Better Data for Cleaner Air

A New Paradigm in Air Quality Monitoring

For decades, air quality measurements have been synonymous with measuring PM2.5 and PM10, the combined weight of particles of size 2.5 and 10 microns, driven by the US EPA and other governmental bodies around the world. While PM2.5 and PM10 do an adequate job of representing outdoor air quality, it paints a woefully incomplete picture when measuring indoor air quality.

Indoors is where most of our time is spent and it's dominated by particles smaller than 2.5 microns – very fine and ultrafine particles. Decades of research demonstrates that these smaller particles are significantly more dangerous to human health thus necessitating better measurement and mitigation of these harmful particles.

This paper intends to provide an overview of the current state of air quality measurements, the detrimental health effects caused by smaller particles, and why shifting the paradigm to measuring smaller particles is paramount to improving air quality and human health everywhere.

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Introduction:

Owing to a confluence of global events including the pandemic, worsening wildfires, increasing urban and industrial pollution, and the devastating impacts of climate change, air quality is on top of everyone's mind. The field of air quality measurement has historically focused on PM2.5 and PM10 which are adequate for measuring outdoor air pollution but measuring air quality indoors requires new technologies that can accurately and affordably measure the smallest particles due to their insignificant contribution to accumulated weight.

Given the much more severe health impacts of smaller particles on human health, accurate data is vital for a better understanding of the environment, possible identification of pollution sources, better and more efficient mitigation, and timely interventions to clean up the air. At the same time, these new technologies need to be affordable in order to monitor continuously, ubiquitously, and with little to no human intervention.

Current state of air quality measurements:

The Clean Air Act of 1970 established the EPA and a nationwide network of air quality stations to monitor emissions from particulate matter, the primary source of air pollution. Using 'gravimetric' instruments, which at the time were state of the art, they focused on particles smaller than 2.5 and 10 microns which are too small to be seen. They also developed an Air Quality Index (AQI) as a simple way to communicate the health threats of smaller particles especially under 2.5 microns. AQI uses the weight of the particles in micrograms/m^3 also called mass concentration (MC). Governments around the world followed. Monitoring the change in MC, or PM2.5 and PM10 has led to a greater understanding of climate change, its health impacts, and fueled the environmental movement.

While tremendously impactful over the decades, the EPA's methodology has three significant drawbacks when it comes to indoor air quality measurement:

- IAQ based on mass concentration is an inadequate metric for representing small particles
- The EPA's monitoring stations while highly accurate are expensive, cumbersome, and too dispersed to have a meaningful impact on IAQ

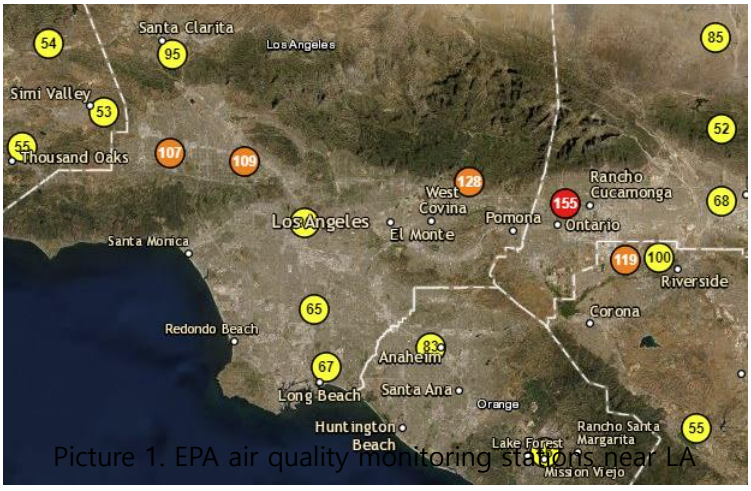
- The equipment requires several hours to a day before yielding data, which is an inherent limitation when it comes to real-time air quality monitoring

Table 1 is the revised (Effective April 7, 2024) standards the EPA uses to report air quality; the index value is determined by level of exposure to PM2.5 and PM 10 per year, based on mass concentration in ug/m^3. This simple chart and metric are easy to understand, easy to measure, and effective in enforcement. However, it is not the full picture. MC is the sum of the weight of particles of various sizes and quantities. The smallest particles are typically a few thousand to million times more than larger particles but have negligible mass, so PM2.5 and PM10 numbers are dominated by the larger particles. The smallest particles are the most dangerous to human health thus making PM2.5 and PM10 numbers inadequate for measuring indoor air quality where small particles dominate the particle counts. To acknowledge this, on Feb 7, 2023 the EPA lowered the annual standard for 'Good' from 12.0 to 9.0 ug/m3, reduced the upper end of the unhealthy, very unhealthy and hazardous categories based on scientific evidence about particle pollution and health.

AQI Category and Index Value	Updated AQI Category Breakpoints
Good (0 – 50)	0.0 to 9.0
Moderate (51 – 100)	9.1 to 35.4
Unhealthy for Sensitive Groups (101 – 150)	35.5 to 55.4
Unhealthy (151 – 200)	55.5 to 125.4
Very Unhealthy (201 – 300)	125.5 to 225.4
Hazardous (301+)	225.5+

Table 1. EPA AQI

The second issue with EPA monitoring pertains to the location of the reference instruments they use to collect air quality data. There are approximately five thousand EPA monitoring stations that measure PM2.5 and PM10. While a large number, the inadequacy of the coverage of these stations becomes clearer if we use an example of the area with the densest coverage. Shown here is a map of the monitoring stations centered around Los Angeles. While better monitored than most of the US, it's simply not enough even for monitoring outdoor air quality much less indoor air. In some instances, the nearest monitoring station is dozens of miles away which means its AQI metrics



Picture 1. EPA air quality monitoring stations near LA

are not only largely inapplicable but they are meaningless when it comes to measuring indoor air quality and identifying possible sources of pollution in a home, hospital, or office. Scaling these stations for better coverage is impractical as they are expensive to install and operate so this is simply not an option to better understand indoor air quality.

Lastly, these instruments are not capable of providing true real-time air quality data, as they require a couple of hours up to a day in order to gather air samples, which makes it impossible to capture any dynamic air quality changes in indoor environments and are also unable to provide further insights into possible sources of pollution.

To address these gaps, the EPA has developed Airnow.gov which shows data from its monitoring stations together with weather data to 'fill in the gaps', provide forecasts and a Fire and Smoke Map to track wildfire pollution.

Why is indoor air quality important?

Indoors is where most of our time is spent and decades of research indicates smaller particles are significantly more dangerous to human health as they stay suspended and recirculate longer (PM10 ~ 8 minutes, PM2.5 ~ 1 1/12 hours, PM1.0 ~ 13.0 hours). A recent editorial in *Science* calls for a "paradigm shift in how we view and address the transmission of respiratory infections to protect against unnecessary suffering and economic losses. It starts with a recognition that preventing respiratory infection, like reducing waterborne or foodborne disease, is a tractable problem." This article in The Atlantic starts with this premise and discusses "The Plan to Stop Every Respiratory Virus at Once" drawing on the decision by London to vanquish Cholera in the 19th century by creating a sewage system. The author points out, "we don't drink contaminated water, why do we tolerate breathing contaminated air?" It's not just virus transmission through aerosols but also wildfire smoke, vaping, wood stoves, cooking, diesel emissions, and much more; all smaller than 1.0 micron, which points to the urgent need to update the standards for measuring both outdoor and indoor air quality.

The UN's Environment Program (UNEP) lists five reasons why you should care about air pollution, the first being that polluted air is creating a health emergency. According to the World Bank, air pollution costs the global economy more than US $5 trillion every year in welfare costs and $225 billion in lost income. Additionally, around 2.4 billion people are exposed to dangerous levels of household air pollution, while using polluting open fires or simple stoves for cooking fueled by kerosene, biomass

(wood, animal dung and crop waste) and coal. The WHO has found that air pollution causes more than 7.0 million deaths per year with 91 % of the world's population living where air quality exceeds WHO 2005 guidelines of 10 ug/m3 (mass concentration). In Dec. 2021, the WHO lowered the guidelines to 5ug based on clear evidence of the damage air pollution inflicts on human health, at even lower concentrations than previously understood.

The cause of this health crisis is particles from industrial emissions, motor vehicles, domestic combustion, smoking/vaping, wildfires, viruses, etc. These particles are so small they penetrate the skin directly and enter the bloodstream, and the more toxic ones can be fatal. There's substantial research showing a strong correlation between small particles and development of various types of cancer, such as lung cancer in people who have never smoked in their life. Scientific American recently reported on a link between air quality and Alzheimer's. Numerous studies have shown that Covid-19, and other respiratory diseases, spread faster in spaces with poor indoor air quality especially from aerosol droplets smaller than 1.0 micron. To address this, the EPA, CDC, and White House together with ASHRAE have developed a new indoor Air Quality Standard, ASHRAE 241 which requires counting particles 1.0 micron or smaller. To learn more, read our paper, **"Particles Matter": Achieving Healthy, Energy-Efficient Indoor Spaces.**

Covid-19 virus transmission together with Climate Change have created tipping points that are forcing us to not only address the pandemic but drive social, economic, environmental, and political change. According to a Pew Research poll most surveyed countries, including the US, say global climate change is a major threat. Getting accurate hyper-local data about PM is key to enforcement, improvement, and slowing climate change. Covid-19 has also exposed a weakness in the role of the EPA, they don't monitor, enforce, and improve indoor air quality.

Why aren't we measuring indoors?

Sophisticated instruments that accurately measure sub-micron particles exist, but they are expensive to purchase and operate. Creating 'Healthy Spaces' will require continuous and ubiquitous air quality monitoring that's fully automated. Recent advances in several technologies now make this a reality:

- AI/ML methodologies to synthesize voluminous data into actionable insights

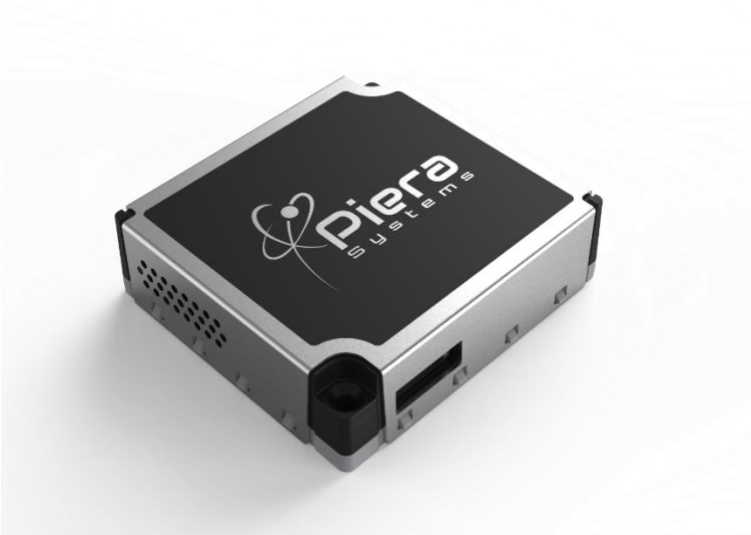
- Cloud technologies that enable monitoring from anywhere
- IoT technologies that automate the harmony of sensors, processors, and air purification systems

At the heart of making indoor air quality monitoring ubiquitous is the availability of low-cost particle sensors that report accurate particle count data across various sizes.

New paradigm in air quality measurements

Piera Systems has developed a new generation of Intelligent Particle Sensors (IPS) that delivers data comparable to reference instruments in a cost-effective, small, easy-to-use sensor utilizing advanced semiconductor technology. It provides accurate data on particle size, count, and mass concentration for all sizes of particles, especially particles smaller than 1.0 micron. Canāree Air Quality Monitors build on this same IPS technology for a readily deployable monitoring solution that's cloud-enabled and monitored in real-time using SenseiAQ software. Delivering cost effective, accurate air quality data and alerts in real-time provides insight into likely sources and dramatically improves the effectiveness of steps to clean the air including increasing ventilation, HVAC filtration, adding air cleaners/filters, and removing likely sources.

Piera's patented technology, based on years of developing specialized chips for X-Ray imaging, utilizes a photon counting approach to see the smallest particles. The IPS sensor uses a high-end laser to illuminate the particles as they flow through an air chamber controlled by a fan running at constant speed. The reflected energy (photons) corresponds to particle size and shape and is analyzed by multiple, distinct analog circuits that convert the signals to digital data. A unique combination of Piera's PSC-1 custom processor, an embedded MCU, and proprietary algorithms forms the intelligence that differentiates IPS from other low-cost sensors which only report mass concentration



Picture 2. IPS 7100 particle sensor

mostly targeted to PM2.5.

IPS can be programmed to detect a wide range of particle sizes allowing for a single sensor to be used in many applications. For the first time, applications can be developed that take advantage of low cost, accurate, detailed, real-time data about particles. Machine Learning and AI algorithms can be employed to classify this data and identify the possible sources of pollution. A highly accurate vape/smoke detection algorithm built into the IPS sensors is a vivid example of the possibilities that classification and identification of pollutants can bring toward better health outcomes.

Picture 3. Canāree air quality monitor

The Canāree family (A1, I1, I5) of compact Air Quality Monitors, utilizing the same ground-breaking technology in IPS sensors, are an affordable, easy to use way to quickly get started. Canāree A1 is a plug and play monitor that measures particles from PCs, mobile devices, and wireless access points. Canāree I1 is a stand-alone monitor with all the features of the A1 plus WIFI/BLE/ethernet. Canāree I5 has the features of I1 & adds temperature, pressure, humidity, TVOC's.

Real-time air quality data is made available through SenseiAQ software that provides particle mass and count data as well as AQI scores and alerts for vape/smoke, etc. using particle data and AI. Additionally, this data can be easily integrated into building management software as well as air purifiers and HVAC equipment to provide enterprise-wide air quality monitoring and mitigation.

Better data for healthier and more productive people

Decades of research makes it clear that cleaner indoor environments lead to healthier and more productive people. Cognitive functions improve significantly (greater than 60%) in clean indoor

environments according to this Harvard study. This Lawrence Berkeley National Laboratory study estimates savings and productivity gains from cleaner indoor environments to be greater than a 100 billion dollars. Improving the quality of indoor air while improving the efficiency of air purification systems, resulting in lower operating costs, further underscores the need for better air quality data.

> *"It is usually more energy-efficient to eliminate sources of pollution than to increase outdoor air supply rates."*
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> - *D. P. Wyon, Technical University of Denmark*

Piera's IPS and Canāree devices provide highly accurate data (particle counts, size, and the number of bins) which has several benefits:

- Identification of possible sources of pollution
- More effective mitigation actions can be employed when source of pollution is known
- Air purifiers and HVAC systems can be automated to run on an as-needed basis

Simply put, by 'knowing' what is in the air, instead of guessing, lead to much better health outcomes for people and significant productivity and efficiency savings for building managers.

Summary / Conclusion

"What's in your Air?" is more than a marketing slogan, it's critical to staying healthy and improving productivity. The disproportionately adverse impacts of the smallest particles on human health makes it imperative to accurately monitor indoor air quality. Breakthrough technologies in the IPS sensors and Canāree create a new paradigm for air quality monitoring that enable affordable and scalable ways to continuously monitor indoor air quality, a necessary first step in creating healthy spaces everywhere.