

Laboratory Evaluation

Wicked Device – Air Quality Egg

2022 Model (O₃ and NO₂)



Outline

1. Background
2. O_3
3. NO_2

DRAFT

Background

Three **Wicked Device – Air Quality Egg 2022 Model (O₃ and NO₂; hereinafter Air Quality Egg 2022 Model)** sensors (unit IDs: 233d, 1f4e, 8a60) were field-tested at the South Coast AQMD Rubidoux fixed ambient monitoring station (03/18/2022 to 05/18/2022) under ambient environmental conditions. Following field testing, the units were subjected to further laboratory testing in the South Coast AQMD Sensor Environmental Test Chamber 2 (SENTEC-2) under controlled pollutant concentration, temperature, and relative humidity conditions.

Air Quality Egg 2022 Model (3 units tested):

- Gas sensor: **Electrochemical; non-FEM (Winsen ZE12A)**
- Each unit reports: O₃ (ppb), NO₂ (ppb), T (°C), RH (%)
- **Unit cost: \$1380 as of August 2023 (was \$971 at time of field testing)**
- Time resolution: 1-min
- Unit IDs: 233d, 1f4e, 8a60



Reference Instruments:

- O₃ instrument (**FEM, T400, Teledyne, San Diego, CA**); **cost: ~\$9,000**
 - Time resolution: 1-min
- NO_x instrument (**FRM, T200, Teledyne, San Diego, CA**); **cost: ~\$13,000**
 - Time resolution: 1-min



FEM T400



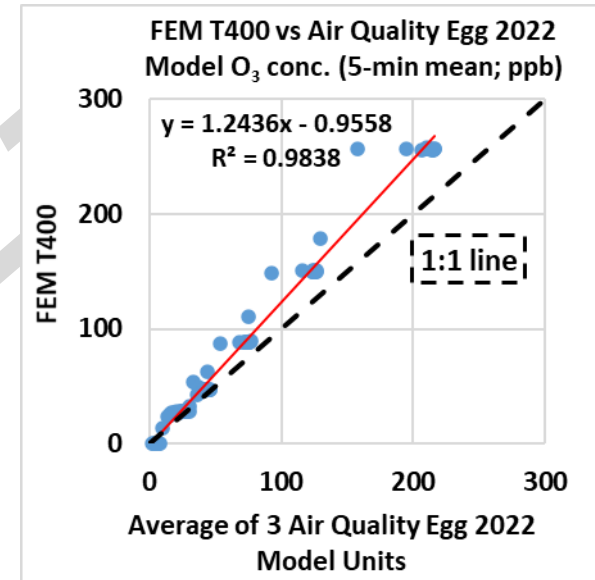
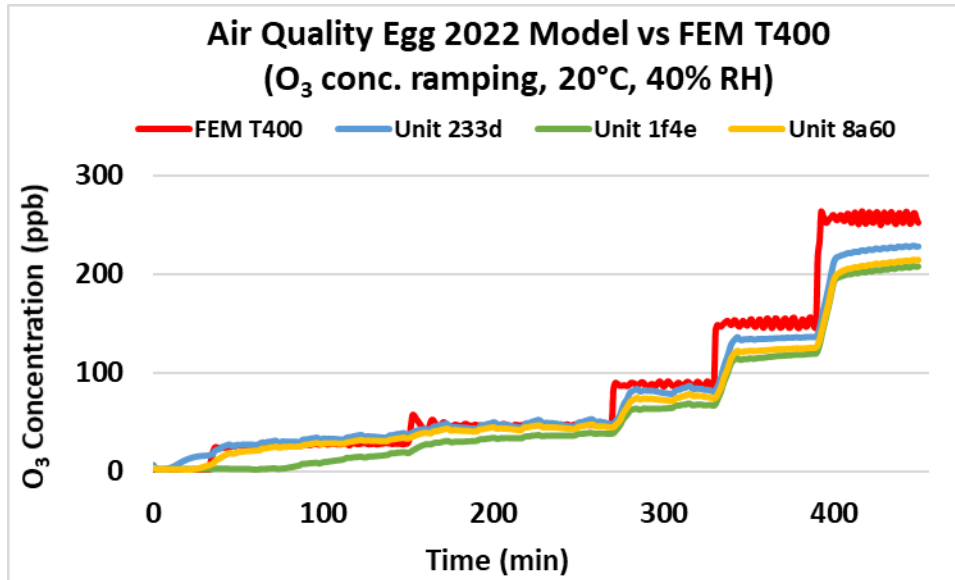
FRM T200



1. **FEM T400 vs Air Quality Egg 2022 Model**
2. **Accuracy, data recovery and intra-model variability**
3. **Precision**
4. **Climate susceptibility**
5. **Interferents**
6. **Discussion**

Air Quality Egg 2022 Model vs FEM T400 (O₃)

Coefficient of Determination



- The FEM T300 instrument reported a baseline of ~0.5 ppb and the Air Quality Egg 2022 Model sensors reported baseline values ~3 ppb for units 1f4e and 8a60. Unit 233d showed a higher baseline of ~12 ppb
- The three Air Quality Egg 2022 Model sensors tracked the O₃ concentration variations recorded by FEM T400 instrument from ~30 to 250 ppb
- The Air Quality Egg 2022 Model sensors underestimated the O₃ concentration as recorded by the FEM T400 instrument
- The Air Quality Egg 2022 Model sensors showed very strong correlations with the corresponding FEM T400 O₃ conc. ($R^2 > 0.98$)

Accuracy: Air Quality Egg 2022 Model vs FEM T400 (O₃)

- Accuracy (20 °C and 40% RH)

| Steady State (#) | Sensor Mean (ppb) | FEM T400 (ppb) | Accuracy (%) |
|------------------|-------------------|----------------|--------------|
| 1 | 28.9 | 28.5 | 98.5 |
| 2 | 45.0 | 47.5 | 94.8 |
| 3 | 76.0 | 88.6 | 85.7 |
| 4 | 126.4 | 150.6 | 83.9 |
| 5 | 215.6 | 257.0 | 83.9 |

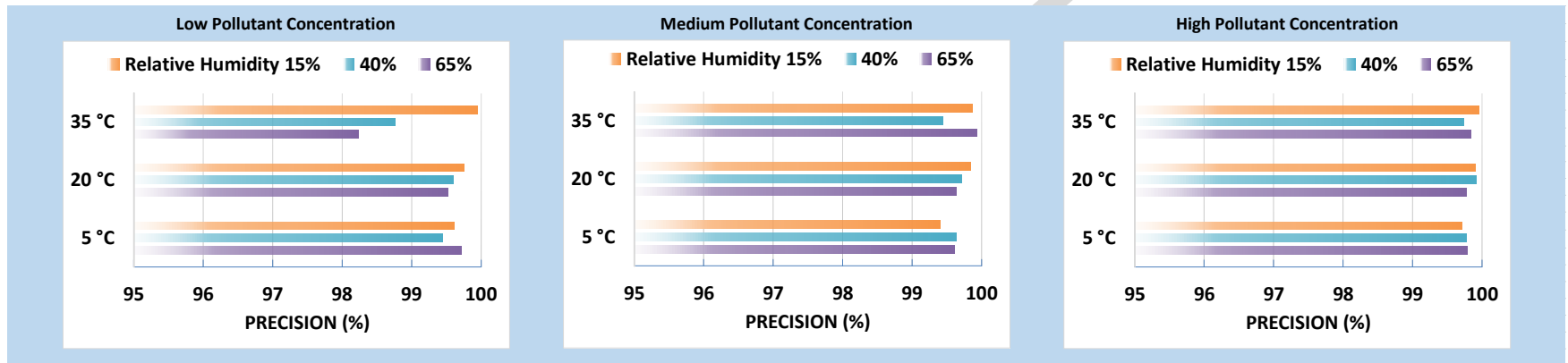
- Accuracy of the three Air Quality Egg 2022 Model sensors ranged from 83.9% to 98.5%. The accuracy decreased as O₃ concentrations increased. The sensors underestimated the FEM T400 O₃ measurements at 20 °C and 40% RH.

Air Quality Egg 2022 Model Data Recovery and Intra-model Variability

- Data recovery for ozone measurements was 99.8%, 99.3%, and 99.6% for Units 233d, 1f4e, and 8a60, respectively.
- Low to moderate O₃ concentration variations were observed between the three units at 20 °C and 40% RH at low, medium and high O₃ concentrations as measured by the FEM T400.

Precision: Air Quality Egg 2022 Model (O₃)

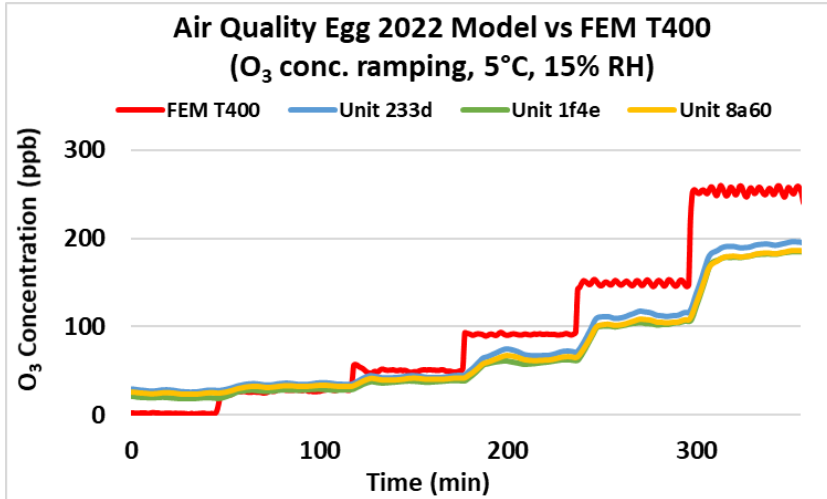
- Precision* (Effect of O₃ conc., temperature and relative humidity)



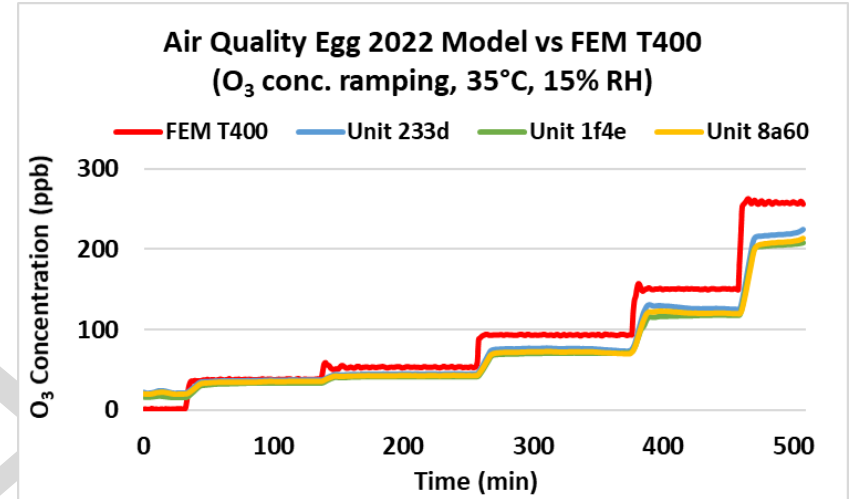
- Overall, the three Air Quality Egg 2022 Model sensors showed high precision for all combinations of medium and high O₃ conc., T, and RH.

Climate Susceptibility: Air Quality Egg 2022 Model (O₃)

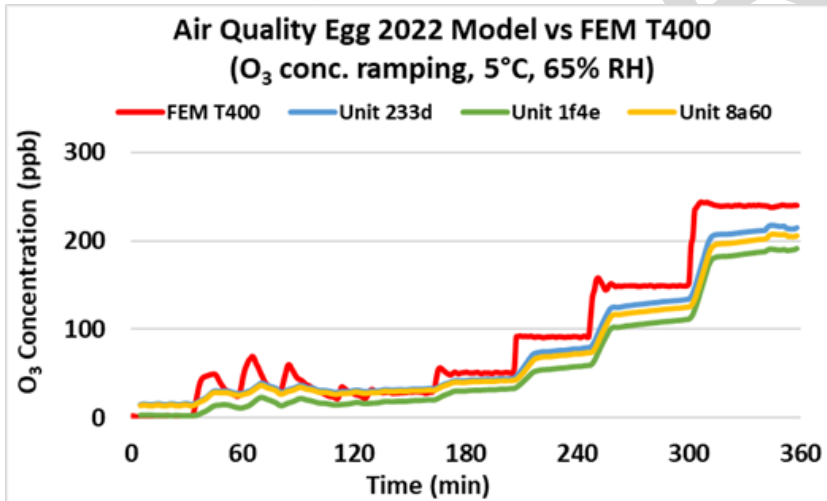
Low Temp-Low RH



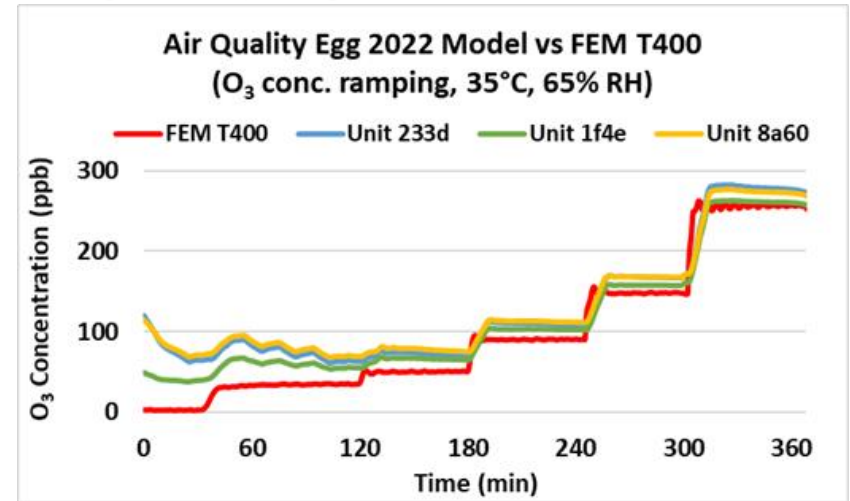
High Temp-Low RH



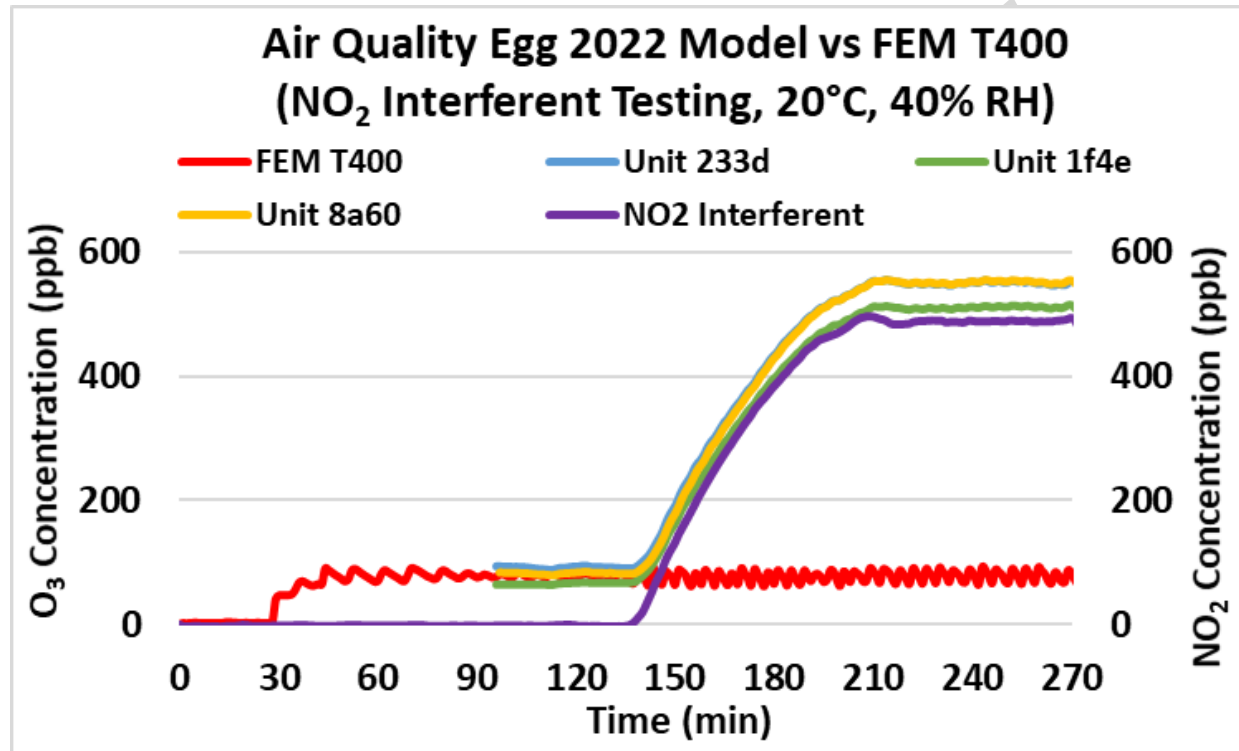
Low Temp-High RH



High Temp-High RH

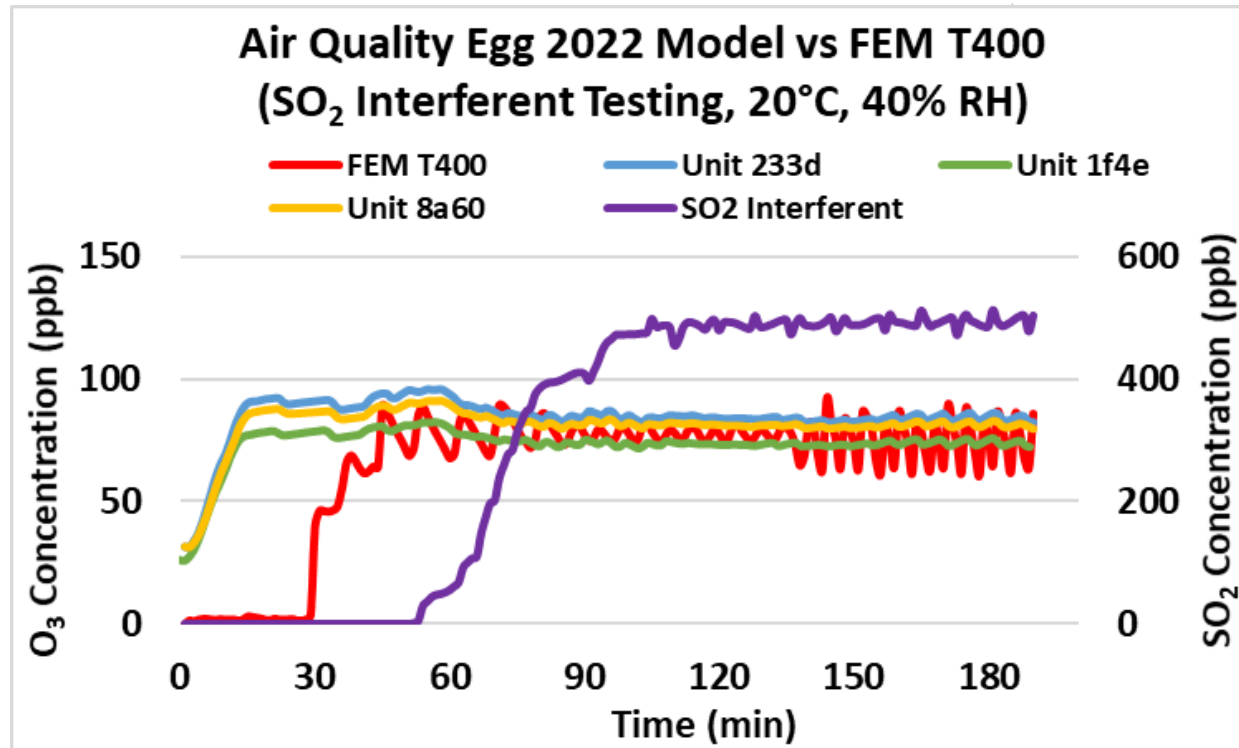


NO₂ Interferent: Air Quality Egg 2022 Model vs FEM T400 T400 (O₃)



In the laboratory, the effect of NO₂ interferent is evaluated by exposing sensors to 500 ppb of NO₂ at 20 °C and 40% RH while holding O₃ concentrations at 80 ppb. As shown in the figure, the FEM T400 was not affected by NO₂ while the sensors' ozone concentrations increased with increasing NO₂.

SO₂ Interferent: Air Quality Egg 2022 Model vs FEM T400 T400 (O₃)



In the laboratory, the effect of SO₂ interferent is evaluated by exposing the sensors to 500 ppb of SO₂ at 20 °C and 40% RH while holding O₃ concentrations at 80 ppb. As shown in the figure, both the FEM T400 and sensors' O₃ measurements were not affected by SO₂.

Discussion: O₃

- **Accuracy:** The three Air Quality Egg 2022 Model sensors showed accuracy ranged from 83.9% to 98.5%.
- **Precision:** The three Air Quality Egg 2022 Model sensors exhibited high precision for all combinations of O₃, T and RH conditions.
- **Intra-model variability:** low to moderate O₃ measurement variations were observed among the three Air Quality Egg 2022 Model sensors at 20°C and 40% RH.
- **Data recovery:** Data recovery for O₃ measurements was 99.8%, 99.3%, and 99.6% for Units 233d, 1f4e, and 8a60, respectively.
- **Baseline:** At all conditions, FEM T400 O₃ instrument baseline was ranging from 0.5 to 2.4 ppb, while the sensors' baseline was ranging from 1 to 75 ppb; high sensor baselines were observed at 35°C. Unit 1f4e generally showed lower baseline compared to Units 233d and 8a60.
- **Response time:** Response time could not be studied due to the system design of the chamber system. With a 1.6 m³ chamber volume and the max gas flow of 20 LPM, it was not possible to reach a high pollutant concentration within a short time.
- **Linear Correlation:** The three Air Quality Egg 2022 Model sensors showed very strong correlation/linear response with the corresponding FEM T400 O₃ measurement data ($R^2 > 0.98$).
- **Interferent (NO₂):** The three Air Quality Egg 2022 Model sensors' ozone readings followed the NO₂ concentrations as NO₂ was increased to 500 ppb at 20°C and 40% RH.
- **Interferent (SO₂):** The three Air Quality Egg 2022 Model sensors were inert to SO₂ at 20°C and 40% RH. When SO₂ was increased to 500 ppb, the sensors maintained their readings at ~ 80 ppb.

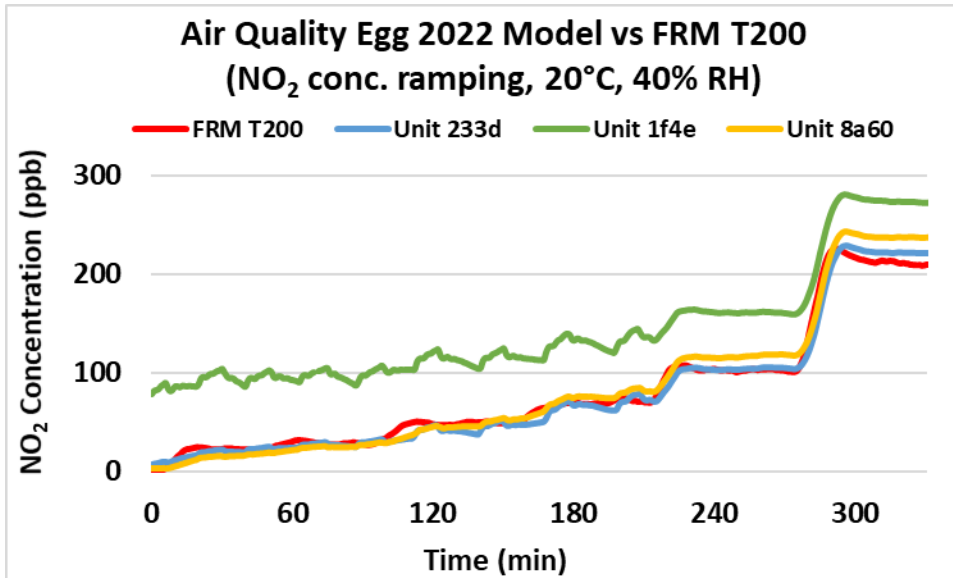
Discussion: O₃

- **Measurement duration:** Air Quality Egg 2022 Model sensors report 1-min averaged values for the duration of all experiments.
- **Measurement frequency:** Air Quality Egg 2022 Model sensors report 1-min averaged values. The obtained data was used as-is for calculation of statistics (e.g. data recovery, intra-model variability, mean, accuracy, precision), but condensed into 5-minute averages for linear correlation studies against the FEM T400.
- **Sensor contamination and expiration:** Prior to the laboratory evaluation, the Air Quality Egg 2022 Model sensors were tested in the field for two months. The O₃ laboratory studies lasted for about 14 days with intermittent non-operating periods and a storage period of ~ 10 months. For O₃ measurements, all three Air Quality Egg 2022 Model sensors maintained their functionalities and operated normally throughout the duration of the testing.
- **Concentration range:** 0-2 ppm O₃ concentration as suggested by the manufacturer. During the laboratory evaluation, the Air Quality Egg 2022 Model sensors were challenged with O₃ concentrations up to 250 ppb.
- **Climate susceptibility:** During the lab studies, temperature and relative humidity generally had little effect on the precision of O₃ concentrations as recorded by the Air Quality Egg 2022 Model sensors.
- **Response to loss of power:** Air Quality Egg 2022 Model sensors were powered through the entirety of the lab tests.

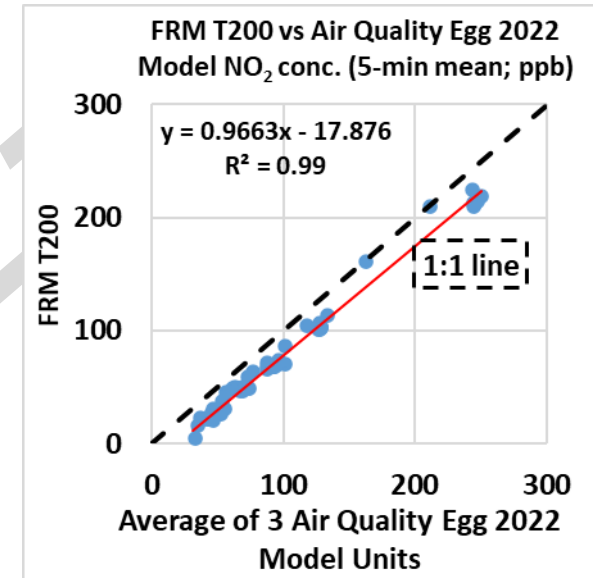
NO₂

- 1. FRM T200 vs Air Quality Egg 2022 Model**
- 2. Accuracy, data recovery and intra-model variability**
- 3. Precision**
- 4. Climate susceptibility**
- 5. Interferents**
- 6. Discussion**

Air Quality Egg 2022 Model vs FRM T200 (NO₂)



Coefficient of Determination



- The FRM T200 instrument reported a baseline of ~0 ppb and the Air Quality Egg 2022 Model sensors reported baseline values ~3 ppb for units 233d and 8a60. Unit 1f4e showed a high baseline of ~65 ppb
- The sensors tracked the NO₂ concentration variations recorded by FRM T200 instrument
- Overall, the sensors overestimated the NO₂ concentration as recorded by the FRM T200 instrument
- Unit 1f4e showed significantly higher NO₂ concentrations than Units 233d and 8a60
- The Air Quality Egg 2022 Model sensors showed very strong correlations with the corresponding FRM T200 NO₂ conc. ($R^2 = 0.99$)

Accuracy: Air Quality Egg 2022 Model vs FRM T200 (NO₂)

- Accuracy (20 °C and 40% RH)

| Steady State (#) | Sensor Mean (ppb) | FRM T200 (ppb) | Accuracy (%) |
|------------------|-------------------|----------------|--------------|
| 1 | 49.6 | 27.6 | 20.2 |
| 2 | 70.3 | 49.6 | 58.2 |
| 3 | 94.4 | 71.3 | 67.5 |
| 4 | 128.0 | 102.6 | 75.3 |
| 5 | 242.1 | 210.9 | 85.2 |

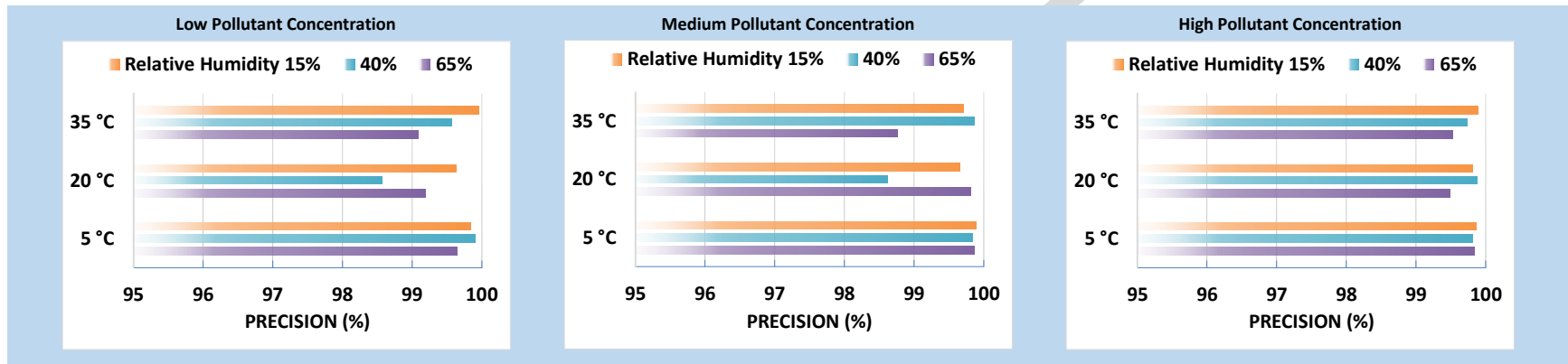
- Accuracy of the three Air Quality Egg 2022 Model sensors ranged from 20.2% to 85.2%. Overall, the sensors overestimated the FRM T200 measurements at all NO₂ concentrations at 20°C and 40% RH.

Air Quality Egg 2022 Model Data Recovery and Intra-model Variability

- Data recovery for NO₂ measurements was 99.7%, 98.8%, and 98.5% for Units 233d, 1f4e, and 8a60, respectively.
- High NO₂ concentration variations were observed between the three units at 20 °C and 40% RH at low, medium and high NO₂ concentrations as measured by the FRM T200.

Precision: Air Quality Egg 2022 Model (NO₂)

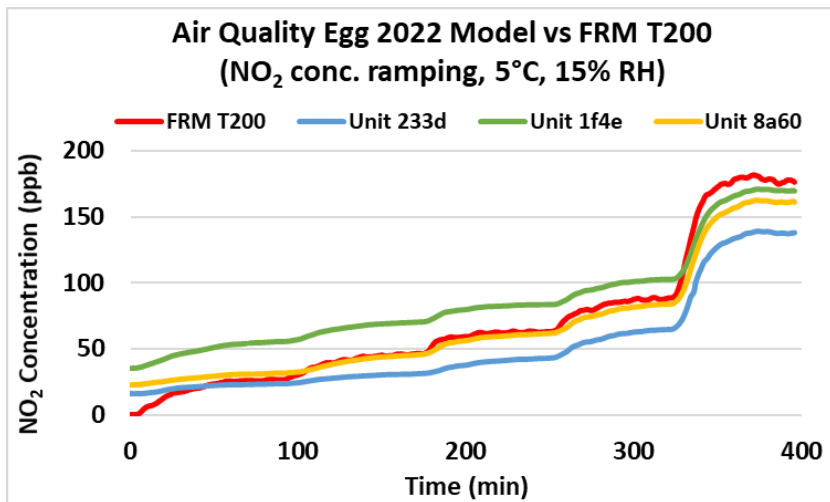
- Precision* (Effect of NO₂ conc., temperature and relative humidity)



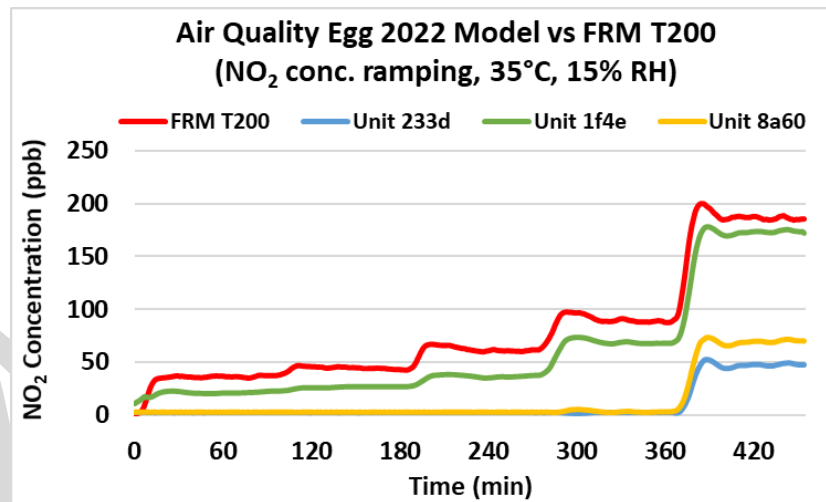
- Overall, the three Air Quality Egg 2022 Model sensors showed high precision for all combinations of NO₂ conc., T, and RH.

Climate Susceptibility: Air Quality Egg 2022 Model (NO₂)

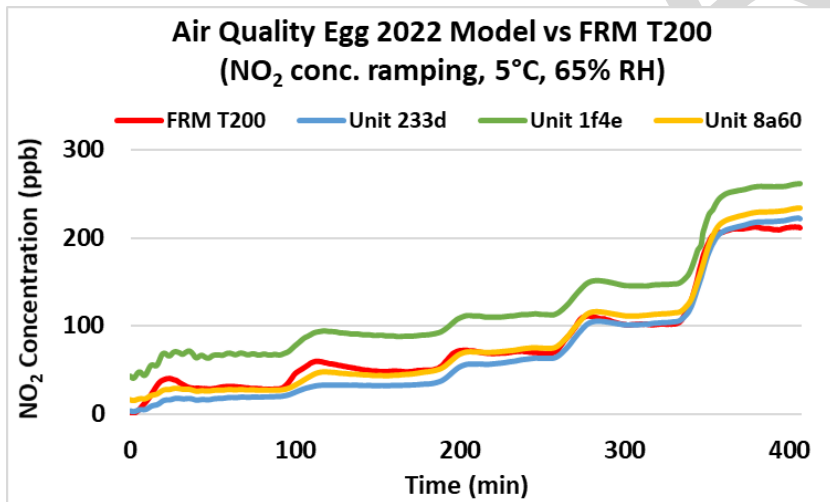
Low Temp-Low RH



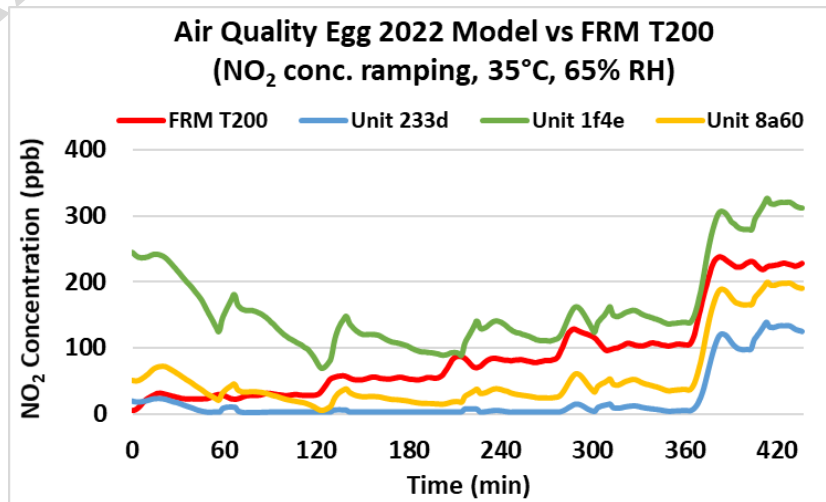
High Temp-Low RH



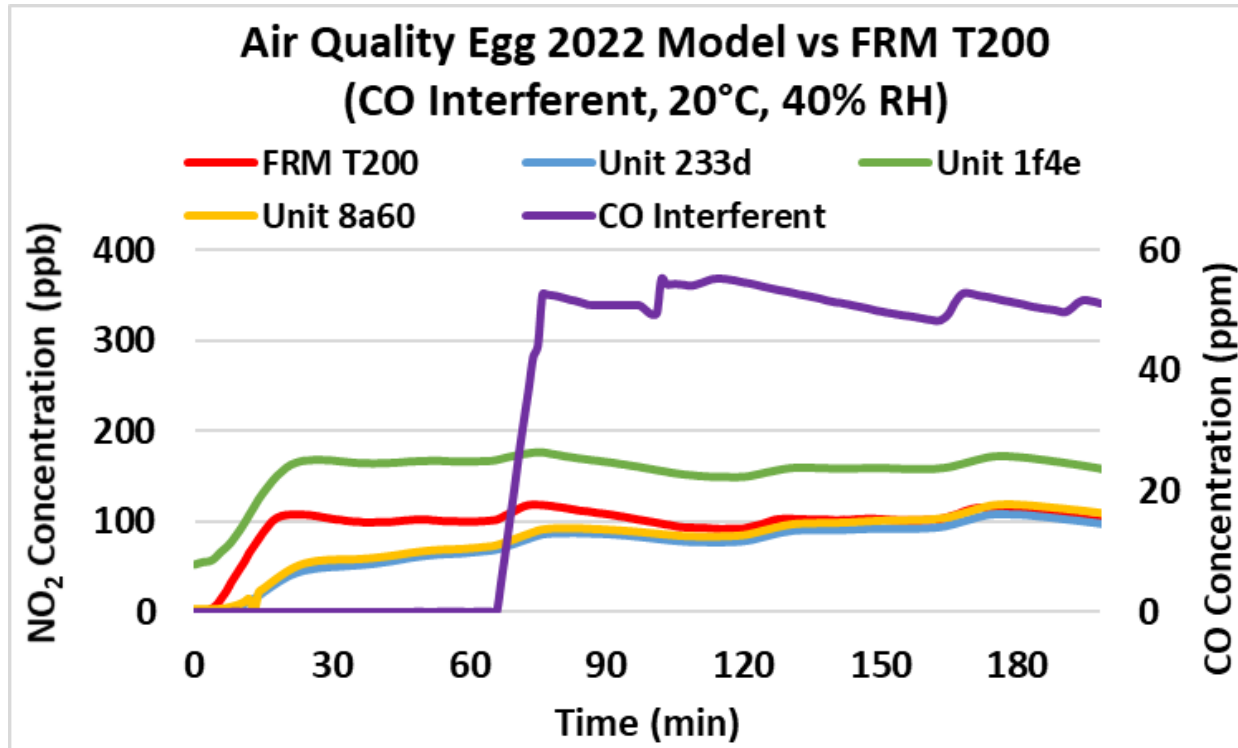
Low Temp-High RH



High Temp-High RH

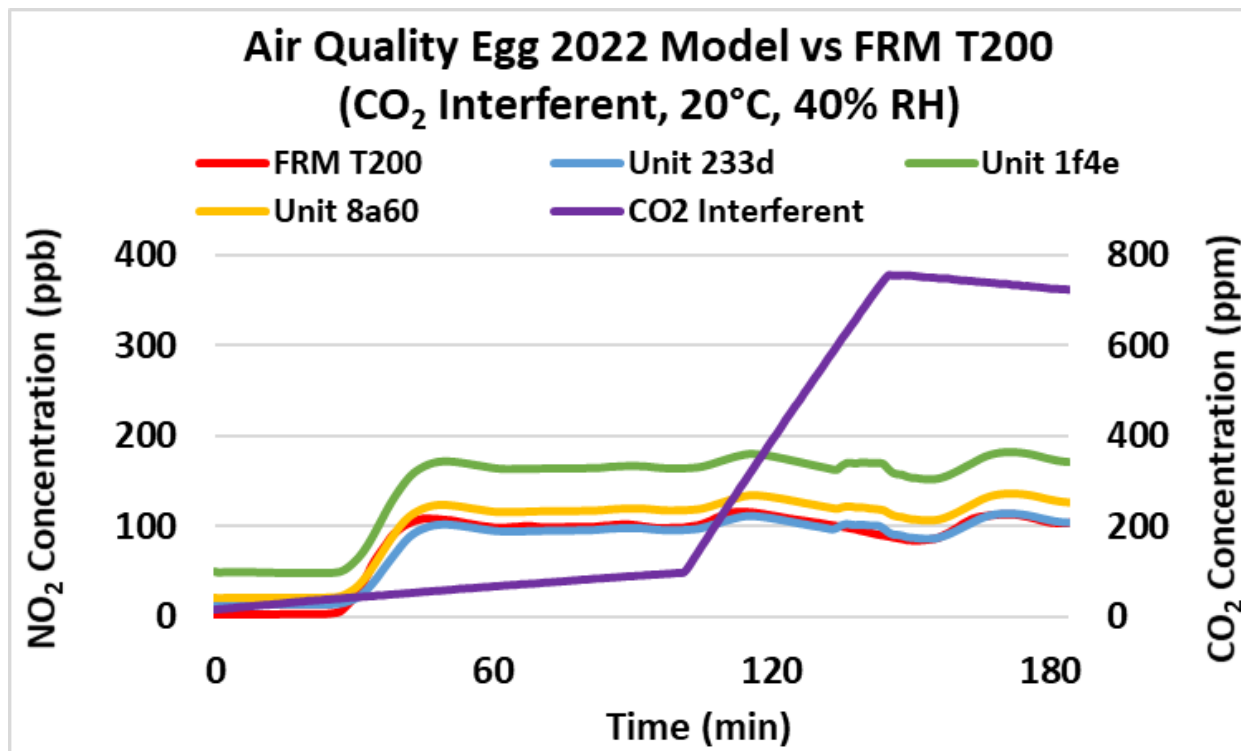


CO Interferent: Air Quality Egg 2022 Model vs FRM T200 (NO₂)



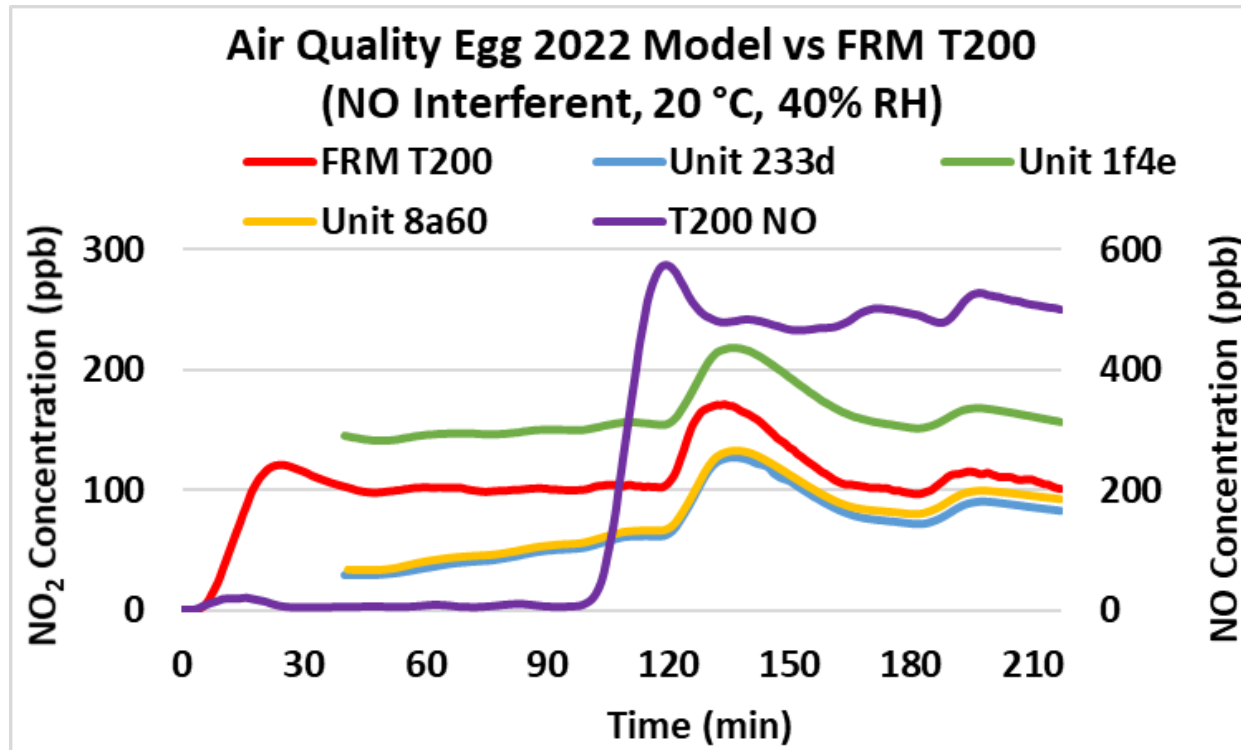
In the laboratory, the effect of CO interferent is evaluated by exposing sensors to 50 ppm of CO at 20 °C and 40% RH while holding the NO₂ concentrations at 100 ppb. As shown in the figure, the FRM T200 and the sensors maintained their readings as the CO concentration increased to 50 ppm.

CO₂ Interferent: Air Quality Egg 2022 Model vs FRM T200 (NO₂)



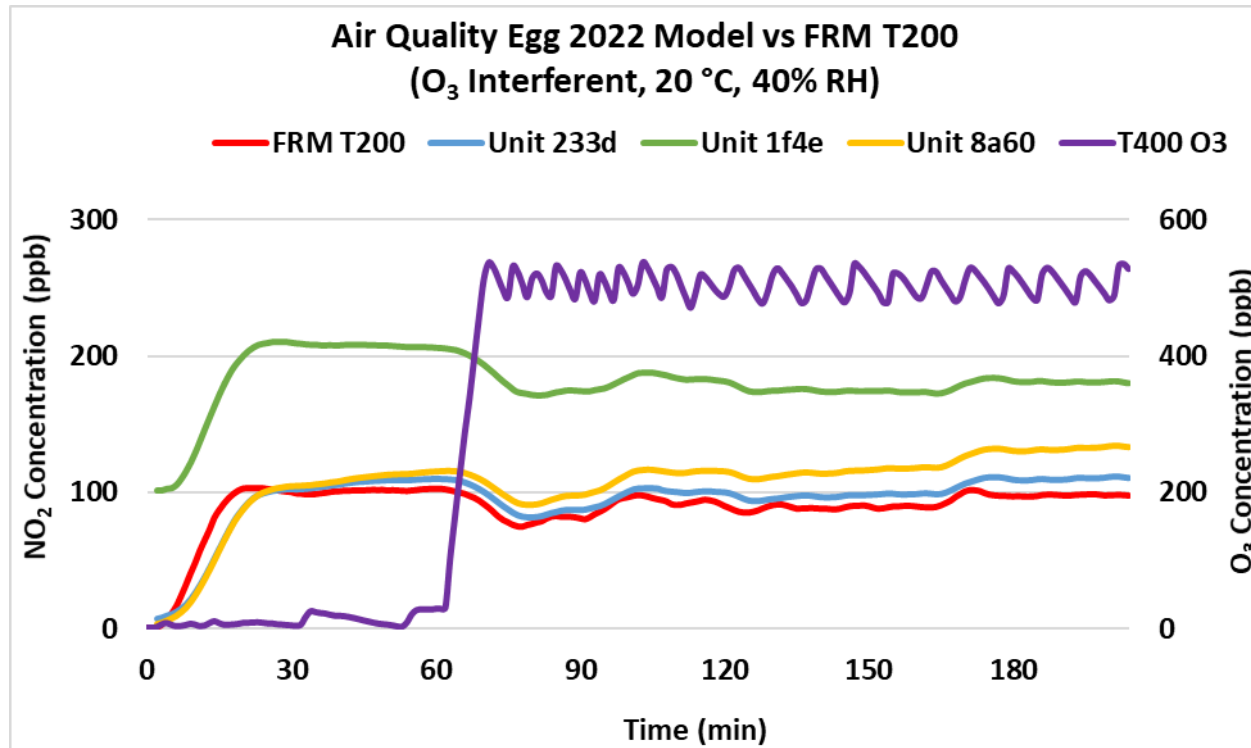
In the laboratory, the effect of CO₂ interferent is evaluated by exposing sensors to 750 ppm of CO₂ at 20 °C and 40% RH while holding the NO₂ concentrations at 100 ppb. As shown in the figure, the FRM T200 and the sensors maintained their readings as the CO₂ concentration increased to 750 ppm.

NO Interferent: Air Quality Egg 2022 Model vs FRM T200 (NO₂)



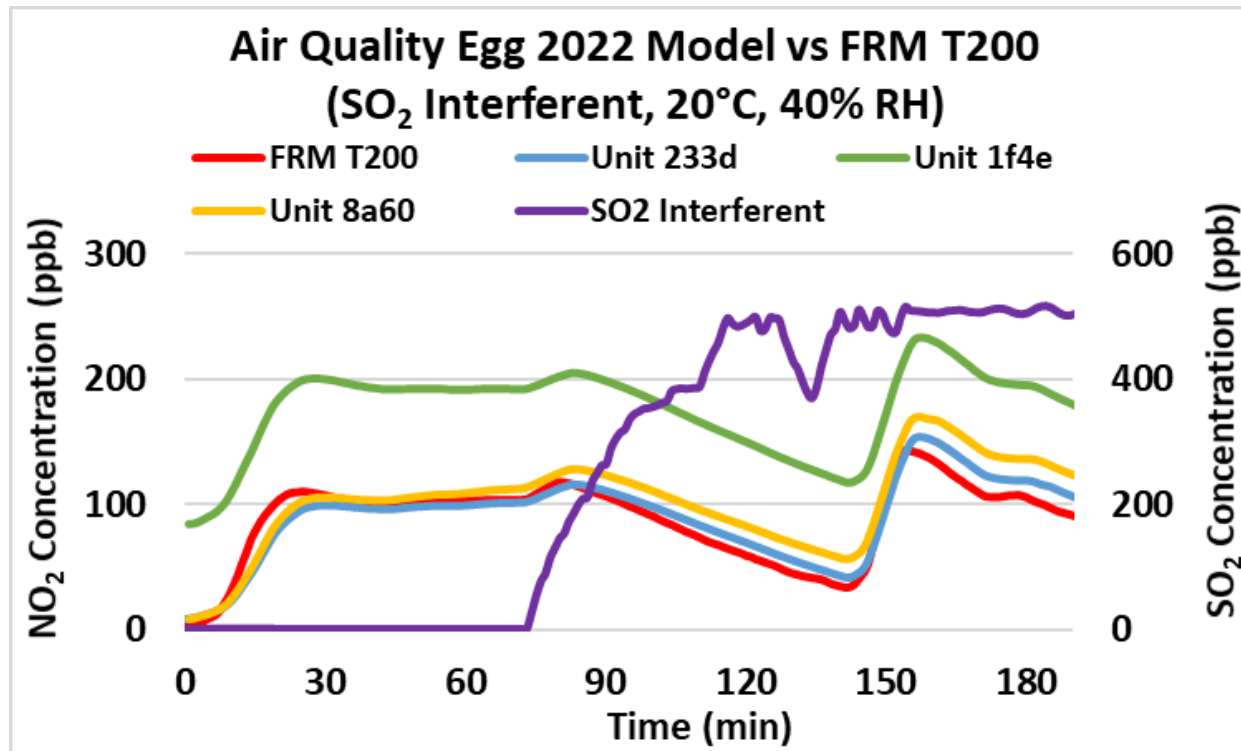
In the laboratory, the effect of NO interferent is evaluated by exposing sensors to 500 ppb of NO at 20 °C and 40% RH while holding the NO₂ concentrations at 100 ppb. As shown in the figure, the FRM T200 and the sensors maintained their readings as the NO concentration increased to 500 ppb.

O₃ Interferent: Air Quality Egg 2022 Model vs FRM T200 (NO₂)



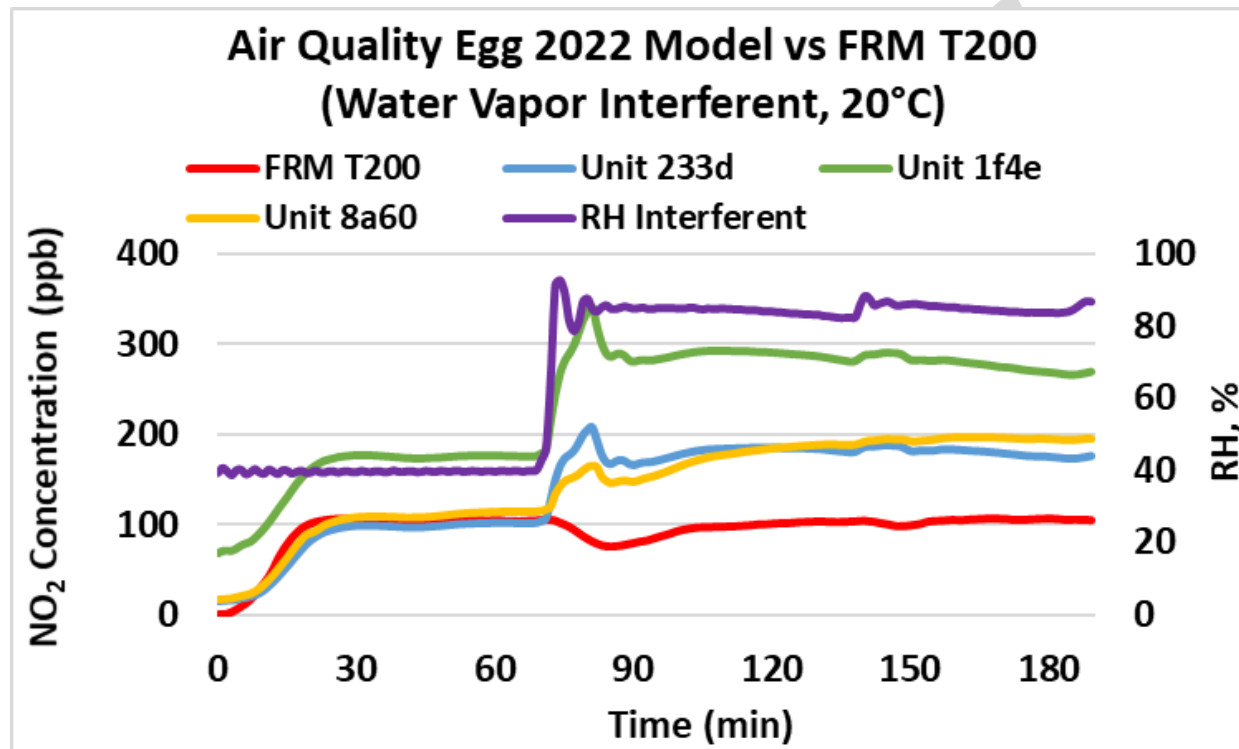
In the laboratory, the effect of O₃ interferent is evaluated by exposing sensors to 500 ppb of O₃ at 20 °C and 40% RH while holding the NO₂ concentrations at 100 ppb. As shown in the figure, the FRM T200 and the sensors maintained their readings as the O₃ concentration increased to 500 ppb.

SO₂ Interferent: Air Quality Egg 2022 Model vs FRM T200 (NO₂)



In the laboratory, the effect of SO₂ interferent is evaluated by exposing sensors to 500 ppb of SO₂ at 20 °C and 40% RH while holding the NO₂ concentrations at 100 ppb. As shown in the figure, the FRM T200 and the sensors maintained their readings as the SO₂ concentration increased to 500 ppb.

Water Vapor Interferent: Air Quality Egg 2022 Model vs FRM T200 (NO₂)



In the laboratory, the effect of water vapor interferent is evaluated by exposing sensors to 20,000 ppm of water vapor, which corresponds to the water content at 20 °C and 85% RH, while holding the NO₂ concentrations at 100 ppb. As shown in the figure, the FRM T200 maintained its NO₂ readings at 100 ppb as RH increased from 40% to 85% while the sensors' NO₂ readings increased as RH increased.

Discussion: NO₂

- **Accuracy:** The three Air Quality Egg 2022 Model sensors showed accuracy ranged from 20.2% to 85.2%.
- **Precision:** The three Air Quality Egg 2022 Model sensors exhibited high precision during all tested NO₂ conc., T, and RH conditions.
- **Intra-model variability:** High NO₂ measurement variations were observed among the three Air Quality Egg 2022 Model sensors at 20°C and 40% RH. Unit 1f4e showed significantly higher NO₂ readings than Units 233d and 8a60.
- **Data recovery:** Data recovery for NO₂ measurements was 99.7%, 98.8%, and 98.5% for Units 233d, 1f4e, and 8a60, respectively.
- **Baseline:** At all conditions, FRM T200 NO₂ instrument baseline was ranging from 0 to 5.4 ppb, while the sensors' baseline was ranging from 2.1 to 264.5 ppb; high sensor baselines were observed at 35°C and high RH conditions. Unit 1f4e generally showed higher baseline compared to Units 233d and 8a60.
- **Response time:** Response time could not be studied due to the system design of the chamber system. With a 1.6 m³ chamber volume and the max gas flow of 20 LPM, it was not possible to reach a high pollutant concentration within a short time.
- **Linear Correlation:** The three Air Quality Egg 2022 Model sensors showed very strong correlation/linear response with the corresponding FRM T200 NO₂ measurement data ($R^2 = 0.99$) except for the NO₂ concentration ramping test at 35°C and 65% RH.
- **Interferents:** The three Air Quality Egg 2022 Model sensors were inert to most interferents (i.e. O₃, NO, CO₂, SO₂ and CO) at 20°C and 40% RH. The sensors' NO₂ readings increased as RH increased from 40% to 85%.

Discussion: NO₂

- **Measurement duration:** Air Quality Egg 2022 Model sensors report 1-min averaged values.
- **Measurement frequency:** Air Quality Egg 2022 Model sensors report 1-min averaged values. The obtained data was used as-is for calculation of statistics (e.g. data recovery, intra-model variability, mean, accuracy, precision), but condensed into 5-minute averages for linear correlation studies against the FRM T200.
- **Sensor contamination and expiration:** Prior to the laboratory evaluation, the Air Quality Egg 2022 Model sensors were tested in the field for two months. The NO₂ laboratory studies lasted for about 14 days with intermittent non-operating periods and a storage period of ~ 10 months. For NO₂ measurements, all three Air Quality Egg 2022 Model sensors maintained their functionalities and operated normally throughout the duration of the testing.
- **Concentration range:** 0-2 ppm NO₂ concentration as suggested by the manufacturer. During the laboratory evaluation, the Air Quality Egg 2022 Model sensors were challenged with NO₂ concentrations up to 200 ppb.
- **Climate susceptibility:** During the lab studies, temperature and relative humidity generally had little effect on the precision of NO₂ concentrations as recorded by the Air Quality Egg 2022 Model sensors.
- **Response to loss of power:** Air Quality Egg 2022 Model sensors were powered through the entirety of the lab tests.