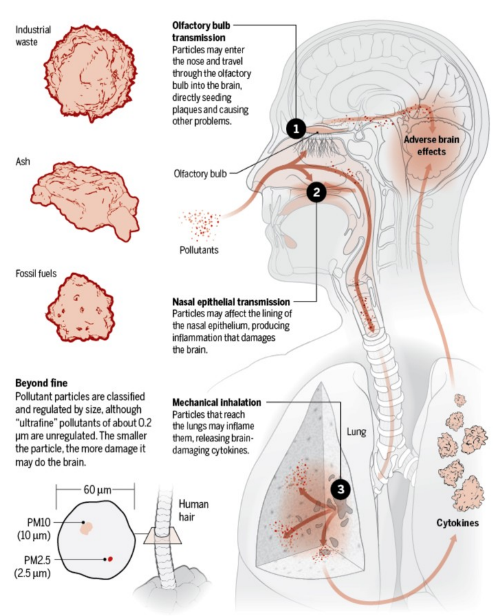


Figure 1. Impacts of inhaled pollutants [1].

BACKGROUND

The Pegasor AQIndoor and AQUrban are nanoparticle environmental monitors for assessing indoor and outdoor air quality. These devices utilize passive charging to measure Active Surface Area (ASA) and Lung Deposited Surface Area (LDSA), and apply a proprietary algorithm to calculate concentrations by mass and number. These devices can measure down to approximately 4 nm and have an optimal size range of detection from 20 nm – 300 nm. The Pegasor particle sensor (PPS) is based on electrically charging the particles and measuring the electrical current carried by particles exiting from the sensor, so called escaping-current technology.

The principle of the device is shown in Figure 2. The device directs clean (1), ionized (2) air in through the sample inlet (3). The air flow experiences turbulent mixing (4), and the charged particles and excess ions (5) enter a measurement channel (6), and travel through an electric field (7). Excess ions are filtered by an ion trap (8), to ensure measurements are not biased. The voltage of the ion trap is adjustable so that the lower cut-off point (particle diameter) can be adjusted to help locate the peak in the size distribution of the measured aerosol.

The primary sensor can measure currents down to 10^{-15}A (= 1 fA). The electrical current carried by charged particles is closely related to particle ASA (usually expressed in $\mu m^2/cm^3$). Knowing the where the peak lies in the particle size distribution allows one to convert the surface area concentration signal to particle number concentration, and the particle mass concentration.

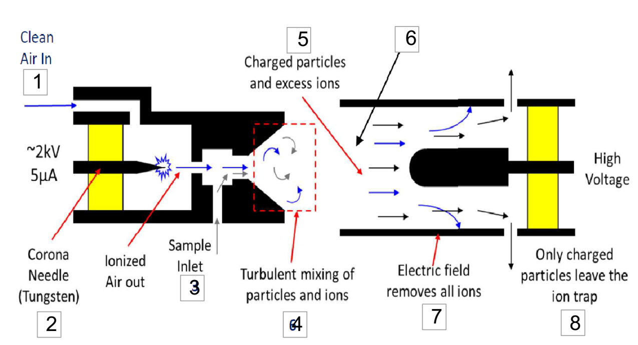


Figure 2. Schematic of Pegasor Particle Sensor principle of operation.

METHOD

Two Pegasor AQUrban and one AQIndoor devices were placed around New Jersey at: the Fort Lee Public Library, and the George Washington Bridge toll plaza (fig. 3). These devices were collocated with Gravimetric Samplers (Federal Reference Method), a Naneos Partector, and a Palas Fidas 200 (EU and UK recognized monitor). The Naneos Partector is a handheld nanoparticle measuring device that uses the same passive charging technique to measure LDSA and has a similar size range of detection. The Fidas 200 is an Optical Particle Spectrometer that measures total suspended particulates, Particle Number concentration, and size fractions PM_{10}, PM_4, $PM_{2.5}$, and PM_1 simultaneously. The NJDEP operates the collocated FRM environmental monitoring device.

Device	Location Details	US-EPA Collocated Devices	Start Date	End Date
Pegasor AQUrban (PE-14)	Fort Lee Public Library (FLPL) Roof	PM2.5 Gravimetric Sampler (3 day average)	18 Mar 2016	30 Jun 2016
Pegasor AQUrban (PE-15)	Fort Lee Near Road (GW Bridge)	PM2.5 Beta Gauge (continuous)	18 Mar 2016	27 May 2016
Pegasor AQIndoor	FLPL Children's Reading Room	None	28 Mar 2016	9 May 2016
Naneos Partector	FLPL Roof	PM2.5 Gravimetric Sampler (3 day average)	18 Mar 2016	30 Jun 2016
Palas Fidas 200	FLPL Roof	PM2.5 Gravimetric Sampler (3 day average)	18 Mar 2016	30 Jun 2016

Table 1. Overview of monitoring devices during the measurement campaign.

Two different cloud based data-logging systems collected data from each device. A GSM enabled data logger by Realin Oy, Finland collected data from the Pegasor instruments.

Envirologger Ltd., UK collected the Partector and Fidas data. Data validation and quality control involved removing all zero and negative values from all datasets. Note that the FRM data analyzed in this study are not yet official because the data have not been reviewed nor submitted to EPA's Air Quality System database.

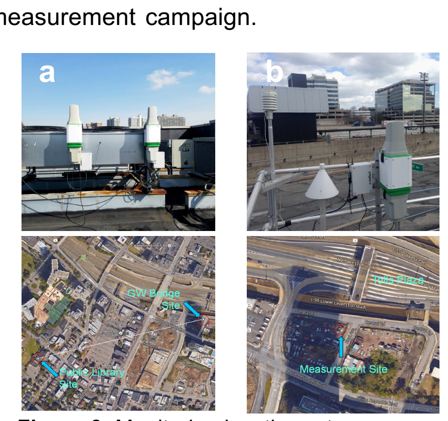


Figure 3. Monitoring locations at (a) the Fort Lee Public Library roof, (b) George Washington Bridge Toll Plaza.

RESULTS

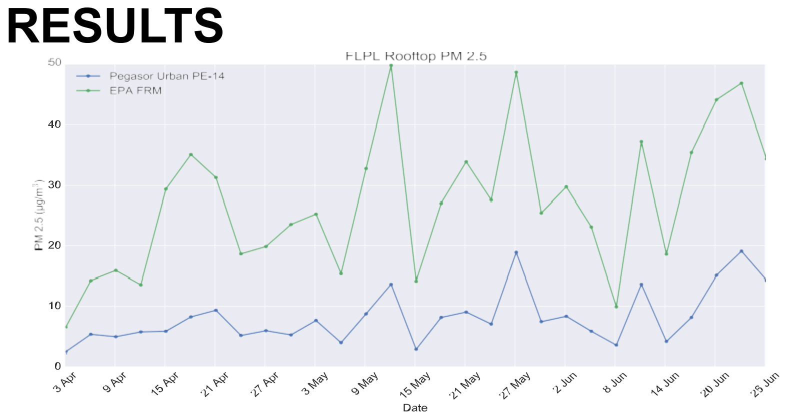


Figure 4. Time series of outdoor PM2.5 at FLPL from PE-14 (blue), FRM (green).

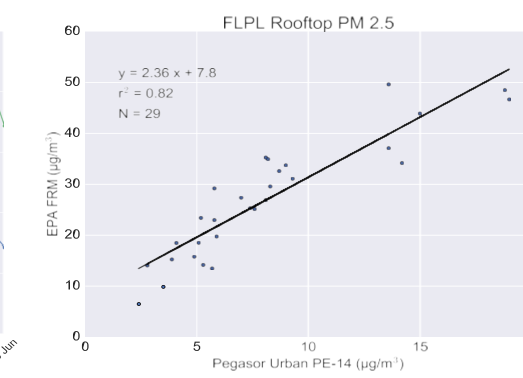


Figure 5. Outdoor PM2.5 correlation at FLPL from PE-14, and EPA FRM.

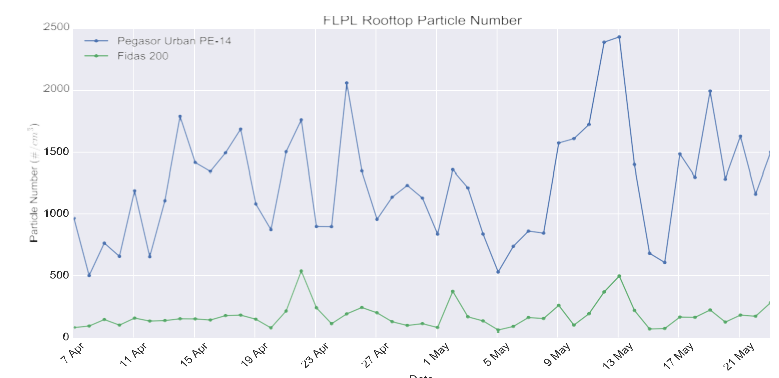


Figure 6. Time series of outdoor Particle Number at FLPL from PE-14 (blue), Fidas 200 (green).

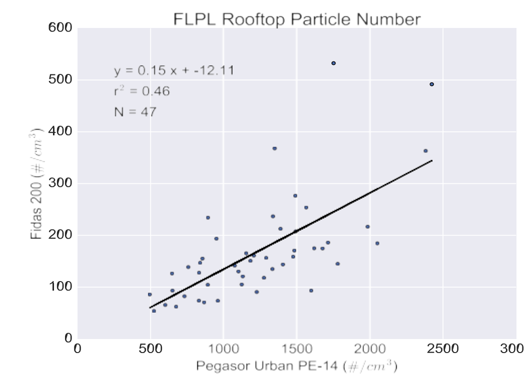


Figure 7. Outdoor PN correlation at FLPL from PE-14, and Fidas 200.

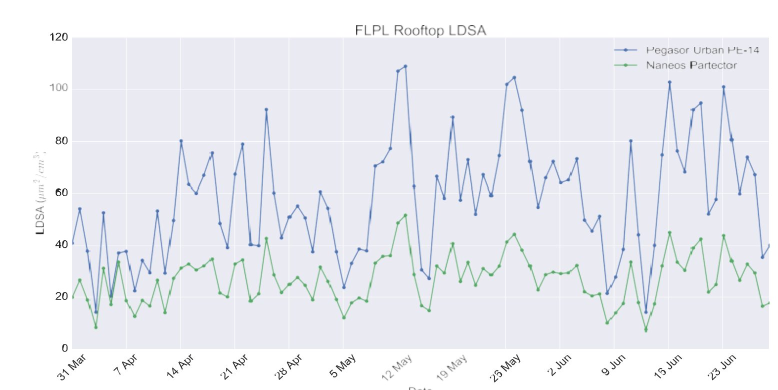


Figure 8. Time series of outdoor LDSA at FLPL from PE-14 (blue), Partector (green).

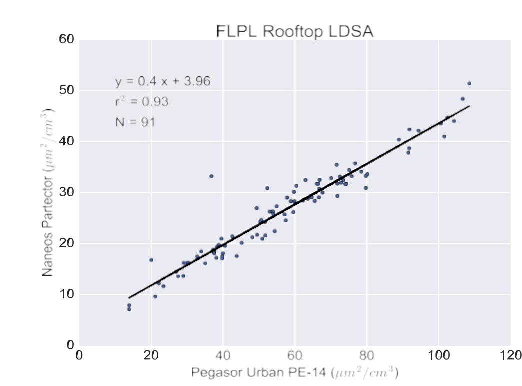


Figure 9. Outdoor LDSA correlation at FLPL from PE-14, and Partector.

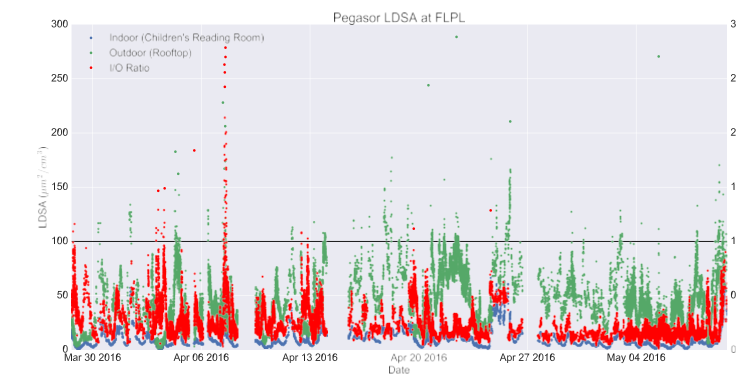


Figure 10. Time series of indoor (blue), outdoor (green), I/O (red) LDSA at FLPL. Black line indicates I/O ratio = 1.

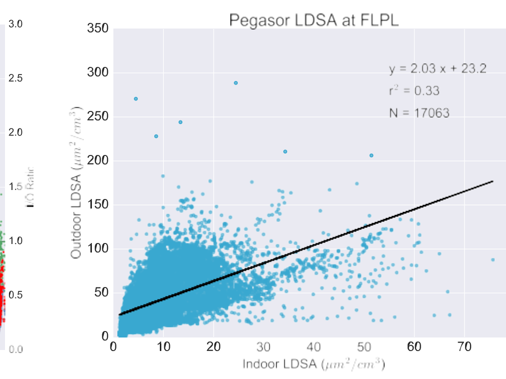


Figure 11. Indoor and outdoor LDSA correlation from Pegasor units.

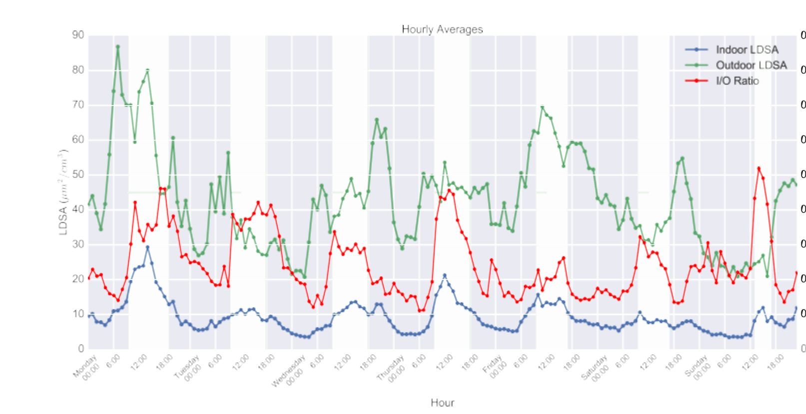


Figure 12. Time series of indoor (blue), outdoor (green), I/O (red) LDSA at FLPL.

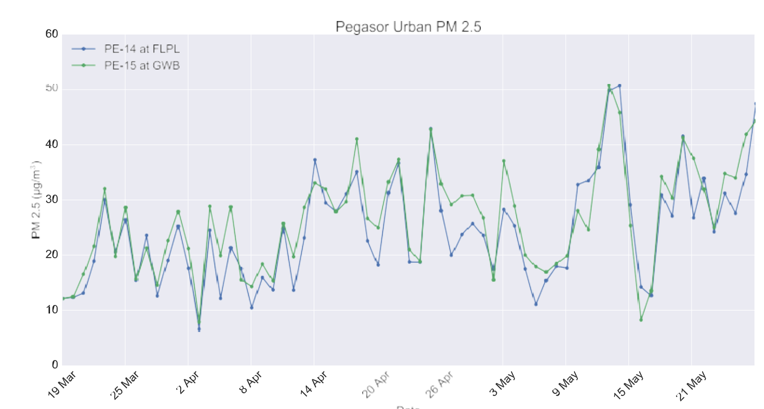


Figure 13. Time series of outdoor PM2.5 at FLPL (blue), and GWB (green).

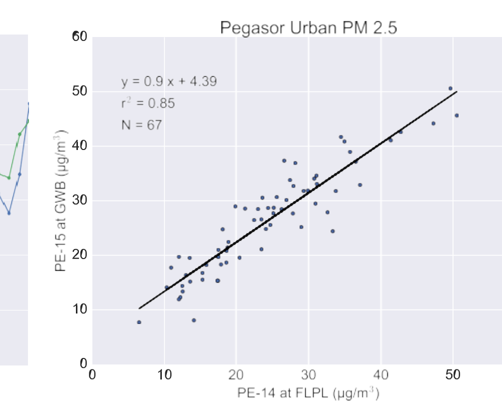


Figure 14. Outdoor PM2.5 correlation between FLPL (PE-14) and GWB (PE-15).

DISCUSSION

Three co-location studies were organized to investigate how well the Pegasor units agree with each other. The correlation coefficients for 2-minute LDSA averages among the urban and indoor units were calculated. Two Pegasor AQUrban devices, units PE-14 and PE-15, were stationed outside a residence adjacent to a highly traveled street in a suburban area in northern New Jersey for 2 days. In this environment, the correlation coefficient was 0.99. A 20-day co-location of AQUrban units PE-13 and PE-14 on the Fort Lee Public Library roof resulted in a 0.92 correlation. Two Pegasor AQIndoor devices were placed in an office for 14 days, and inside an enclosure for 5 days. In both experiments, the correlation was 0.98.

The Pegasor units demonstrated that they agree well when comparing LDSA measurements. They were compared with an EPA instrument, which measures PM2.5, to investigate the Pegasor devices with government standards. Daily averages of PM2.5 from Pegasor AQUrban (PE-14) were compared with an EPA Gravimetric Sampler (FRM), which reports every third day at the Fort Lee Public Library Roof. The correlation remained strong at 0.82 between the two instruments for PM2.5 (figs. 4, 5).

Palas' Fidas 200 is an EU/UK recognized Optical Particle Spectrometer. We compared particle number measured by the Fidas 200, and Pegasor AQUrban unit PE-14 on top of the Fort Lee Public Library roof. Daily particle number averages yielded a correlation of 0.46 between the two instruments (figs. 6, 7). The Naneos Partector is a comparable device to the Pegasor units in terms of measurement principle. We compare LDSA measurements from the Partector with the Pegasor AQUrban unit PE-14 on the roof of the Fort Lee Public Library. Daily LDSA averages resulted in a 0.93 correlation between the two instruments (figs. 8, 9).

There are several possible reasons for why the correlation coefficients were weaker comparing the Pegasor units to a Gravimetric Sampler and the Fidas 200. One is that the optimal size range of detection for electrometer based sensors is 20-300 nm, a region that does not contribute a substantial amount to particle mass concentrations. Further, as an optical particle spectrometer, the Fidas 200 has a detection limit of 200 nm, thus the overlap of particle size range is narrower with the AQUrban. The relatively small sample sizes could affect the statistical power of the associations under scrutiny. Lastly, size selective inlets were not used for the AQUrban devices. The Pegasor AQUrban device agreed well with the Naneos Partector, which utilizes similar measuring principles and has the same size range of optimal detection.

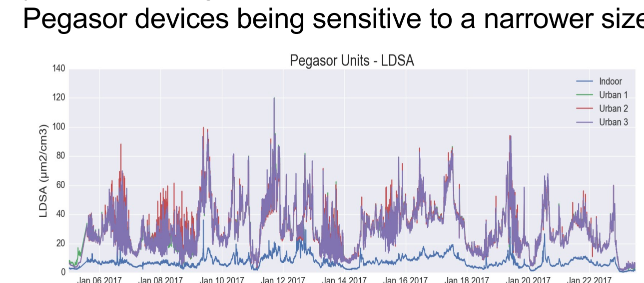
Indoor and Outdoor LDSA measurements were compared at the Fort Lee Public Library to quantify the indoor/outdoor (I/O) ratio of UFPs. A Pegasor AQIndoor was placed in the Children's Reading Room where it captured the influence of human activity and changes in ambient concentrations when building doors were opened. The correlation between indoor and outdoor LDSA was relatively weak (R^2 = 0.33). Although there are times the indoor LDSA exceeds those outdoors, the average I/O ratio is 0.25 indicating LDSA in the Children's Reading Room is lower than ambient concentrations for most of the monitoring period (fig. 10). The time series (fig. 11) indicates there may be indoor sources that cause local peaks in LDSA. Figure 12 shows hourly averages of outdoor and indoor LDSA and I/O ratios with green shading indicating times when the library is open. Indoor LDSA trends follow outdoor LDSA, particularly as the library is in use. The Pegasor AQUrban unit PE-15 at the GWB toll plaza was compared with PE-14 on the roof of the library (fig. 13). The two devices yield a 0.85 correlation for PM2.5 (fig. 14). These data suggest that the indoor LDSA is largely influenced by traffic in and around Fort Lee, NJ.

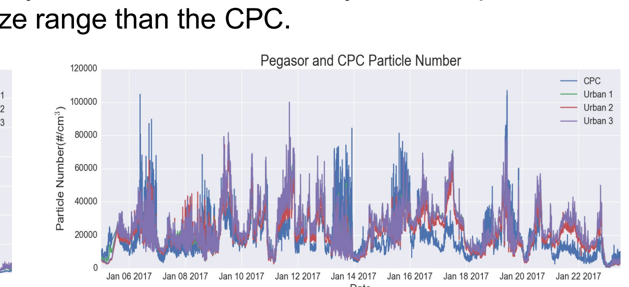
CONCLUSION

- Pegasor AQU units correlated strongly with each other while monitoring LDSA outside a residence in northern NJ, and at the Fort Lee Public Library: 0.99, 0.92, respectively.
- Two Pegasor AQI devices yielded a correlation of 0.98 for LDSA when co-located together in two separate environments.
- Daily averages of $PM_{2.5}$ between a Pegasor AQU and an EPA Gravimetric Sampler on the roof of the Fort Lee Public Library remained strongly correlated (R^2 = 0.82).
- Daily averages of particle number between a Pegasor AQU and an EU/UK recognized optical spectrometer, the Fidas 200, yielded a relatively weak correlation of 0.46.
- Daily LDSA averages from the Partector and Pegasor AQU on the roof of the Fort Lee Public Library resulted in a 0.93 correlation.
- The correlation between LDSA concentrations inside the Children's Reading Room, and outside on the roof of the Fort Lee Public Library were weak (R^2 = 0.33).
- Average I/O ratio was 0.24 indicating LDSA in the Children's Reading Room is lower than ambient concentrations for most of the monitoring period.
- Pegasor AQU devices on the roof of the FLPL and the GWB toll plaza result in a 0.85 correlation.

FUTURE WORK

Three Pegasor AQU and one AQI units are monitoring the environment at an NYSDEC site, Queens College in NY. The outdoor units sit on the roof of the station the indoor unit occupies. Preliminary results from 5-23 January show an average correlation of 0.93 between the three urban units for 1-minute LDSA data. The average I/O ratio is 0.27 during this period. Particle Number from the NYSDEC's Condensation Particle Counter (CPC) was compared with each of the Pegasor AQUs yield an average correlation of 0.40. This relatively weak correlation is likely a consequence of the Pegasor devices being sensitive to a narrower size range than the CPC.





REFERENCE

[1] Underwood, E. The Polluted Brain. *Science Magazine* **355**, 342–345 (2017).

ACKNOWLEDGEMENT

We thank the Bureau of Air Monitoring of the NJDEP, NYDEC, and the staff of the Fort Lee Public Library for their assistance throughout our studies.