Field Evaluation
Wicked Device – Air Quality Egg
2022 Model
From 11/20/2021 to 1/19/2022, three Wicked Device – Air Quality Egg 2022 Model (hereinafter Air Quality Egg 2022 Model) sensors were deployed at the South Coast AQMD stationary ambient monitoring site in Rubidoux and were run side-by-side with Federal Equivalent Method (FEM) and Federal Reference Method (FRM) instruments measuring the same pollutants.

Air Quality Egg 2022 Model (3 units tested):
- Particle sensor: optical; non-FEM (dual Plantower PMS5003)
- Gas-phase sensor: Electrochemical; non-FEM (Winsen ZE12A)
- Each unit reports: CO (ppm), PM$_{1.0}$, PM$_{2.5}$ and PM$_{10}$ ($\mu$g/m$^3$)
- Unit cost: $671 (with offline data logging option)
- Time resolution: 1-min
- Units IDs: 582f, 6c91, 6108

South Coast AQMD Reference instruments:
- Horiba APMA 370 (FRM CO); cost: ~$10,000
- Time resolution: 1-min
- MetOne BAM (FEM PM$_{2.5}$ & FEM PM$_{10}$); cost: ~$20,000
- Time resolution: 1-hr
- Teledyne API T640 (FEM PM$_{2.5}$); cost: $21,000
- Time resolution: 1-min
- GRIMM EDM 180 (FEM PM$_{2.5}$); cost: $25,000
- Time resolution: 1-min
- Met station (T, RH, P, WS, WD); cost: ~$5,000
- Time resolution: 1-min
Carbon Monoxide (CO) in Air Quality Egg 2022 Model
Data validation & recovery

- Basic QA/QC procedures were used to validate the collected data (i.e., obvious outliers, negative values, and invalid data-points were eliminated from the data-set)
- Data recovery for CO from all units was ~ 99%

Air Quality Egg 2022 Model; Intra-model variability

- Absolute intra-model variability was ~ 0.10 ppm for the CO measurements (calculated as the standard deviation of the three sensor means)
- Relative intra-model variability was ~ 18.7% for the CO measurements (calculated as the absolute intra-model variability relative to the mean of the three sensor means)
The Air Quality Egg 2022 Model sensors showed moderate to strong correlations with the corresponding FRM Horiba CO data ($0.60 < R^2 < 0.79$).

Overall, the Air Quality Egg 2022 Model sensors overestimated the CO concentration as measured by the FRM Horiba instrument.

The Air Quality Egg 2022 Model sensors seemed to track the diurnal CO variations as recorded by the FRM Horiba instrument.
The Air Quality Egg 2022 Model sensors showed moderate to strong correlations with the corresponding FRM Horiba CO data (0.62 < $R^2$ < 0.82).

Overall, the Air Quality Egg 2022 Model sensors overestimated the CO concentration as measured by the FRM Horiba instrument.

The Air Quality Egg 2022 Model sensors seemed to track the diurnal CO variations as recorded by the FRM Horiba instrument.
The Air Quality Egg 2022 Model sensors showed strong to very strong correlations with the corresponding FRM Horiba CO data ($0.85 < R^2 < 0.92$).

Overall, the Air Quality Egg 2022 Model sensors overestimated the CO concentration as measured by the FRM Horiba instrument.

The Air Quality Egg 2022 Model sensors seemed to track the diurnal CO variations as recorded by the FRM Horiba instrument.
## Summary: CO

<table>
<thead>
<tr>
<th></th>
<th>Average of 3 Sensors CO</th>
<th>Air Quality Egg 2022 Model vs FRM Horiba, CO</th>
<th>FRM Horiba, CO (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average (ppm)</td>
<td>SD (ppm)</td>
<td>R²</td>
</tr>
<tr>
<td>5-min</td>
<td>0.56</td>
<td>0.31</td>
<td>0.60 to 0.78</td>
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<tr>
<td>1-hr</td>
<td>0.56</td>
<td>0.30</td>
<td>0.63 to 0.81</td>
</tr>
<tr>
<td>24-hr</td>
<td>0.56</td>
<td>0.22</td>
<td>0.85 to 0.92</td>
</tr>
</tbody>
</table>

1. **Mean Bias Error (MBE)**: the difference between the sensors and the reference instruments. MBE indicates the tendency of the sensors to underestimate (negative MBE values) or overestimate (positive MBE values).

2. **Mean Absolute Error (MAE)**: the absolute difference between the sensors and the reference instruments. The larger MAE values, the higher measurement errors as compared to the reference instruments.

3. **Root Mean Square Error (RMSE)**: another metric to calculate measurement errors.
Particulate Matter (PM) in Air Quality Egg 2022 Model
PM Data Handling

• The Wicked Device – Air Quality Egg 2022 Model sensor uses a combination of two Plantower PMS5003 nephelometric optical particle sensors (OPS) to characterize PM$_{1.0}$, PM$_{2.5}$, and PM$_{10}$. As of this writing, the data download web portal only allows users to download the PM value from the aggregation of the two OPS, and not data from an individual OPS.

• Manufacturer statement:
  “The Air Quality Eggs [2022 Model] use an aggregate value of two PMS 5003 nephelometers to characterize PM1.0, PM2.5 and PM10. The average mean value of the two nephelometers is used if both sensors are reporting reliably, otherwise the aggregate value reflects the value of the single working sensor. The AQI calculation is also based on the aggregate.”
Data validation & recovery

- Basic QA/QC procedures were used to validate the collected data (i.e. obvious outliers, negative values and invalid data-points were eliminated from the data-set)
- Data recovery from all units was ~ 99% for all PM measurements

Air Quality Egg 2022 Model; intra-model variability

- Absolute intra-model variability was ~ 0.29, 0.63, and 1.14 μg/m³ for PM$_{1.0}$, PM$_{2.5}$ and PM$_{10}$, respectively (calculated as the standard deviation of the three sensor means)
- Relative intra-model variability was ~ 2.1%, 2.8%, and 4.2% for PM$_{1.0}$, PM$_{2.5}$ and PM$_{10}$, respectively (calculated as the absolute intra-model variability relative to the mean of the three sensor means)
Reference Instruments: PM$_{1.0}$
GRIMM and T640

- Data recovery for PM$_{1.0}$ from GRIMM and T640 was ~98% and 98%, respectively.
- Very strong correlations between the reference instruments for PM$_{1.0}$ measurements (R$^2$ ~ 0.99) were observed.
Reference Instruments: $\text{PM}_{2.5}$
FEM BAM, FEM GRIMM and FEM T640

- Data recovery for $\text{PM}_{2.5}$ from FEM BAM, FEM GRIMM and FEM T640 was ~ 90%, 98% and 98%, respectively.
- Very strong correlations between the reference instruments for $\text{PM}_{2.5}$ measurements ($0.91 < R^2 < 0.98$) were observed.
Reference Instruments: PM$_{10}$
FEM BAM, GRIMM and T640

- Data recovery for PM$_{10}$ from FEM BAM, GRIMM and T640 was ~ 99%, 98% and 98%, respectively.
- Strong to very strong correlations between the reference instruments for PM$_{10}$ measurements ($0.88 < R^2 < 0.96$) were observed.
The Air Quality Egg 2022 Model sensors showed strong correlations with the corresponding GRIMM data ($0.87 < R^2 < 0.89$).

Overall, the Air Quality Egg 2022 Model sensors overestimated the PM$_{1.0}$ mass concentrations as measured by GRIMM.

The Air Quality Egg 2022 Model sensors seemed to track the PM$_{1.0}$ diurnal variations as recorded by GRIMM.
The Air Quality Egg 2022 Model sensors showed strong correlations with the corresponding FEM GRIMM data ($0.87 < R^2 < 0.89$)

Overall, the Air Quality Egg 2022 Model sensors overestimated the PM$_{2.5}$ mass concentrations as measured by FEM GRIMM

The Air Quality Egg 2022 Model sensors seemed to track the PM$_{2.5}$ diurnal variations as recorded by FEM GRIMM.
The Air Quality Egg 2022 Model sensors showed very weak to weak correlations with the corresponding GRIMM data ($0.29 < R^2 < 0.31$).

Overall, the Air Quality Egg 2022 Model sensors underestimated the PM$_{10}$ mass concentrations as measured by GRIMM.

The Air Quality Egg 2022 Model sensors did not seem to track the PM$_{10}$ diurnal variations as recorded by GRIMM.
The Air Quality Egg 2022 Model sensors showed strong correlations with the corresponding GRIMM data ($0.88 < R^2 < 0.90$).

Overall, the Air Quality Egg 2022 Model sensors overestimated the PM$_{1.0}$ mass concentrations as measured by GRIMM.

The Air Quality Egg 2022 Model sensors seemed to track the PM$_{1.0}$ diurnal variations as recorded by GRIMM.
The Air Quality Egg 2022 Model sensors showed strong correlations with the corresponding FEM GRIMM data (0.89 < R² < 0.90).

Overall, the Air Quality Egg 2022 Model sensors overestimated the PM₂.₅ mass concentrations as measured by FEM GRIMM.

The Air Quality Egg 2022 Model sensors seemed to track the PM₂.₅ diurnal variations as recorded by FEM GRIMM.
The Air Quality Egg 2022 Model sensors showed weak correlations with the corresponding GRIMM data ($0.30 < R^2 < 0.33$).

Overall, the Air Quality Egg 2022 Model sensors underestimated the PM$_{10}$ mass concentrations as measured by GRIMM.

The Air Quality Egg 2022 Model sensors did not seem to track the PM$_{10}$ diurnal variations as recorded by GRIMM.
Air Quality Egg 2022 Model vs GRIMM (PM$_{1.0}$; 24-hr mean)

- The Air Quality Egg 2022 Model sensors showed very strong correlations with the corresponding GRIMM data ($0.91 < R^2 < 0.93$)
- Overall, the Air Quality Egg 2022 Model sensors overestimated the PM$_{1.0}$ mass concentrations as measured by GRIMM
- The Air Quality Egg 2022 Model sensors seemed to track the PM$_{1.0}$ diurnal variations as recorded by GRIMM
The Air Quality Egg 2022 Model sensors showed strong to very strong correlations with the corresponding FEM GRIMM data (0.89 < R² < 0.91).

Overall, the Air Quality Egg 2022 Model sensors overestimated the PM\textsubscript{2.5} mass concentrations as measured by FEM GRIMM.

The Air Quality Egg 2022 Model sensors seemed to track the PM\textsubscript{2.5} diurnal variations as recorded by FEM GRIMM.
The Air Quality Egg 2022 Model sensors showed very weak correlations with the corresponding GRIMM data ($0.27 < R^2 < 0.30$)

Overall, the Air Quality Egg 2022 Model sensors underestimated the PM$_{10}$ mass concentrations as measured by GRIMM

The Air Quality Egg 2022 Model sensors did not seem to track the PM$_{10}$ diurnal variations as recorded by GRIMM
The Air Quality Egg 2022 Model sensors showed strong correlations with the corresponding T640 data ($0.84 < R^2 < 0.86$).

Overall, the Air Quality Egg 2022 Model sensors underestimated the PM$_{1.0}$ mass concentrations as measured by T640.

The Air Quality Egg 2022 Model sensors seemed to track the PM$_{1.0}$ diurnal variations as recorded by T640.
The Air Quality Egg 2022 Model sensors showed strong correlations with the corresponding FEM T640 data (0.88 < $R^2$ < 0.90)

Overall, the Air Quality Egg 2022 Model sensors overestimated the PM$_{2.5}$ mass concentrations as measured by FEM T640

The Air Quality Egg 2022 Model sensors seemed to track the PM$_{2.5}$ diurnal variations as recorded by FEM T640
Air Quality Egg 2022 Model vs T640 (PM$_{10}$; 5-min mean)

- Air Quality Egg 2022 Model sensors showed moderate correlations with the corresponding T640 data (0.50 < $R^2$ < 0.53)
- Overall, the Air Quality Egg 2022 Model sensors underestimated the PM$_{10}$ mass concentrations as measured by T640
- The Air Quality Egg 2022 Model sensors seemed to track the PM$_{10}$ diurnal variations as recorded by T640
The Air Quality Egg 2022 Model sensors showed strong correlations with the corresponding T640 data ($0.85 < R^2 < 0.87$).

Overall, the Air Quality Egg 2022 Model sensors underestimated the PM$_{1.0}$ mass concentrations as measured by T640.

The Air Quality Egg 2022 Model sensors seemed to track the PM$_{1.0}$ diurnal variations as recorded by T640.
The Air Quality Egg 2022 Model sensors showed strong to very strong correlations with the corresponding FEM T640 data (0.89 < $R^2$ < 0.91).

Overall, the Air Quality Egg 2022 Model sensors overestimated the PM$_{2.5}$ mass concentrations as measured by FEM T640.

The Air Quality Egg 2022 Model sensors seemed to track the PM$_{2.5}$ diurnal variations as recorded by FEM T640.
- The Air Quality Egg 2022 Model sensors showed moderate correlations with the corresponding T640 data ($0.51 < R^2 < 0.54$)
- Overall, the Air Quality Egg 2022 Model sensors underestimated the PM$_{10}$ mass concentrations as measured by T640
- The Air Quality Egg 2022 Model sensors seemed to track the PM$_{10}$ diurnal variations as recorded by T640

![Graphs showing correlation between Air Quality Egg 2022 Model vs T640 PM$_{10}$ data for different units.](image)
The Air Quality Egg 2022 Model sensors showed strong to very strong correlations with the corresponding T640 data (0.89 < R² < 0.91).

Overall, the Air Quality Egg 2022 Model sensors underestimated the PM₁₀ mass concentrations as measured by T640.

The Air Quality Egg 2022 Model sensors seemed to track the PM₁₀ diurnal variations as recorded by T640.
The Air Quality Egg 2022 Model sensors showed very strong correlations with the corresponding FEM T640 data ($0.92 < R^2 < 0.94$).

Overall, the Air Quality Egg 2022 Model sensors overestimated the PM$_{2.5}$ mass concentrations as measured by FEM T640.

The Air Quality Egg 2022 Model sensors seemed to track the PM$_{2.5}$ diurnal variations as recorded by FEM T640.
The Air Quality Egg 2022 Model sensors showed moderate correlations with the corresponding T640 data (0.59 < R² < 0.62).

Overall, the Air Quality Egg 2022 Model sensors underestimated the PM_{10} mass concentrations as measured by T640.

The Air Quality Egg 2022 Model sensors seemed to track the PM_{10} diurnal variations as recorded by T640.
The Air Quality Egg 2022 Model sensors showed strong correlations with the corresponding FEM BAM data ($0.80 < R^2 < 0.82$).

Overall, the Air Quality Egg 2022 Model sensors overestimated the PM$_{2.5}$ mass concentrations as measured by FEM BAM.

The Air Quality Egg 2022 Model sensors seemed to track the PM$_{2.5}$ diurnal variations as recorded by FEM BAM.
The Air Quality Egg 2022 Model sensors showed very weak to weak correlations with the corresponding FEM BAM data (0.29 < $R^2$ < 0.31).

Overall, the Air Quality Egg 2022 Model sensors underestimated the PM$_{10}$ mass concentrations as measured by FEM BAM.

The Air Quality Egg 2022 Model sensors did not seem to track the PM$_{10}$ diurnal variations as recorded by FEM BAM.
The Air Quality Egg 2022 Model sensors showed strong correlations with the corresponding FEM BAM data ($0.88 < R^2 < 0.90$).

Overall, the Air Quality Egg 2022 Model sensors overestimated the PM$_{2.5}$ mass concentrations as measured by FEM BAM.

The Air Quality Egg 2022 Model sensors seemed to track the PM$_{2.5}$ diurnal variations as recorded by FEM BAM.
The Air Quality Egg 2022 Model sensors showed weak correlations with the corresponding FEM BAM data (0.33 < $R^2$ < 0.36).

Overall, the Air Quality Egg 2022 Model sensors underestimated the PM$_{10}$ mass concentrations as measured by FEM BAM.

The Air Quality Egg 2022 Model sensors did not seem to track the PM$_{10}$ diurnal variations as recorded by FEM BAM.
<table>
<thead>
<tr>
<th></th>
<th>Average of 3 Sensors, PM$_{1.0}$</th>
<th>Air Quality Egg 2022 Model vs GRIMM &amp; T640, PM$_{1.0}$</th>
<th>GRIMM &amp; T640 (PM$_{1.0}$, μg/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average (μg/m$^3$)</td>
<td>SD (μg/m$^3$)</td>
<td>$R^2$</td>
</tr>
<tr>
<td>5-min</td>
<td>13.9</td>
<td>12.4</td>
<td>0.84 to 0.89</td>
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<tr>
<td>1-hr</td>
<td>13.9</td>
<td>12.3</td>
<td>0.85 to 0.90</td>
</tr>
<tr>
<td>24-hr</td>
<td>13.9</td>
<td>10.1</td>
<td>0.89 to 0.93</td>
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<table>
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<th>Average of 3 Sensors, PM$_{2.5}$</th>
<th>Air Quality Egg 2022 Model vs FEM BAM, FEM GRIMM &amp; FEM T640, PM$_{2.5}$</th>
<th>FEM BAM, FEM GRIMM &amp; FEM T640 (PM$_{2.5}$, μg/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average (μg/m$^3$)</td>
<td>SD (μg/m$^3$)</td>
<td>$R^2$</td>
</tr>
<tr>
<td>5-min</td>
<td>22.4</td>
<td>21.1</td>
<td>0.88 to 0.90</td>
</tr>
<tr>
<td>1-hr</td>
<td>22.4</td>
<td>20.9</td>
<td>0.81 to 0.91</td>
</tr>
<tr>
<td>24-hr</td>
<td>22.4</td>
<td>18.0</td>
<td>0.89 to 0.93</td>
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<table>
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<tr>
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<th>Average of 3 Sensors, PM$_{10}$</th>
<th>Air Quality Egg 2022 Model vs FEM BAM, GRIMM &amp; T640, PM$_{10}$</th>
<th>FEM BAM, GRIMM &amp; T640 (PM$_{10}$, μg/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average (μg/m$^3$)</td>
<td>SD (μg/m$^3$)</td>
<td>$R^2$</td>
</tr>
<tr>
<td>5-min</td>
<td>27.0</td>
<td>26.2</td>
<td>0.29 to 0.52</td>
</tr>
<tr>
<td>1-hr</td>
<td>27.0</td>
<td>26.1</td>
<td>0.30 to 0.54</td>
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<tr>
<td>24-hr</td>
<td>27.0</td>
<td>22.5</td>
<td>0.27 to 0.62</td>
</tr>
</tbody>
</table>

1 Mean Bias Error (MBE): the difference between the sensors and the reference instruments. MBE indicates the tendency of the sensors to underestimate (negative MBE values) or overestimate (positive MBE values).

2 Mean Absolute Error (MAE): the absolute difference between the sensors and the reference instruments. The larger MAE values, the higher measurement errors as compared to the reference instruments.

3 Root Mean Square Error (RMSE): another metric to calculate measurement errors.
The Air Quality Egg 2022 Model sensors showed very strong correlations with the corresponding South Coast AQMD Met Station data ($R^2 \sim 0.97$).

Overall, the Air Quality Egg 2022 Model sensors overestimated the temperature measurement as recorded by South Coast AQMD Met Station.

The Air Quality Egg 2022 Model sensors seemed to track the diurnal temperature variations as recorded by South Coast AQMD Met Station.
The Air Quality Egg 2022 Model sensors showed very strong correlations with the corresponding South Coast AQMD Met Station data ($R^2 \sim 0.98$).

Overall, the Air Quality Egg 2022 Model sensors underestimated the RH measurement as recorded by South Coast AQMD Met Station.

The Air Quality Egg 2022 Model sensors seemed to track the diurnal RH variations as recorded by South Coast AQMD Met Station.
Discussion

- The three Air Quality Egg 2022 Model sensors’ data recovery from all units was ~ 99% for all CO and PM measurements.
- The absolute intra-model variability was ~ 0.10 ppm for CO and ~ 0.29, 0.63 and 1.14 µg/m³ for PM₁₀, PM₂.₅ and PM₁₀, respectively.
- CO concentrations measured by the Air Quality Egg 2022 Model sensors showed moderate to strong correlations with the corresponding FRM Horiba CO data (0.60 < R² < 0.79, 5-min mean). The sensors overestimated CO concentrations as measured by FRM Horiba.
- Very strong correlations between GRIMM and T640 for PM₁₀ (R² ~ 0.99, 1-hr mean); very strong correlations between FEM BAM, FEM GRIMM and FEM T640 for PM₂.₅ (0.91 < R² < 0.98, 1-hr mean); and strong to very strong correlations between FEM BAM, GRIMM and T640 for PM₁₀ (0.88 < R² < 0.96, 1-hr mean) mass concentration measurements.
- PM₁₀ mass concentrations measured by the Air Quality Egg 2022 Model sensors showed strong correlations with the corresponding GRIMM and T640 data (0.85 < R² < 0.90, 1-hr mean). The sensors overestimated PM₁₀ mass concentrations as measured by GRIMM and underestimated PM₁₀ mass concentrations as measured by T640.
- PM₂.₅ mass concentrations measured by the Air Quality Egg 2022 Model sensors showed strong to very strong correlations with the corresponding FEM GRIMM, FEM T640 and FEM BAM data (0.80 < R² < 0.91, 1-hr mean). The sensors overestimated PM₂.₅ mass concentrations as measured by FEM GRIMM, FEM T640 and FEM BAM.
- PM₁₀ mass concentrations measured by the Air Quality Egg 2022 Model sensors showed very weak to moderate correlations with the corresponding GRIMM, T640 and FEM BAM data (0.29 < R² < 0.54; 1-hr mean). The sensors underestimated PM₁₀ mass concentrations as measured by GRIMM, T640 and FEM BAM.
- No sensor calibration was performed by South Coast AQMD Staff for this evaluation.
- Laboratory chamber testing is necessary to fully evaluate the performance of these sensors under known aerosol concentrations and controlled temperature and relative humidity conditions.
- All results are still preliminary.