Low-cost sensor technologies, bluff or reality?

Opportunities, challenges and the way forward

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Opportunities

Supplement routine ambient air monitoring networks

Monitor personal exposure

Monitoring at the source and where people is affected

Stimulate citizen participation and increase awareness

Air quality monitoring in the palm of your hand…

AirBeam: Share & Improve Your Air

AirBeam is a wearable air monitor that maps, graphs & crowdsources your pollution exposures in real-time.

3 JANUARY 2017 — PLUME LABS

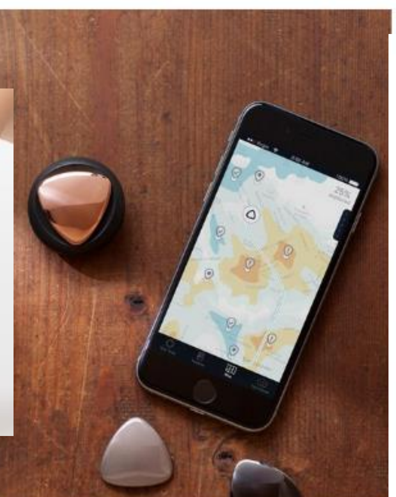
Meet Flow, your smart mobile air quality tracker

For the past two years, Plume Labs has had one mission: helping you stay ahead of air pollution to improve your environmental health.

Today we are incredibly proud to **unveil the design of** Flow by Plume Labs, the first smart, mobile air quality tracker.

With Wearable Devices That Monitor Air Quality, Scientists Can Crowd-source Pollution Maps

Emerging technology means anyone with a smartphone can become a mobile environmental monitoring station



Personal environmental monitors, such as TZOA (shown here), measure air quality and stream that information to users who may otherwise have no idea what they are breathing. (TZOA)

By Brian Handwerk
SMITHSONIAN.COM

Make your home healthier, your office more productive

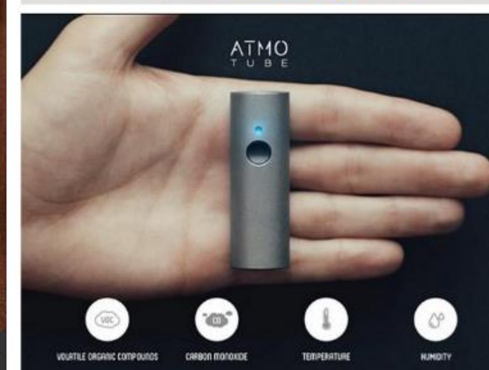
Uncover the simple solutions. Just place a small, stylish, cordless and connected Cube in each room.

Cubes are SOLD OUT!

Personal air quality sensor monitors user's environment

December 01, 2015 // By Rich Pell   0 Comments

Email print Share Share reddit G+1



The Atmotube wearable air pollution sensor sends local air quality data to a user's smartphone in real time.

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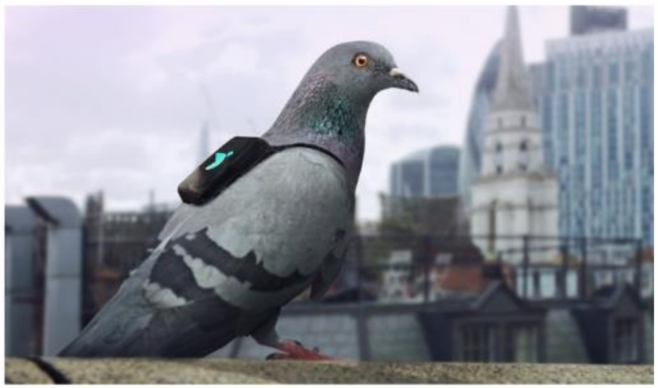
Challenges

… but is the data reliable?

Air Patrol and Flow by Plume labs

Pigeon Air Patrol to the rescue! Birds with backpacks track air pollution

By Sheena McKenzie, CNN
Updated 1415 GMT (2215 HKT) March 16, 2016



The Pigeon Air Patrol measures nitrogen dioxide in London, which has a high level of air pollution.

TRACK

OUTDOOR & INDOOR POLLUTION

- **PM2.5**: Particulate Matter and Dust
- **NOx**: Exhaust Fumes
- **Ozone**: Irritating Gas
- **VOCs**: Household Chemicals
- **Temperature**
- **Humidity**

MONITOR

AND REDUCE YOUR EXPOSURE

- Receive **tailored air quality alerts**.
- Discover easy ways to **escape pollution**.
- Find the **ideal moment** for an outdoor activity.

"I have respiratory problems. A device like this would help protect me and my two young children!"

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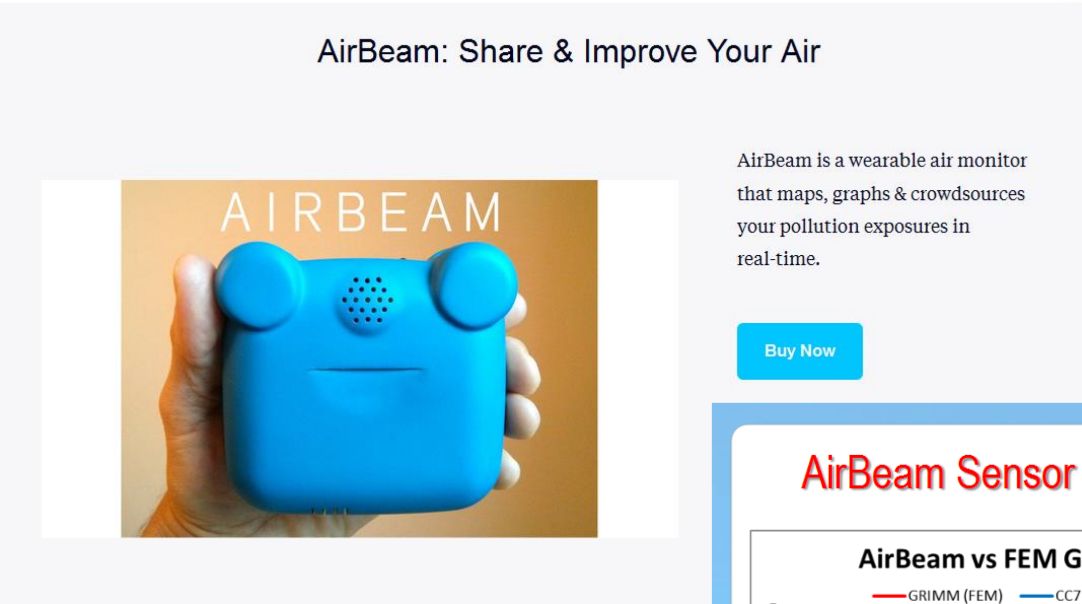
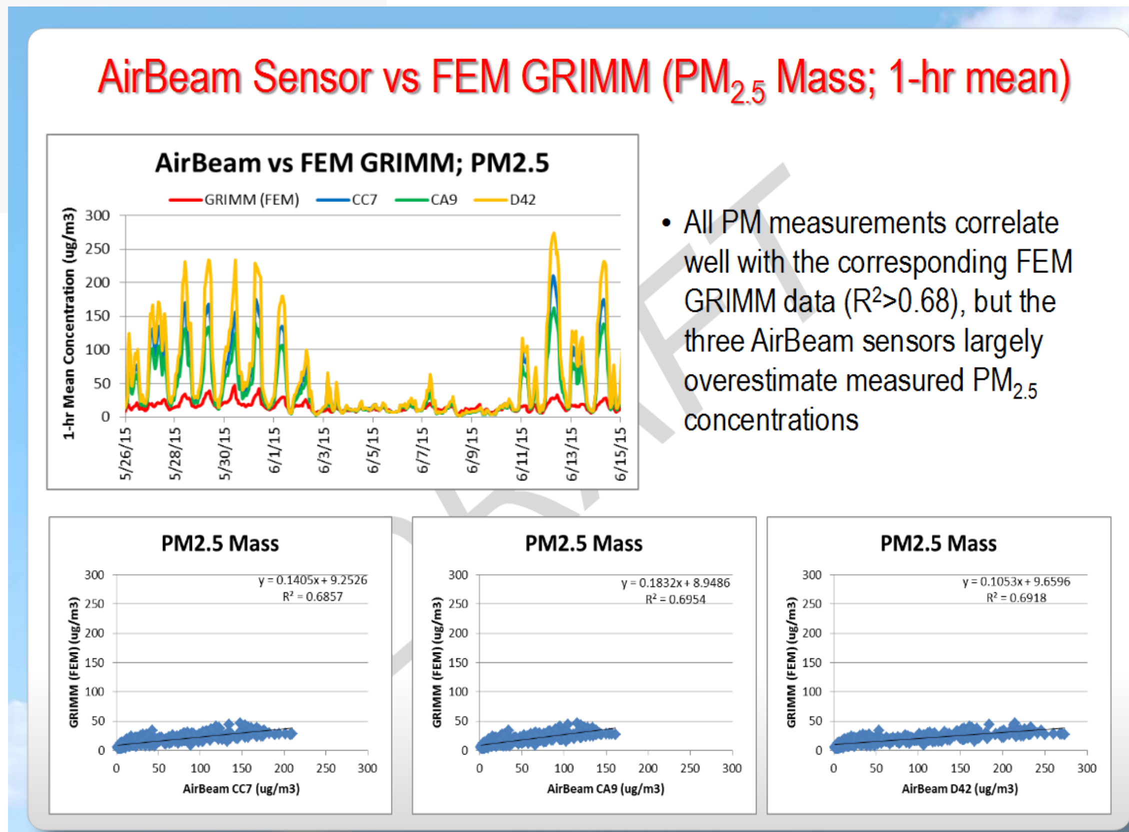
No information about the performance

Airbeam



No information about the performance in their website but independent field calibration by AQMD



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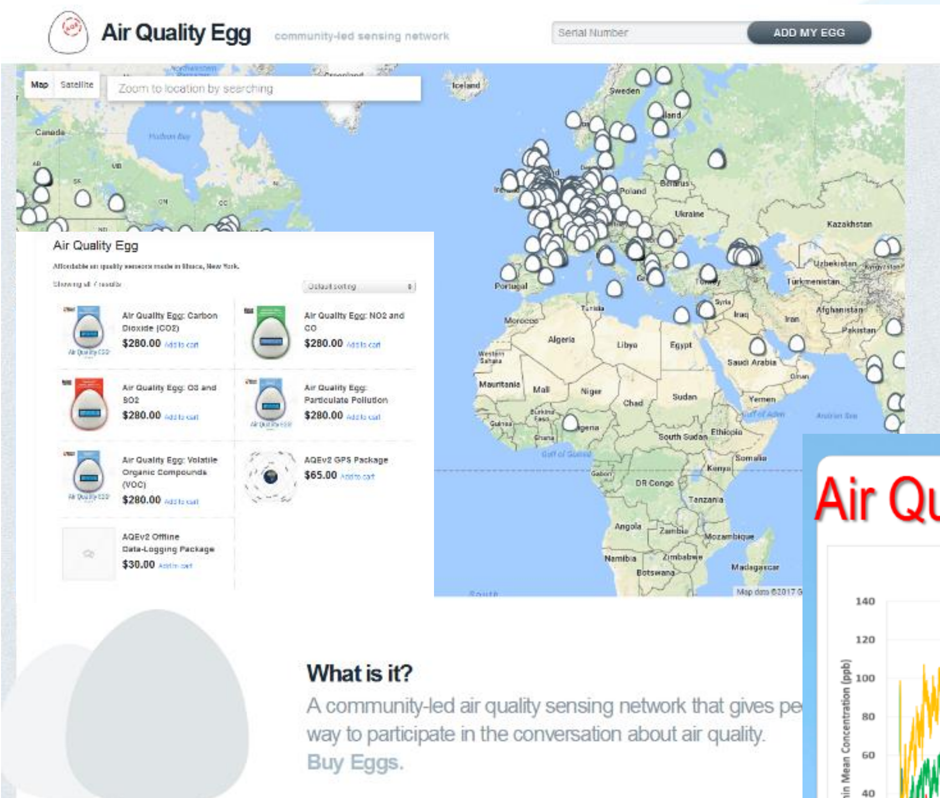
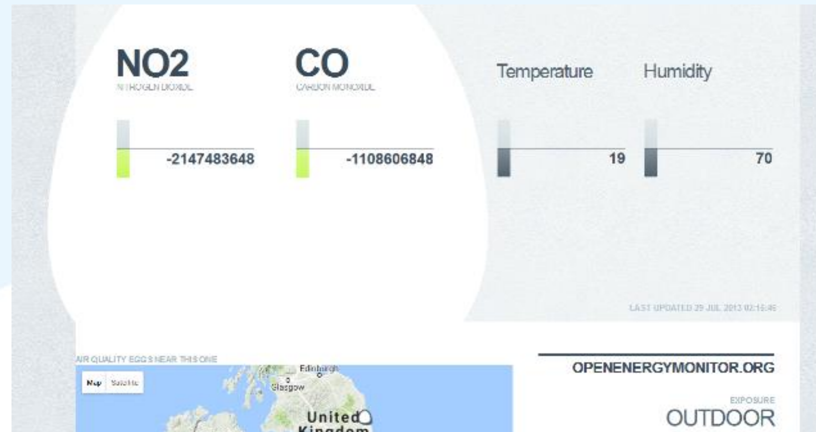
South Coast AQMD

http://www.aqmd.gov

Air quality Egg





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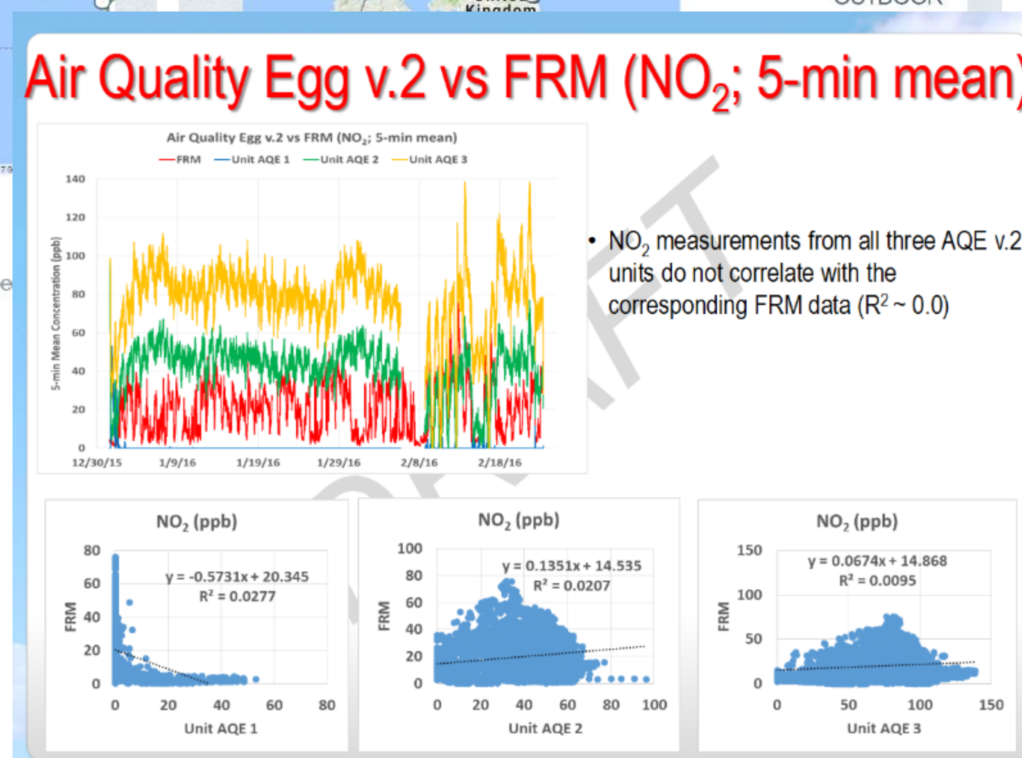

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Libelium Smart Cities Platform

Libelium releases new IoT Smart Cities Platform enhancing accuracy in noise level and air quality pollution sensors

The **new generation of the IoT Sensor Plaform for Smart Cities** features more accurate sound level and air quality sensors. These sensors address current market demands of **higher precision in measurements** and are aimed to complete the pricey equipments like professional sonometers and weather stations to **increase city capillarity** on these services.

Traffic noise and air pollution together represent the two most important environmental risk factors in urbanized societies. Libelium has improved its sensors design **according to regulations of noise and environmental control**.

A new set of factory-calibrated gas sensors allows to calculate the AQI (Air Quality Index) following the international worldwide directives measuring CO, NO, NO2, SO2 and dust/particle matter (PM1 / PM2.5 / PM1). This new generation of gas sensors offers **extra accuracy detecting variations as small as 0.1 ppm in many cases**.

The new sound level sensor can be placed outdoors as it includes a **waterproof microphone**. Libelium Plug&Sense! Smart Cities is the first IoT platform to be **fully certified** with CE (Europe), FCC (US), IC (Canada), ANATEL (Brazil), RCM (Australia), PTCRB (US) and AT&T (US).

Read more

This new generation of gas sensors offers extra accuracy detecting variations as small as ***0.1 ppm*** *in many cases*

0.1 ppm = 100 ppb
(for NO_2 this is approximately the hourly limit value)

The first IoT platform to be fully certified with CE (Europe), FCC (US), …

It might give the wrong impression that the air quality sensors are certified and therefore performing good

Application	Description	Sensors
Air Quality Index monitoring	Monitor the overall quality of the air with maximum accuracy and according to international standards.	Temperature, Humidity and Pressure, Carbon Monoxide (CO), Ozone (O_3), Nitric Dioxide (NO_2), Sulfur Dioxide (SO_2), Particle Matter (PM1 / PM2.5 / PM10) - Dust

Ref / Total Price AQIIVK-EU/ 5,150 €

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Libelium Smart Cities Platform (2)

Should I choose Gases or Gases PRO?

Libelium created 2 different systems in terms of accuracy and pricing. The customer should consider Gases PRO if he needs maximum performance sensors for metering in accurate ppm or percentage. If the project just needs to detect gas presence or gas levels, the standard Gases Sensor Board can be enough.

The Gases PRO Sensor Board can read up to 17 gas sensors; it also has a high-end sensor for 3 parameters, temperature, humidity and pressure.

Gases PRO v3.0			
Parameter	**Range**	**Calibration***	**Max Consumption**
Temperature	-40 to +85 ºC	Calibrated ±1 ºC (±0.5 ºC at 25 ºC)	2 µA @ 3V3
Humidity	0 to 100% HR	Calibrated ±3% RH (at 25 ºC, range 20 ~ 80% RH)	2.8 µA @ 3V3
Pressure	30 to 110 kPa	Calibrated ±0.1 kPa (range 0 ~ 65 ºC)	4.2 µA @ 3V3
Carbon Monoxide for high concentrations CO	0 to 500 ppm	Calibrated ±1 ppm	351 µA @ 3V3
Carbon Monoxide for low concentrations CO	0 to 25 ppm	Calibrated ±0.1 ppm	312 µA @ 3V3
Carbon Dioxide CO_2	0 to 5000 ppm	Calibrated ±50 ppm (range 0~2500 ppm) ±200 ppm (range 2500~5000 ppm)	85 mA @ 3V3
Molecular Oxygen O_2	0 to 30%	Calibrated ±0.1%	402 µA @ 3V3
Ozone O_3	0 to 18 ppm	Calibrated ±0.2 ppm	< 1 mA @ 3V3
Nitric Oxide for high concentrations NO	0 to 250 ppm	Calibrated ±0.5 ppm	441 µA @ 3V3

Gases PRO v3.0			
Parameter	**Range**	**Calibration***	**Max Consumption**
Nitric Dioxide NO_2	0 to 20 ppm	Calibrated ±0.2 ppm	335 µA @ 3V3
Sulfur Dioxide SO_2	0 to 20 ppm	Calibrated ±0.2 ppm	333 µA @ 3V3
Ammonia NH_3	0 to 100 ppm	Calibrated ±0.5 ppm	338 µA @ 3V3
Methane and other combustible gases CH_4	0 to 100% / LEL	Calibrated ±0.15% LEL	68 mA @ 3V3
Molecular Hydrogen H_2	0 to 1000	Calibrated ±10 ppm	520 µA @ 3V3
Hydrogen Sulfide H_2S	0 to 100 ppm	Calibrated ±0.1 ppm	352 µA @ 3V3
Hydrogen Chloride HCl	0 to 50 ppm	Calibrated ±1 ppm	341 µA @ 3V3
Hydrogen Cyanide HCN	0 to 50 ppm	Calibrated ±0.2 ppm	327 µA @ 3V3
Phosphine PH_3	0 to 20 ppm	Calibrated ±0.1 ppm	361 µA @ 3V3
Ethylene Oxide ETO	0 to 100 ppm	Calibrated ±1 ppm	360 µA @ 3V3
Chlorine Cl_2	0 to 50 ppm	Calibrated ±0.1 ppm	353 µA @ 3V3
Isobutane C_4H_{10}	-	-	-
Ethanol CH_3CH_2OH	-	-	-
			-
			-
			-
			200+ mA @ 5V

r with different temperature and pressure
ter for more detail.

All the gas sensors for Gases PRO are calibrated by the sensor manufacturers, in their laboratories. A two-point calibration process is performed to get maximum accuracy, with controlled concentrations of gas in vacuum chambers. Due to the linear nature of the sensors, those 2 points are enough to correct the 2 possible drifts in *m* (slope) and *c* (constant offset). Our sensor

The calibration of each sensor is only valid for a time which can go from 6 to 12 months. Every sensor looses a small percentage of its original calibration monthly in a range that may go from 0.5% to 2% (depending on the external conditions: humidity, temperature, measured gas concentration, if there are another type of gas present which corrode the sensor, etc). Recalibration performed by the user is possible although not recommended as it needs of a special laboratory with vacuum chambers and samples of the original gases. Our experience in current projects shows as it is much cheaper and convenient for customers to buy a new sensor probe and replace it by the old one after 6 or 12 months depending on the accuracy needed for the project.

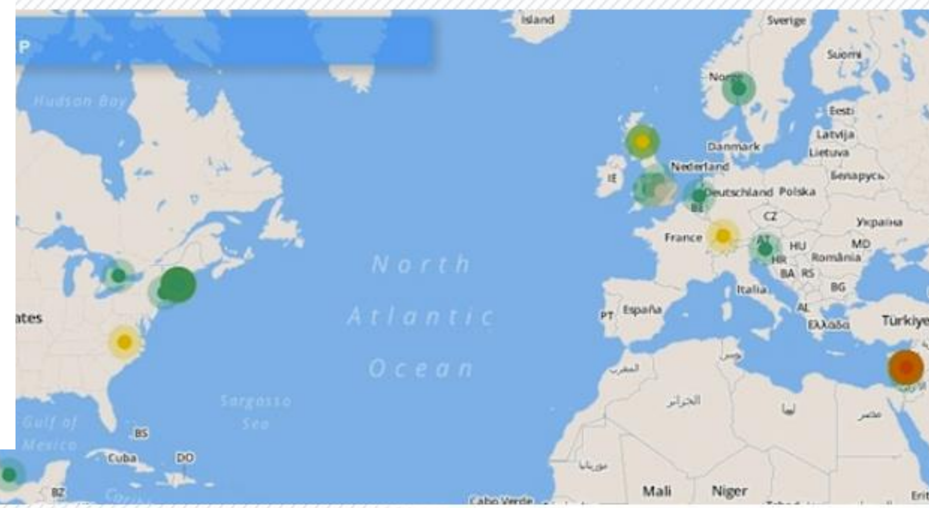
Perkin Elmer ELM Air platform

Real-Time Air Quality Sensor Network Launched in Boston

A network of real-time air quality sensors, capable of taking readings every 20 seconds, is now online in Boston, MA, giving citizens up-to-the-minute data on the air they breathe.

The Elm network consists of a series of connected sensors capable of measuring seven different air quality indicators, including particulates, nitrogen dioxide, nitrous oxide, ozone, volatile organic compounds, noise levels, temperature, and humidity, and uploading the data to a secure network, where it can be viewed and analyzed by anyone.

> *"Elm delivers an interactive, map-based interface to air-quality data that's relevant to people everywhere. For cities, Elm is the first platform to link environmental monitoring to real-time actions cities can take to improve public health, optimize urban planning and leverage science for the betterment of health. It's dynamic, relevant and hyper-local, enabling everyone to be aware of the environment in your community – anywhere." – PerkinElmer*



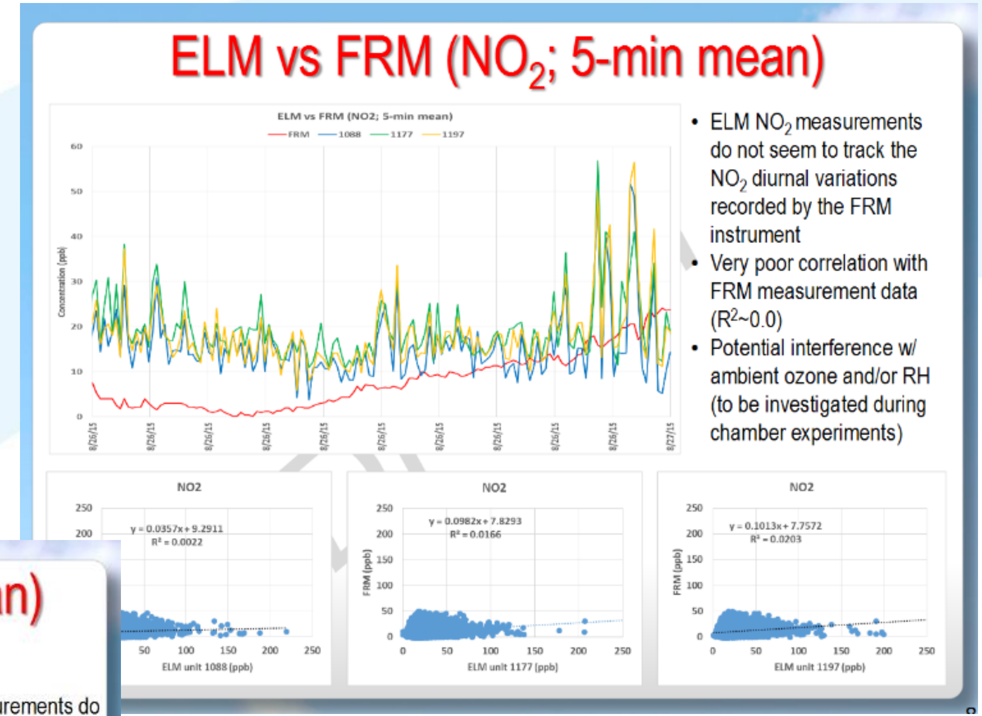
ELM Airir Quality sensor network

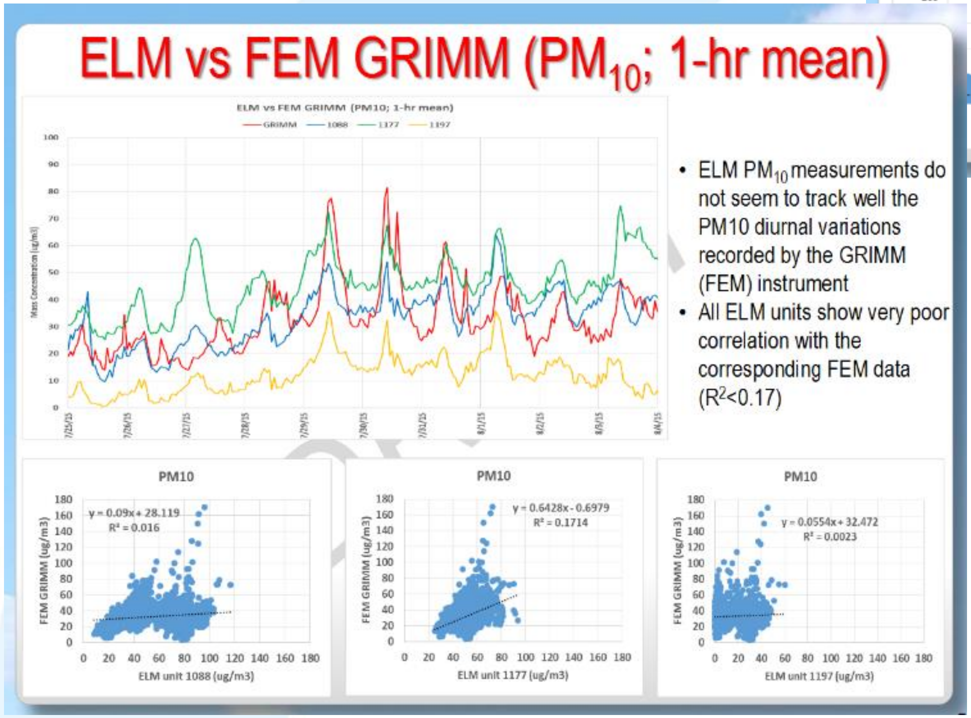
Part Number	Quantity	Description	Unit Price	Total
L1340223	1	Elm Air Unit V1.2-GSM	4,433.00	4,433.00 £

Not in the market any longer

Perkin Elmer ELM Air platform (2)

No information about the performance in their website but independent field calibration by AQMD





AQMesh

AQMesh

A revolution in air quality monitoring

HOME ABOUT PRODUCT PERFORMANCE SUPPORT NEWS CONTACT

Search ... SEARCH

Rental costs:
1 unit (4 gases and PM10, PM2.5),
3 months: 2025 £

Special full-length reports

The following reports are available to view/download as PDFs and contain in-depth analysis for each parameter:

USA (Colorado) October 2015 – February 2016

NO2 trial results

- East Anglia, UK (v4.2)
- Benelux (v4.2)
- London, UK (v4.2)
- France (v4.1)
- London, UK (v4.1)
- California, USA (v4.1)
- France (v4.0 and v4.1)
- Scotland, UK (v4.0)
- Belgium (v4.0)
- Colorado, USA (v4.0)
- Sweden (v4.0)
- Germany (v4.0)

NO trial results

- Benelux (v4.2)
- London, UK (v4.2)
- California, USA (v4.1)
- France (v4.0 and v4.1)
- Germany (v4.0)
- Sweden (v4.0)
- Colorado, USA (v4.0)
- Belgium (v4.0)
- Scotland (v4.0)

PM2.5 trial results

- Scotland, UK (v2.0)
- Tewkesbury, UK (v2.0)
- France (v1.0)

PM10 trial results

- Scotland (v2.0)
- Tewkesbury, UK (v2.0)
- France (v1.0)

O3 trial results

- London, UK (v4.2)
- California, USA (v4.1)
- Belgium (v4.0)
- Colorado, USA (v4.0)

PM1 trial results

- Scotland (v2.0)

CO trial results

- California, USA (v4.1)
- Belgium (v4.0)
- Colorado, USA (v4.0)

SO2 trial results

- London, UK (v4.2)
- London, UK (v4.1)
- France (v4.0 and v4.1)
- Scotland (v4.0)
- Belgium (v4.0)

NOx trial results

- Germany (v4.0)

NO2					
Version	v3.0	v3.5	v4.0	v4.1	v4.2
Date	To December 2014	January 2015 – October 2015	January 2015 – October 2016	Limited release	October 2016 – present
NO2 sensor	Significant O3 cross-gas effect	O3-filtered	O3-filtered	O3-filtered	O3-filtered and improved respoonse at higher ambient temperatures
NO2 sensor characterisation	Manufacturer's data	Manufacturer's data	Manufacturer's data plus characterisation at factory	Quality check	Quality check, accuracy and precision tests
Online processing	Correction for cross-gas effects and environmental factors	Correction for cross-gas effects and environmental factors	Correction for cross-gas effects and environmental factors	More sophisticated correction for cross-gas effects and environmental factors	Optimised electronic set-up and performance enhancements below LOD
Typical R2 against reference in co-location trials*	0-0.3	0.1-0.7	0.5-0.8	0.7-0.95	>0.8
Typical pre-scaled mean variance*	Requires scaling	Requires scaling	Requires scaling	Dependent on variance between sensors	<+/-5ppb

R2 of >0.6 for NO2 is generally considered to be a strong enough performance for AQMesh to be suitable for most air quality monitoring applications.

*Readings at 15 minute average intervals

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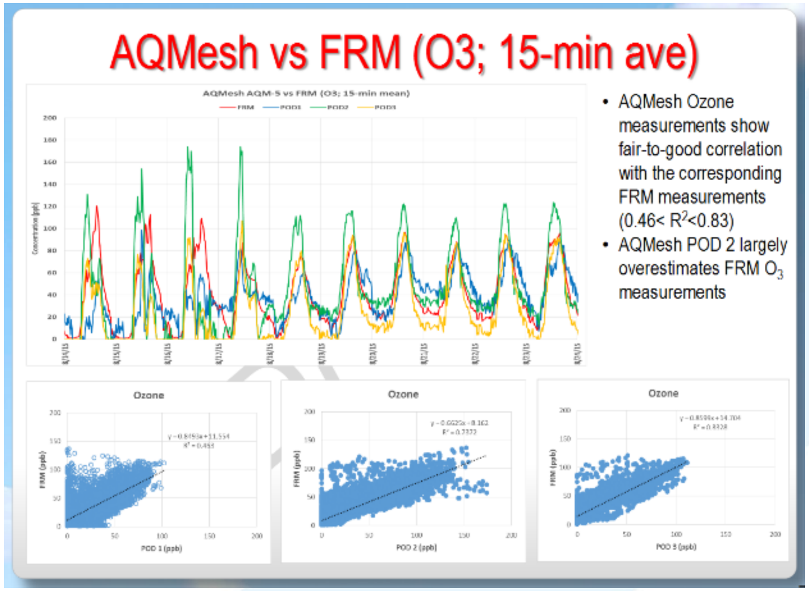
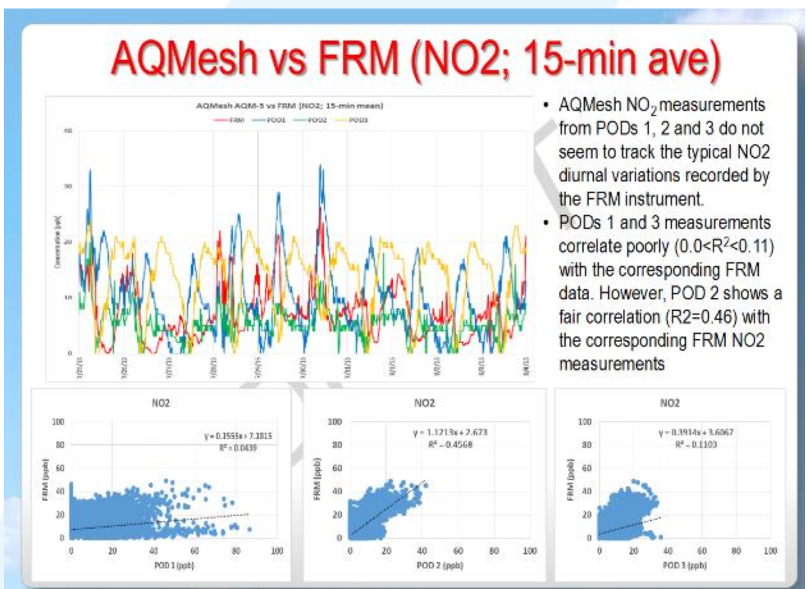
AQMesh version 4.0 field evaluation





O3 results Colorado USA, 2015

Tested during October, November and December 2015 resulting in R2 value of 0.59

Parameter	O3
R2 Value	0.59
Date	1st October 2015 - 31st December 2015
Location	Colorado, USA
Temperature Range	-12.2 degrees C to 32 degrees C
RH Range (%)	7 to 98
Version of Algorithm	v4.0

O3 results Belgium, December 2015

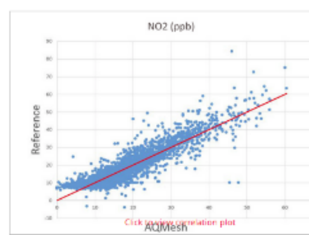
Testing resulted in R2 values of 0.91, 0.81 and 0.88

Parameter	O3
R2 Value	0.91, 0.81, 0.88
Date	December 2015
Location	Belgium
Version of Algorithm	v4.0
Averaged sample interval	Hourly

NO2 results Sweden, December 2015

Testing resulted in R2 values of 0.83

Parameter	NO2
R2 Value	0.83

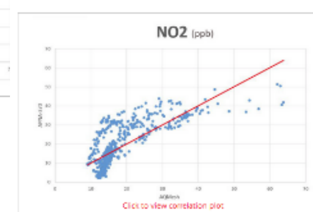


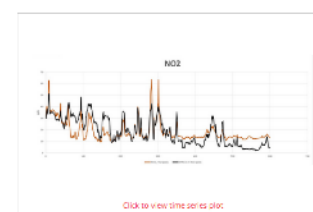
Date
Location
Version of Algorithm
Averaged sample interval

NO2 results Germany, January 2016

R2 values diminished due to inclusion of stabilisation and rebasing periods within analysis

Parameter	NO2
R2 Value	0.57





Date	19th January 2016 - 1st February 2016
Location	Germany
Version of Algorithm	v4.0
Averaged sample interval	30 minutes

We have observed that

- **Calibration** of the data can decrease the errors.
  - Laboratory calibration is not enough.
  - Field calibration is necessary.
- High **variability** in the performance **sensor-to-sensor.**
  - Not enough with testing only one sensor.
  - Necessary individual calibration.
- Sensors change behaviour during **long-term deployment.**
  - Not possible to ensure that the calibration parameters will not change over time.
  - Once deployed, we don’t know if the sensor is under- or over-estimating the concentrations
- Information provided by **manufacturers** is usually not sufficient.
- Necessary to manage **user expectations**.

The way forward

- Necessary to implement **more sophisticated calibration methods** to account for interferences with temperature, relative humidity and other gases, e.g. multilinear regression, machine learning.
- Necessary a **common guidance** on how to evaluate sensor performance.
- Manufacturers need to provide users with **better specifications**.
- **Dense sensor networks and data fusion techniques** can provide useful information, but still necessary to ensure good sensor performance.
- Users, manufacturers and scientists need to **work together** towards the new generation of low-cost air quality platforms.

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Thank you for your attention

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