Laboratory Evaluation: SGS Galson SmartSense

South Coast AQMD

AQ-SPEC
Air Quality Sensor Performance Evaluation Center

Background

Three **SGS Galson SmartSense** sensors (hereinafter **SGS SmartSense**) were evaluated in the South Coast AQMD Chemistry Laboratory under controlled Volatile Organic Compound (VOC) and interferent gas concentrations, temperature, and relative humidity. The sensor measurements were compared with two reference instruments (Thermo Fisher Scientific, Model 55i; hereinafter **Thermo 55i** and Agilent gas chromatograph with flame ionization detection, Model 6890N Network; hereinafter **GC-FID**).

SGS SmartSense (*3 units tested*):

- VOC Sensor – PID (non-FEM)
  - VOC operable range: 0 – 20 ppm
  - Manufacturer stated Accuracy: ±50 ppb
  - Measurement interval: 1-min
- Measures: VOC (ppm)
- Unit cost: ~$1972 + $275/year for web interface
- Units IDs: 6555, 7206, 7289

Note: Unit 6555 did not function properly after the Phase 1 and was not included in the rest of the tests. Unit 7206 did not function properly partway through Phase 3 and was not included in the rest of the tests.

SGS SmartSense

Thermo 55i

GC-FID

***Reference Instruments*:**

- **Thermo Fisher 55i**
  - Measures: methane (CH_4) and total non-methane hydrocarbon (NMHC)
  - Unit cost: ~$27,000
  - Specifications:
  - Measurement ranges: 0-50 ppm
  - Limit of Detection (LOD): 50 ppb
  - Analysis time: ~70 seconds
  - Accuracy: ±1% of range
  - Repeatability: ±2% of measured value or 50 ppb (whichever is larger)
  - Drift: ±2% of span over 24 hours
  - Ambient operating temperature: 15-35 °C
  - Sample temperature: ambient to 35 °C
- **Agilent Gas Chromatograph**
  - Flame Ionization Detection
  - Time Resolution: 22-min
  - Unit cost: ~ $100,000
  - Limit of Detection (LOD): dependent on the species, typically <1 ppb

Outline

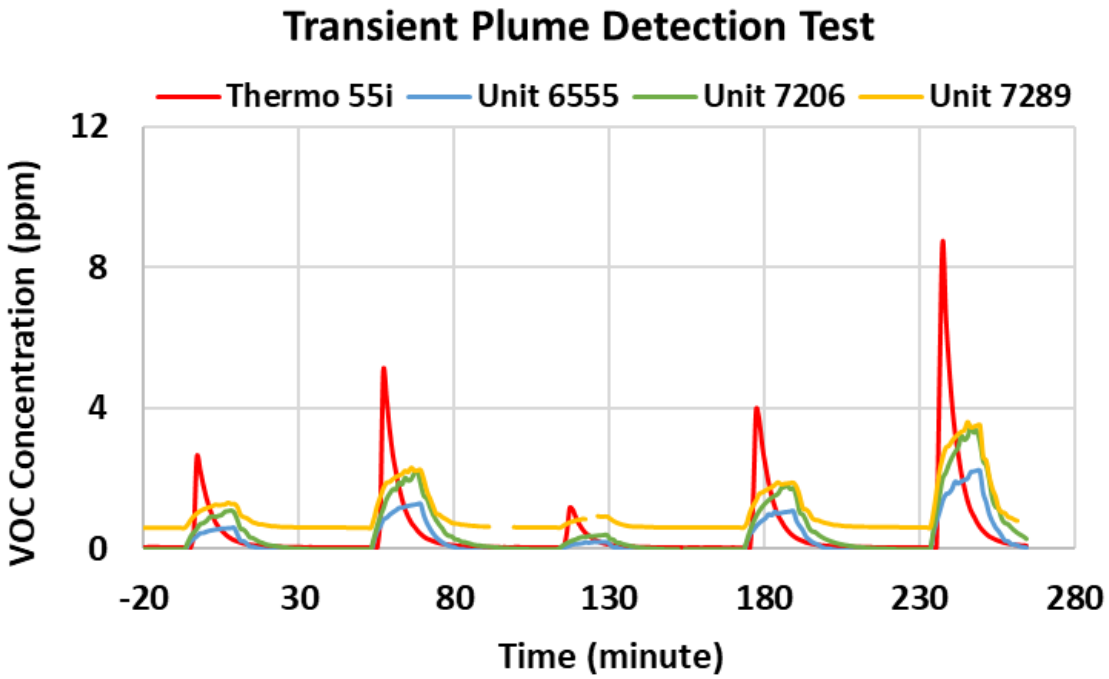
1. Reference instruments comparison
2. VOC blend results (Phase 1 through Phase 6)
3. Benzene-only results (Phase 2 and Phase 6)
4. Discussion

VOC Blend Results

Phase 1: Transient Plume Detection

Testing Phase #1	Method	Parameters Evaluated
Transient Plume Detection	5 VOC plume events at various concentrations in randomized order	• Response time • % of peak detection

SGS SmartSense vs Thermo 55i



- The SGS SmartSense sensors responded to 100% of the VOC peaks generated.
- The SGS SmartSense sensors detected the peaks on average about 10 minutes later than the Thermo 55i.

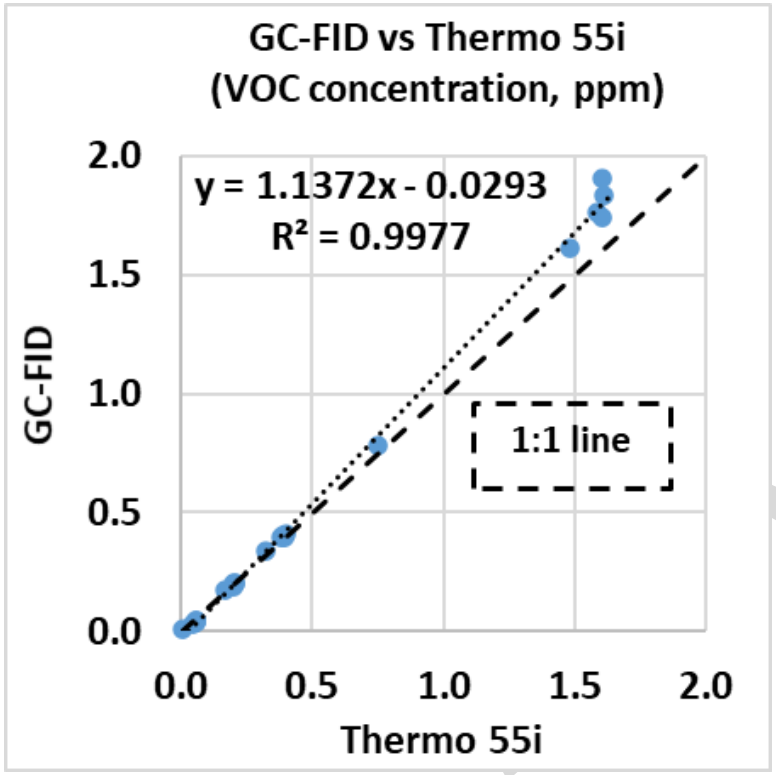
Phase 2:
Initial Concentration Ramping

Testing Phase #2	Method	Parameters Evaluated
Initial Concentration Ramping	• Low conc. ramping with VOC blend (0.06 to 1.6 ppm) • High conc. ramping with VOC blend (2 to 8 ppm) • Low conc. ramping with benzene-only (0.015 to 0.4 ppm) • High conc. ramping with benzene-only (0.5 to 2 ppm)	• Sensor Detection Limit, R^2, Accuracy, Precision, IMV, Data Recovery

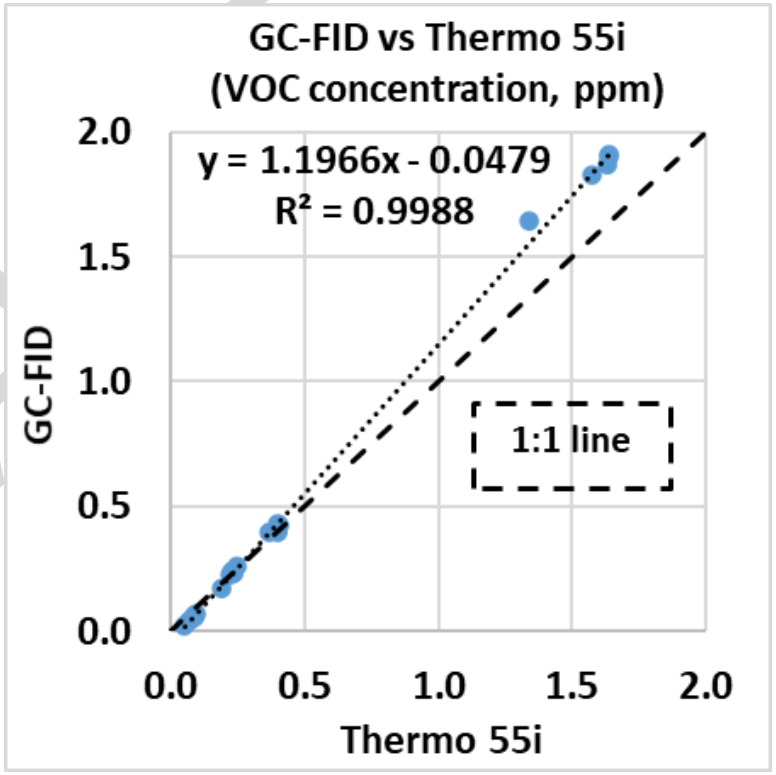
Note: Unit 6555 did not function properly after the Phase 1 and was not included in the rest of the tests.

GC-FID vs Thermo 55i: VOC Blend

Beginning of Evaluation



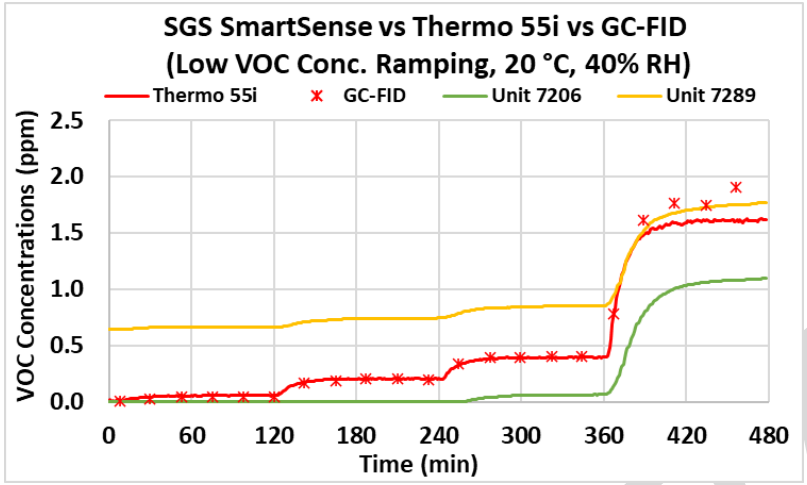
End of Evaluation

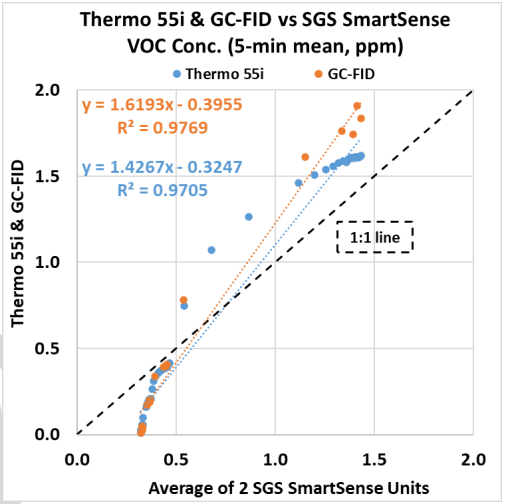


- Very strong correlations between the Thermo 55i and GC-FID ($R^2 > 0.99$).
- The two reference instruments reported similar VOC concentrations at both the beginning and the end of evaluation.

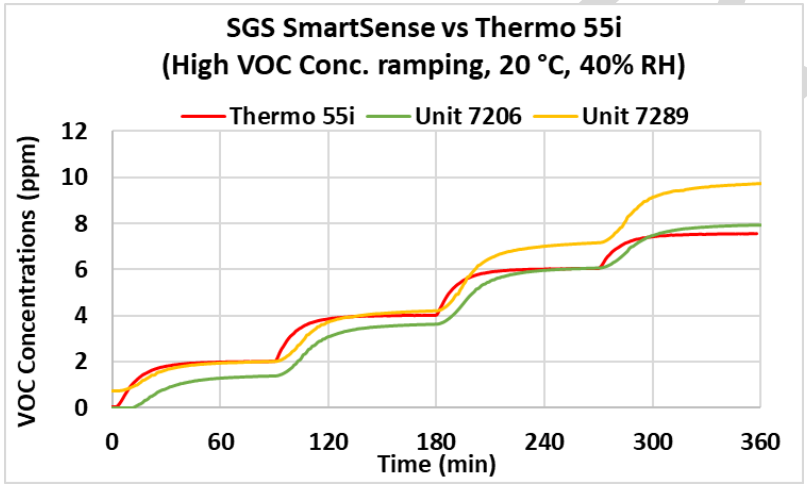
SGS SmartSense vs Thermo 55i vs GC-FID

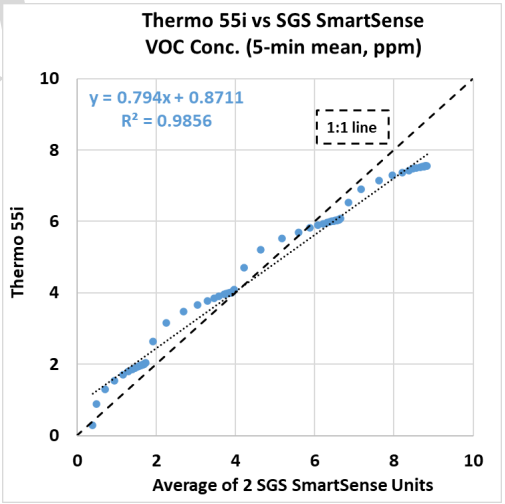
Low Ramp





High Ramp





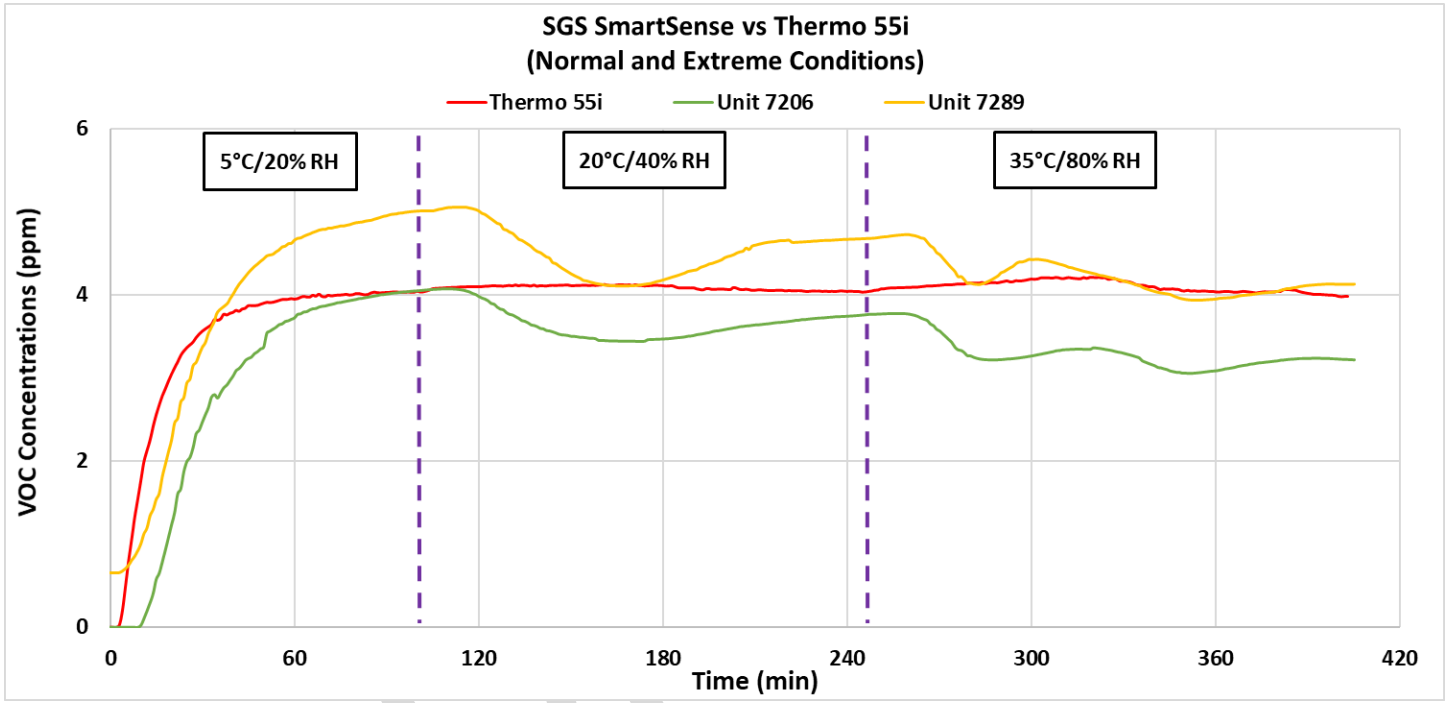
- The SGS SmartSense sensors tracked the VOC concentration variation as recorded by the reference instruments.
- The SGS SmartSense sensors showed very strong correlations (R^2 > 0.97) in both the low and high concentration ramps against the reference instruments.
- Unit 7206 generally underestimated while Unit 7289 generally overestimated the VOC concentrations measured by the reference instruments.

Phase 3: Effect of Temperature and Relative Humidity

Testing Phase #3	Method	Parameters Evaluated
Effect of Temperature and RH	• Extreme Conditions: hot/humid; cold/dry and VOC = 4ppm • RH interference: 15% to 80% RH; T = 20°C and VOC = 4 ppm • T interference: 20°C to 10°C to 30°C to 20°C; RH = 40% and VOC = 4 ppm • *T interference: 20°C to 10°C to 30°C to 20°C; AH = constant and VOC = 4 ppm	• Climate susceptibility, Accuracy, Precision, IMV, Data Recovery

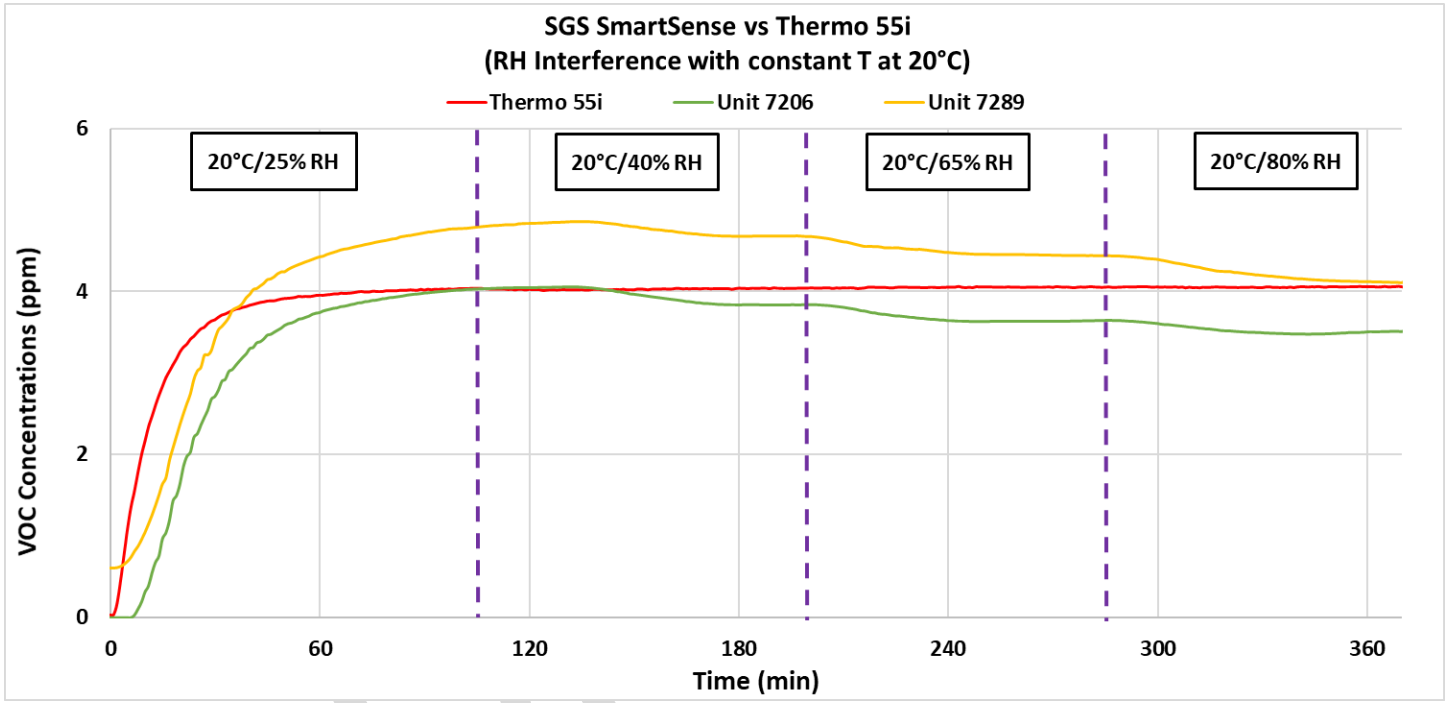
Note: Unit 6555 did not function properly after the Phase 1 and was not included in the rest of the tests. Unit 7206 did not function properly partway through Phase 3 and was not included in the rest of the tests.

Normal and Extreme Conditions



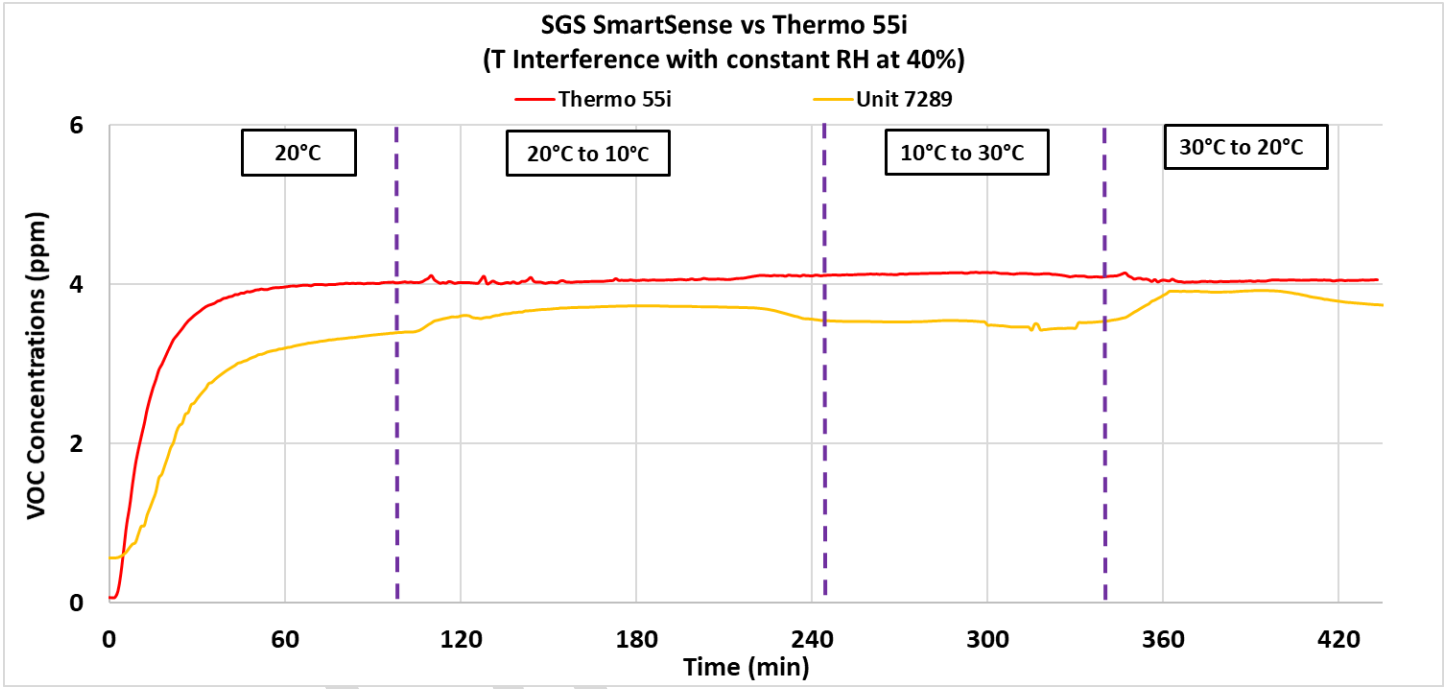
- The SGS SmartSense sensors showed a decrease in mean VOC concentrations as T/RH increased from 5°C/20% RH to 20°C/40% RH, and then decreased further in mean VOC concentrations as temperature/RH was further increased to 35°C/80% RH.
- The SGS SmartSense sensors' VOC concentrations decreased by ~17-19% at 35°C/80% RH as compared to the VOC concentrations at 5°C/20% RH.

RH Interference



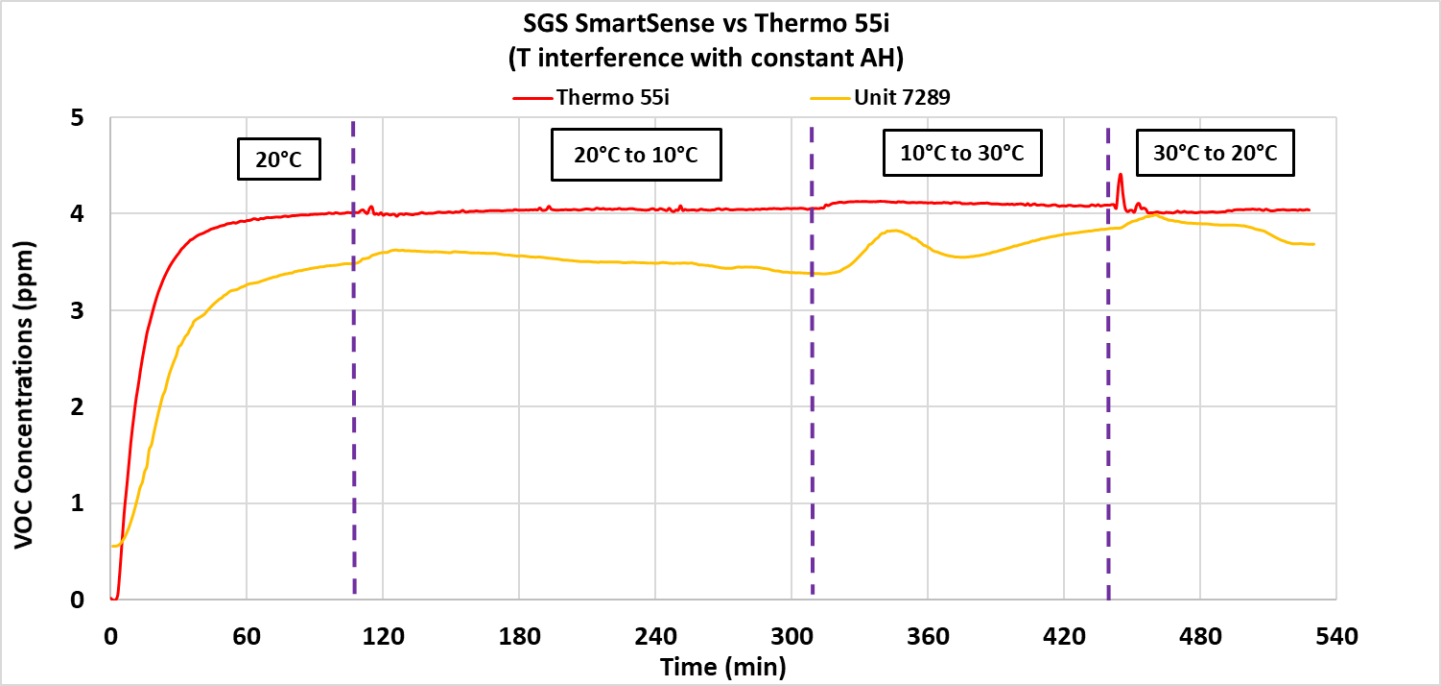
- The RH interference test was conducted at constant temperature of 20°C with RH increasing from 25% to 80%.
- The SGS SmartSense sensors' VOC concentrations decreased by ~12-13% as RH increased from 25% to 80%.

Temperature Interference at Constant RH



- The Temperature interference test was conducted at constant RH of 40%.
- A temperature change at constant RH appears to cause sensor response to move in the opposite direction, i.e. the sensors' VOC reading increases when temperature decreases and vice versa, after steady-state temperature and RH conditions are realized. The average change of VOC concentrations between the initial and final 20°C/40% RH conditions was ~12%.

Temperature Interference at Constant Absolute Humidity (AH)



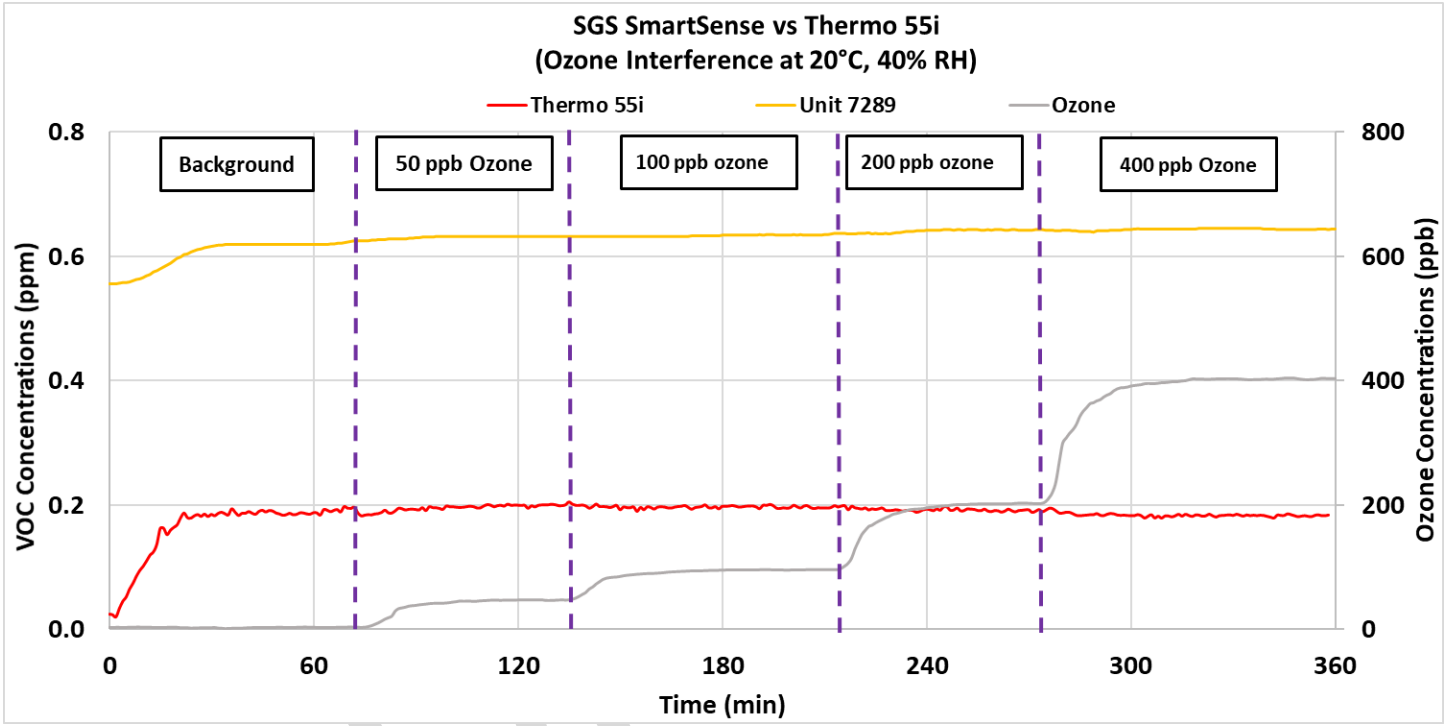
- The Temperature interference at constant AH setpoint was conducted at the moisture content corresponding to 20°C and 40% RH.
- A temperature change at constant AH setpoint appeared to cause the sensor response to change in the same direction of temperature change. The average change of VOC concentrations between the initial and final 20°C with constant AH conditions was ~7.1%.

Phase 4:
Effect of Gaseous Interferents

Testing Phase #4	Method	Parameters Evaluated
Effect of gaseous interferents	• Ozone (1 to 400 ppb; 20 °C/40% RH and VOC = 200 ppb) • Carbon Monoxide (background to 8 ppm; 20 °C/40% RH and VOC = 4 ppm) • Carbon Dioxide (background to 8000 ppm; 20 °C/40% RH and VOC = 4 ppm)	• Response to interferents, Accuracy, Precision, IMV, Data Recovery

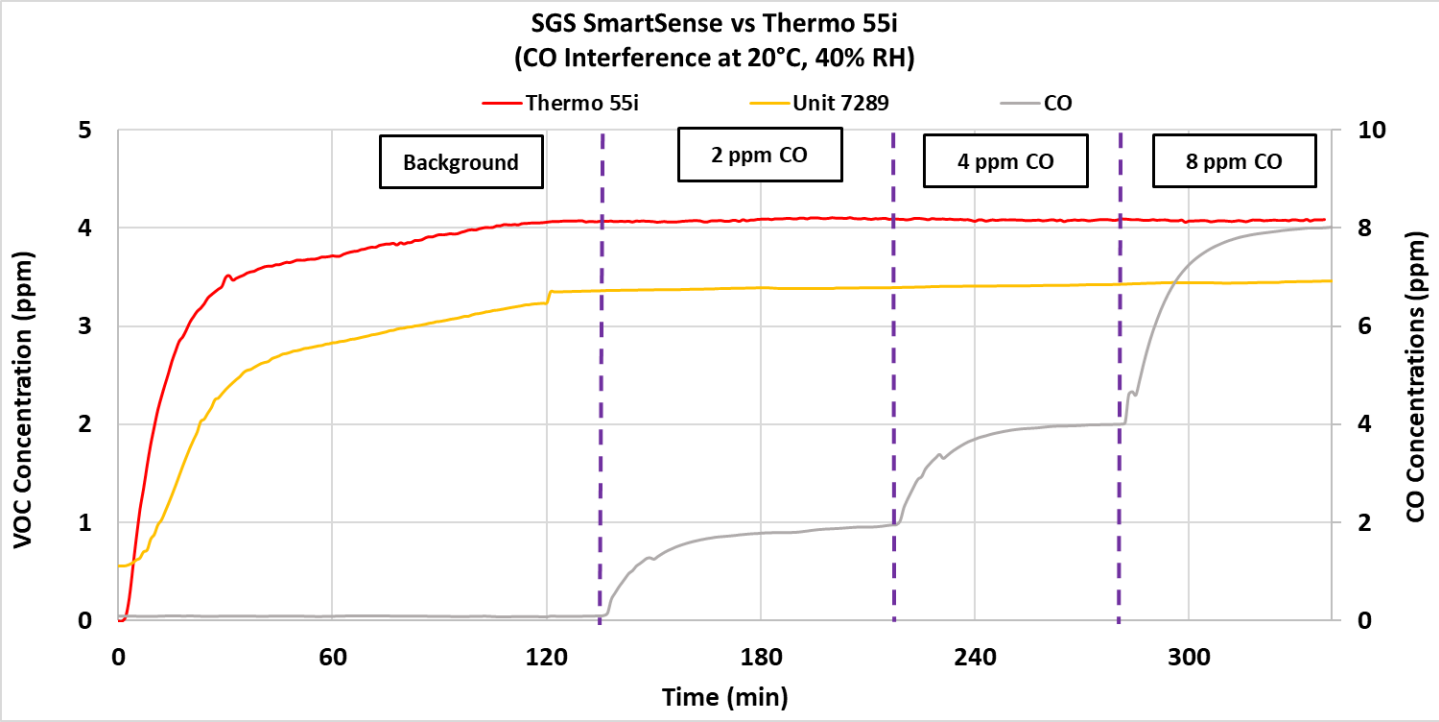
Note: Unit 6555 did not function properly after the Phase 1 and was not included in the rest of the tests. Unit 7206 did not function properly partway through Phase 3 and was not included in the rest of the tests.

Ozone Interferent



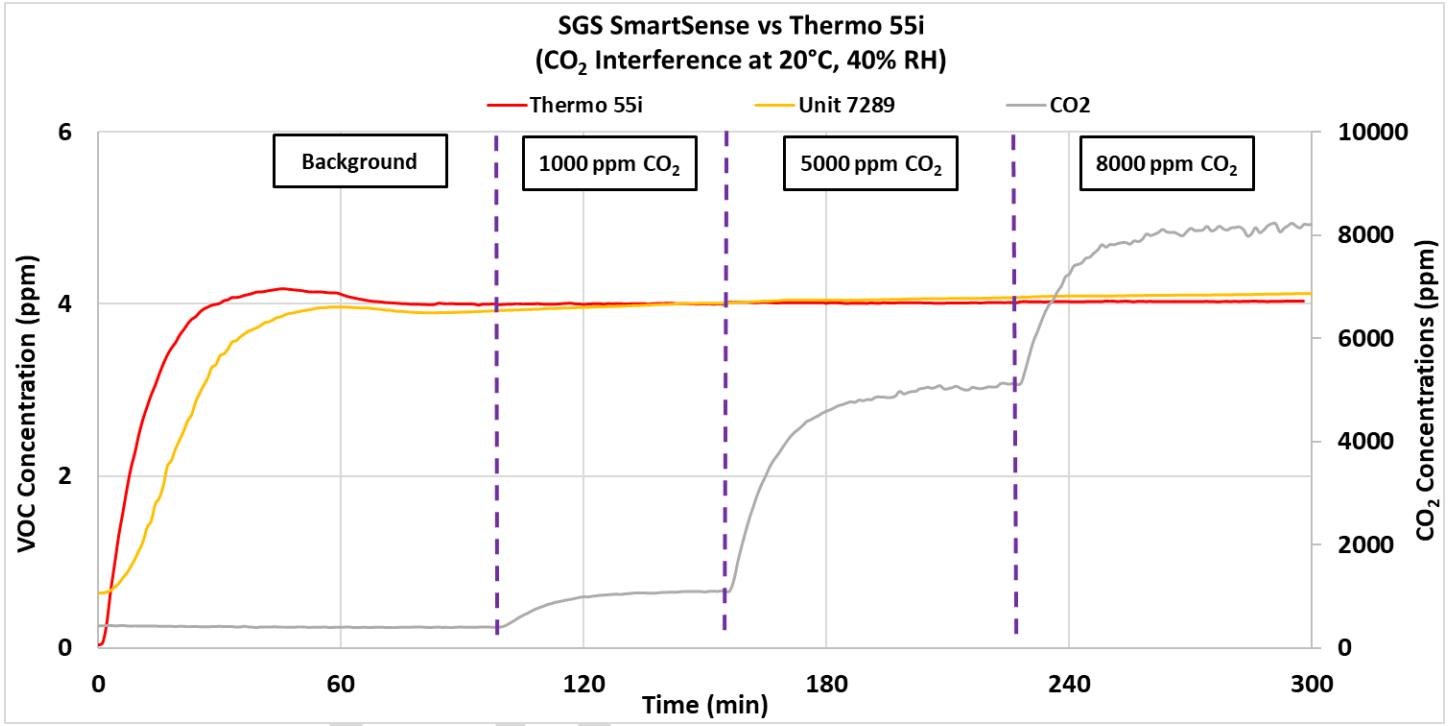
- Ozone interferent test: sensors were subjected to increasing ozone concentration from background level to 400 ppb while holding VOC concentration constant at 0.2 ppm.
- Ozone had minimal effect on the VOC concentrations measured by the Thermo 55i and the SGS SmartSense sensor as O_3 increased from background to ~400 ppb.

CO Interferent



- CO interferent test: sensors were subjected to increasing CO concentration from background level to 8ppm while holding VOC concentration constant at ~4 ppm.
- CO had minimal effect on the VOC concentrations measured by the Thermo 55i and the SGS SmartSense sensor as CO increased from background to ~8 ppm.

CO_2 Interferent



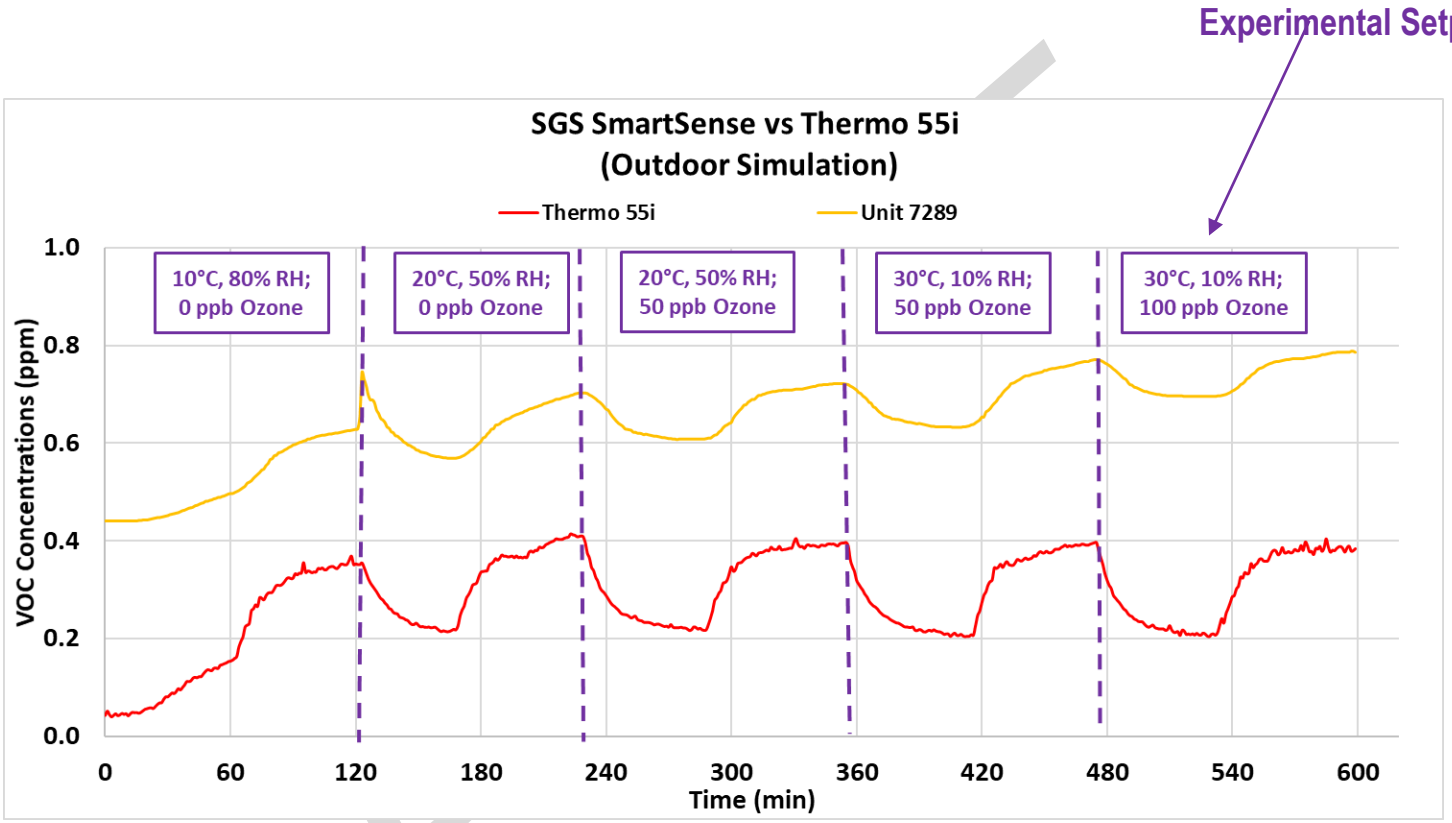
- CO_2 interferent test: sensors were subjected to increasing CO_2 concentration from background level to 8 ppm while holding VOC concentration constant at ~4 ppm.
- CO_2 had minimal effect on the VOC concentrations measured by the Thermo 55i and the SGS SmartSense sensor as CO_2 increased from background to ~8000 ppm.

Phase 5: Outdoor Simulation

Testing Phase #5	Method	Parameters Evaluated
Outdoor Simulation	• Various combination of Ozone (0 to 100 ppb) and VOC (200 to 400 ppb) concentrations, T (10 to 30 °C) and RH (10 to 80%)	• Accuracy, precision, IMV, Data Recovery, Analysis of Variance (ANOVA),

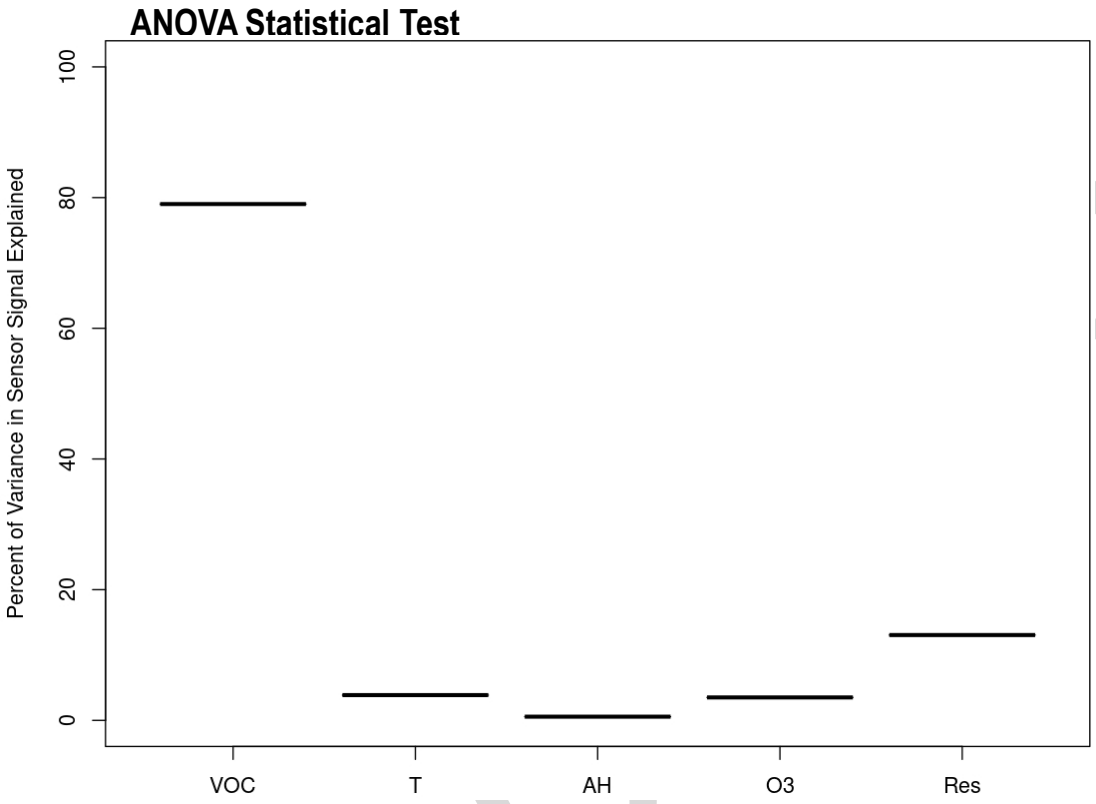
Note: Unit 6555 did not function properly after the Phase 1 and was not included in the rest of the tests. Unit 7206 did not function properly partway through Phase 3 and was not included in the rest of the tests.

Outdoor Simulation



- The SGS SmartSense sensor generally tracked well with the VOC concentration variation as recorded by Thermo 55i.

Outdoor Simulation



	Variance Explained by Explainable Variables, %				
	Ref	T	AH	Ozone	Res
Unit 7289	79.0	3.9	0.6	3.5	13.1

- VOC concentration as measured by the Thermo 55i explained ~ 79% of the SGS SmartSense VOC readings on average in the ANOVA statistical test.
- **Temperature, AH and Ozone** explained a small percentage (<4%) of the variance when T, AH and ozone are included in the ANOVA statistical test.

Notes:
"REF" is the Thermo 55i reference VOC monitor reading
"RES" is the residual, or variance that is not explained by the other variables

Phase 6:
Final Concentration Ramping

Testing Phase #6	Method	Parameters Evaluated
Final Concentration Ramping	• Low conc. ramping with VOC blend (0.06 to 1.6 ppm) • High conc. ramping with VOC blend (2 to 8 ppm) • Low conc. ramping with benzene-only (0.015 to 0.4 ppm) • High conc. ramping with benzene-only (0.5 to 2 ppm)	• Sensor Detection Limit, R^2, Accuracy, Precision, IMV, Data Recovery

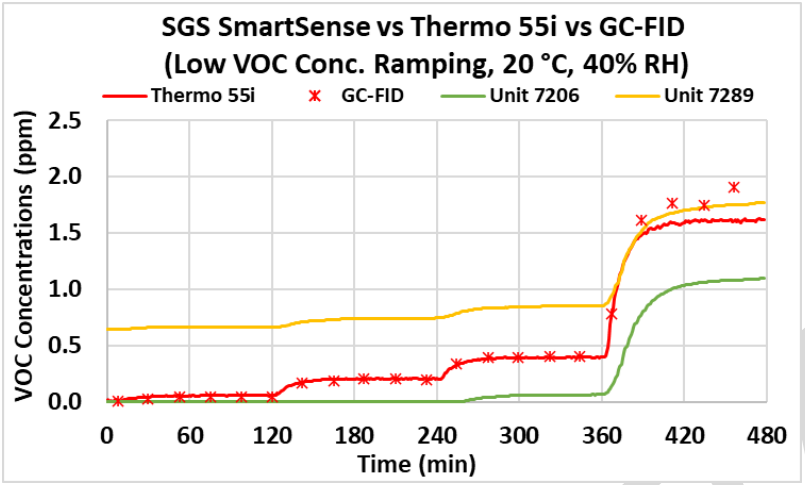
Note: Unit 6555 did not function properly after the Phase 1 and was not included in the rest of the tests. Unit 7206 did not function properly partway through Phase 3 and was not included in the rest of the tests.

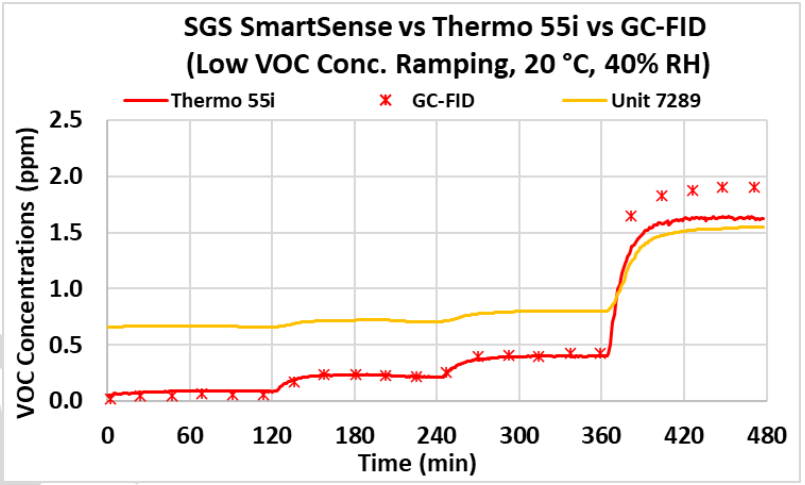
SGS SmartSense vs Thermo 55i vs GC-FID

Initial Ramp

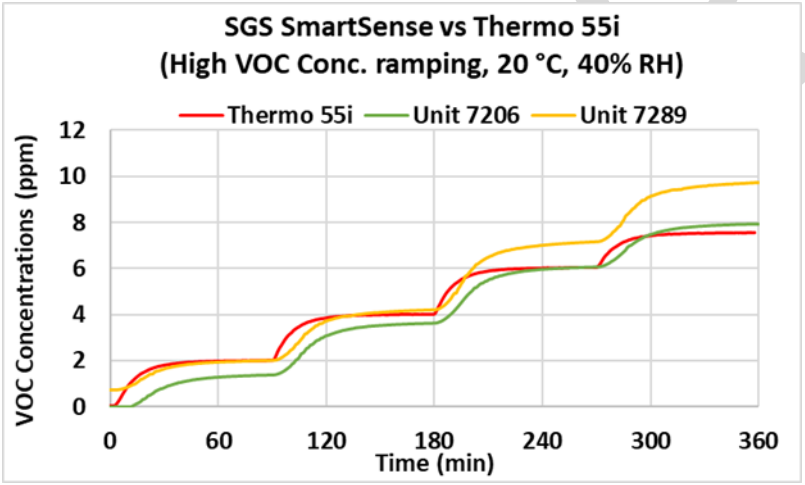
Final Ramp

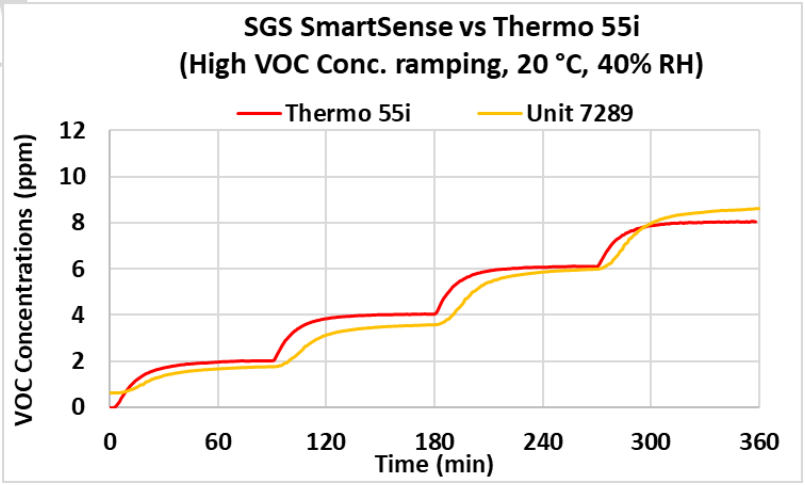
Low Ramp





High Ramp





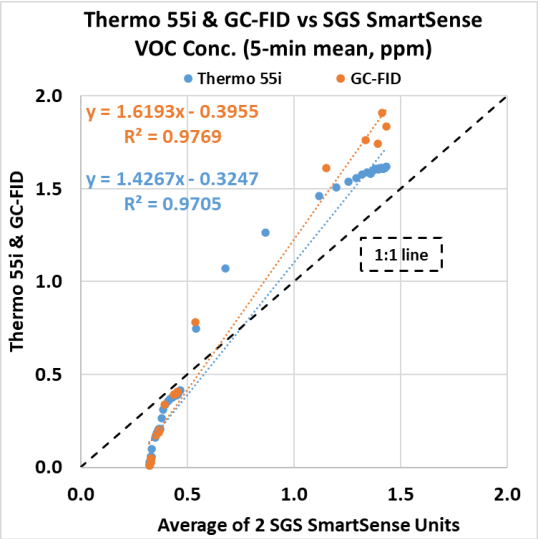
SGS SmartSense vs Thermo 55i vs GC-FID

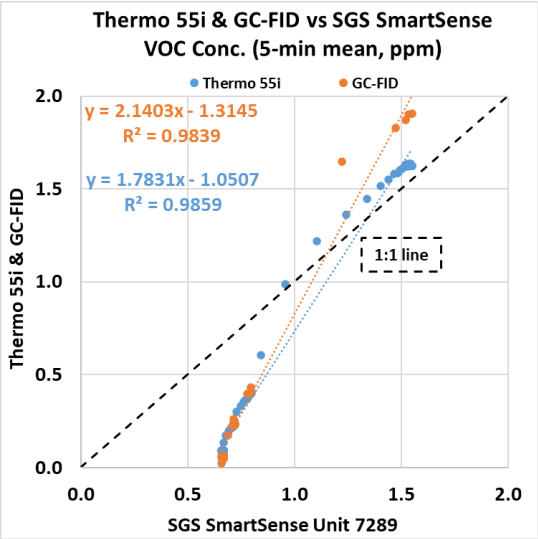
Initial Ramp

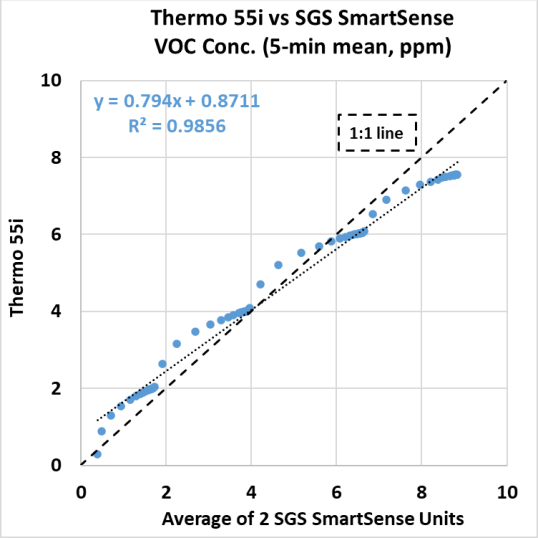
Final Ramp

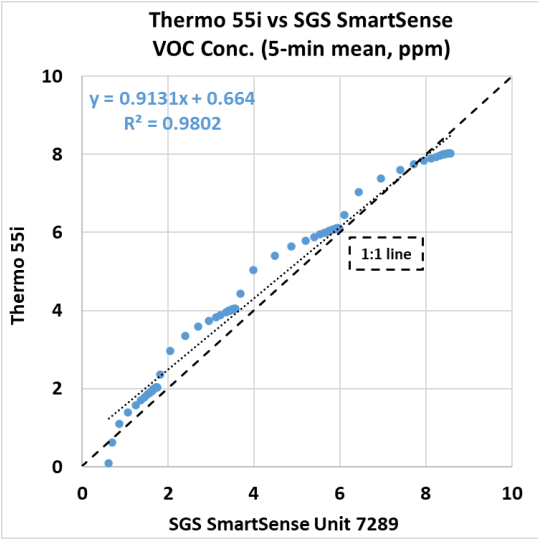
Low Ramp

High Ramp



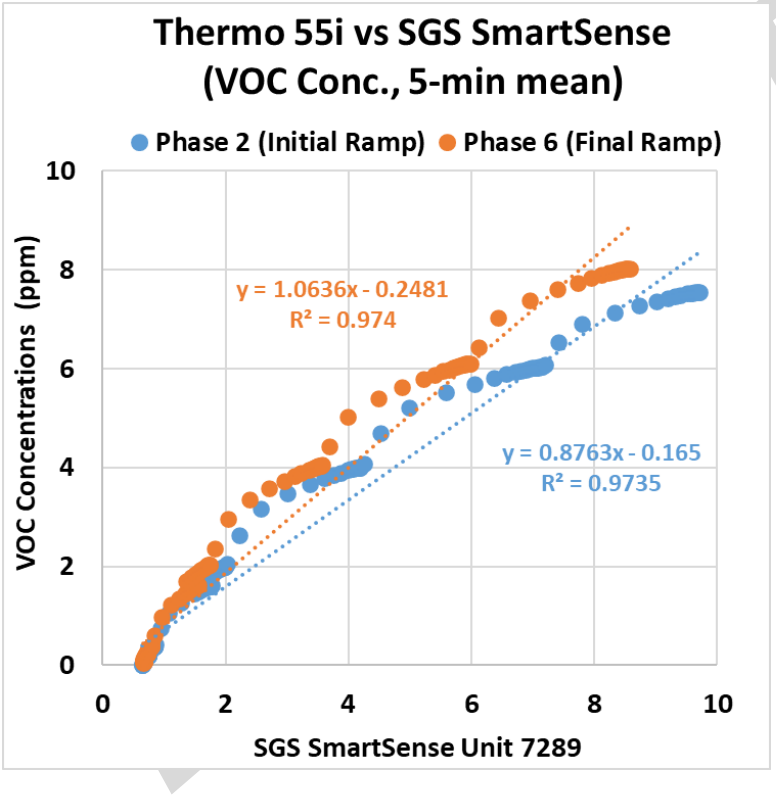






Short-Term Sensor Response Change

- Short-term sensor response change is characterized as the change in reference-sensor regression between the initial and final concentration ramping experiments



- Combining data from both low and high concentration ramps of the VOC blend, the slope of the final concentration ramping was higher, suggesting that the SGS SmartSense sensors on average became less sensitive to unit changes in VOC concentrations compared to the initial concentration ramping.

Summary Statistics

Initial Ramp (Units 7206 and 7289 only)

Sensors					Thermo 55i			GC-FID		
Nominal VOC Conc., ppm	Avg, ppm	Precision, %	IMV, %	SDL, ppm	Ref avg, ppm	Sensor Bias Error, ppm	Sensor Accuracy, %	Ref avg, ppm	Sensor Bias Error, ppm	Sensor Accuracy, %
0.06	0.33	100	200	Unit 7206: 0.14-0.50 Unit 7289: 0.07-0.24	0.06	0.27	-395.9	0.05	0.28	-510.5
0.2	0.37	99.9	200		0.20	0.17	18.5	0.20	0.17	13.7
0.4	0.45	99.9	173.1		0.39	0.06	84.8	0.41	0.05	88.5
1.6	1.43	99.9	47.3		1.61	-0.19	88.4	1.83	-0.40	78.1
2	1.68	99.8	36.6		1.99	-0.32	84.1			
4	3.90	99.9	14.2		4.01	-0.11	97.3			
6	6.59	99.9	16.0		6.04	0.55	90.9			
8	8.82	100	19.8		7.55	1.3	83.3			

Note: Unit 6555 did not function properly after the Phase 1 and was not included in these metrics.

Summary Statistics

Final Ramp (Unit 7289 only)

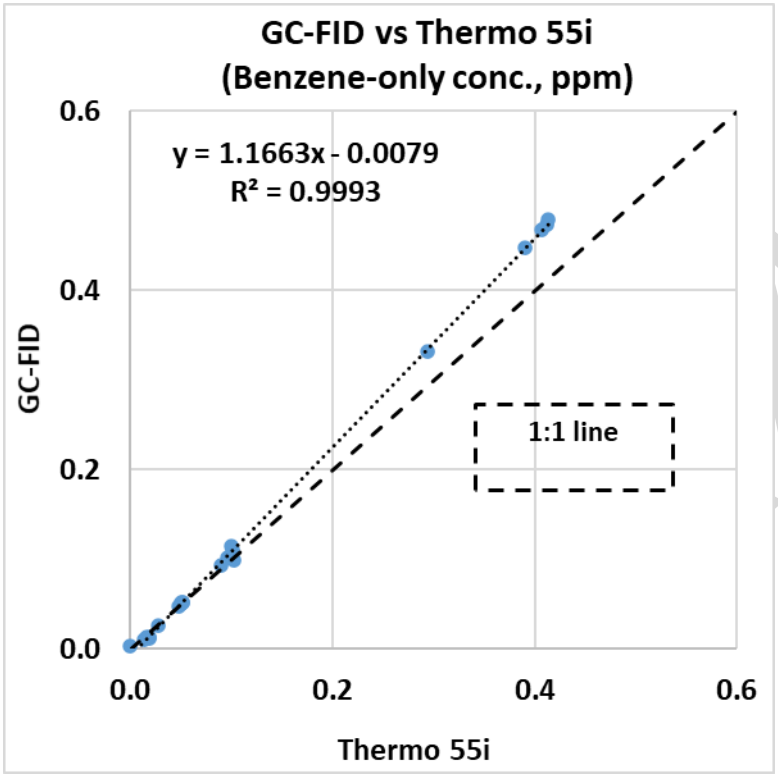
Sensors					Thermo 55i			GC-FID		
Nominal VOC Conc., ppm	Avg, ppm	Precision, %	IMV, %	SDL, ppm	Ref avg, ppm	Sensor Bias Error, ppm	Sensor Accuracy, %	Ref avg, ppm	Sensor Bias Error, ppm	Sensor Accuracy, %
0.06	0.66	100	N/A	Unit 7289: 0.09-0.31	0.09	0.57	-537.6	0.06	0.60	-572.7
0.2	0.71	100	N/A		0.22	0.49	-125.1	0.22	0.48	-117.3
0.4	0.80	100	N/A		0.40	0.40	0.8	0.43	0.37	15.0
1.6	1.55	100	N/A		1.63	-0.08	95.1	1.91	-0.36	81.2
2	1.73	99.8	N/A		2.03	-0.30	85.2			
4	3.54	99.9	N/A		4.04	-0.50	87.6			
6	5.94	99.9	N/A		6.11	-0.16	97.4			
8	8.56	99.9	N/A		8.03	0.53	93.4			

Note: Unit 6555 did not function properly after the Phase. Unit 7206 did not function properly partway through Phase 3. Both units were not included in these metrics.

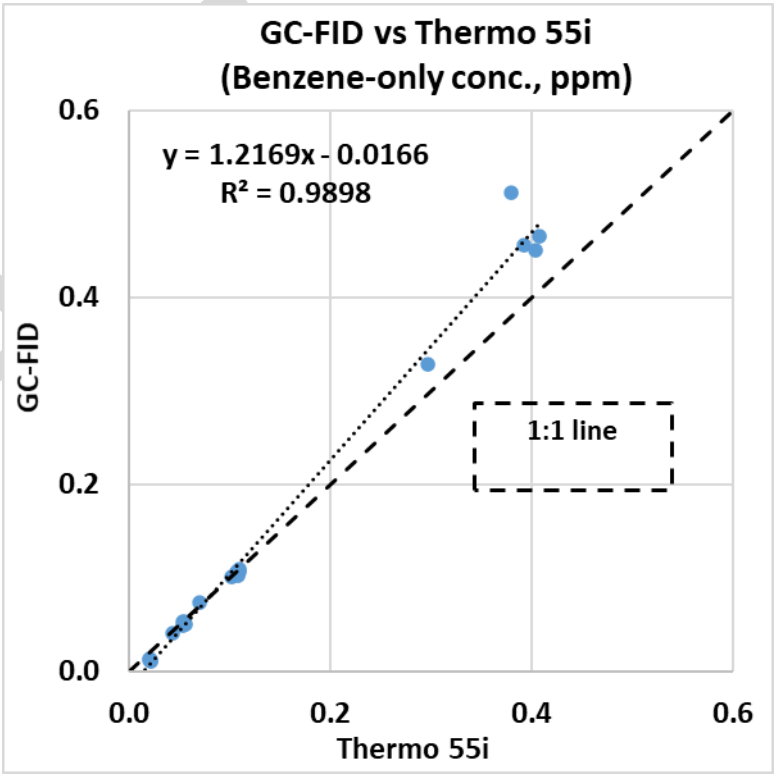
Benzene-Only Results

GC-FID vs Thermo 55i: Benzene-only

Beginning of Evaluation



End of Evaluation



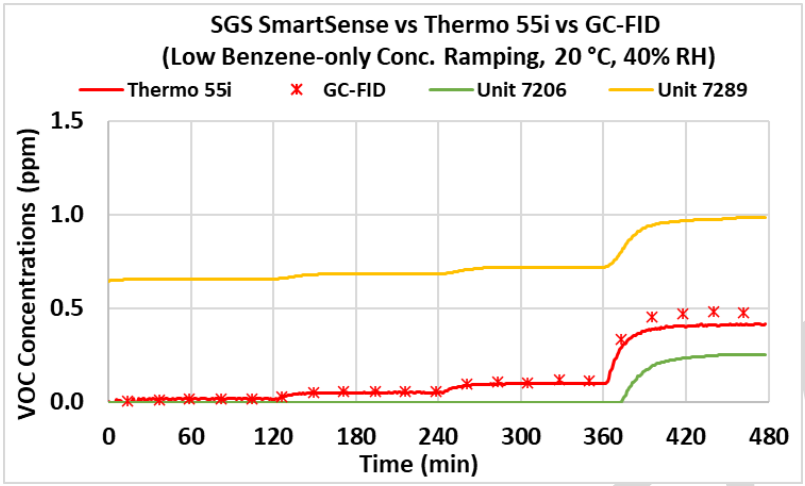
- Very strong correlations between the Thermo 55i and GC-FID (R^2 > 0.98).
- The two reference instruments reported similar VOC concentrations at both the beginning and the end of evaluation.

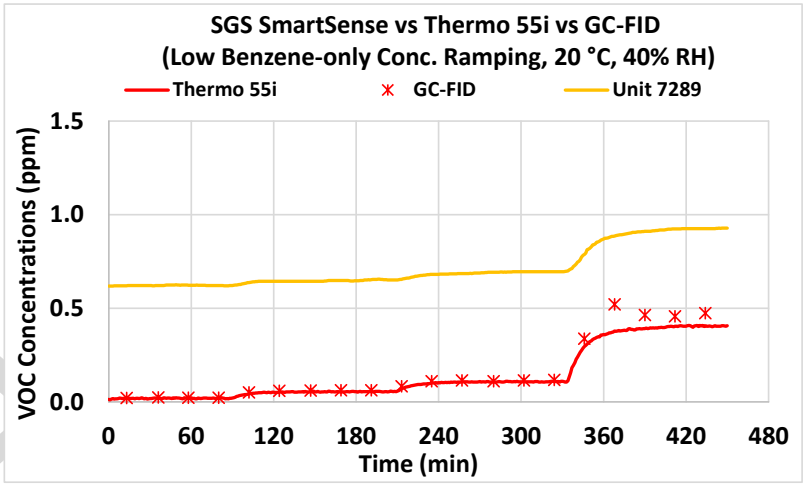
SGS SmartSense vs Thermo 55i vs GC-FID

Initial Ramp

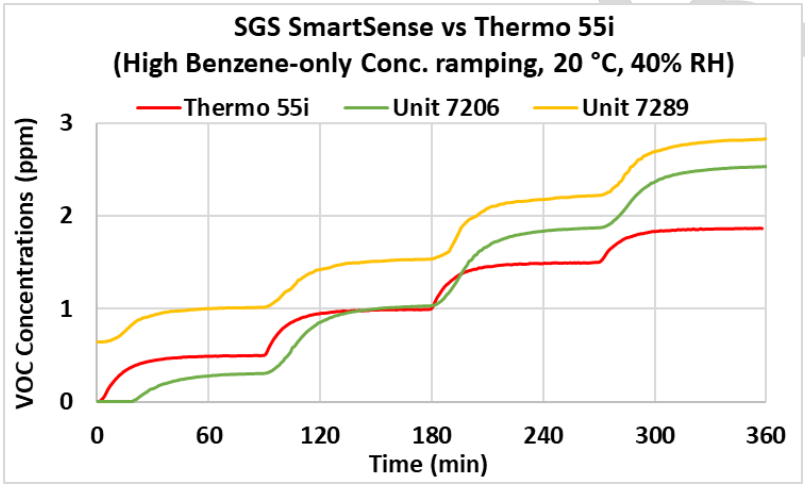
Final Ramp

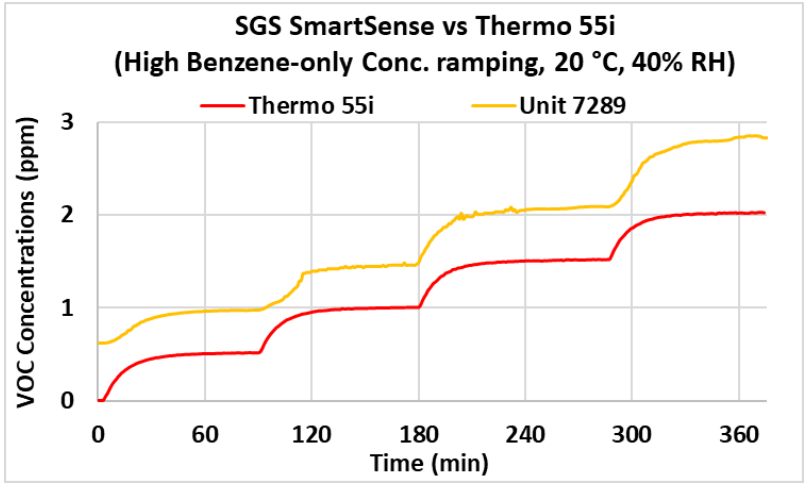
Low Ramp





High Ramp





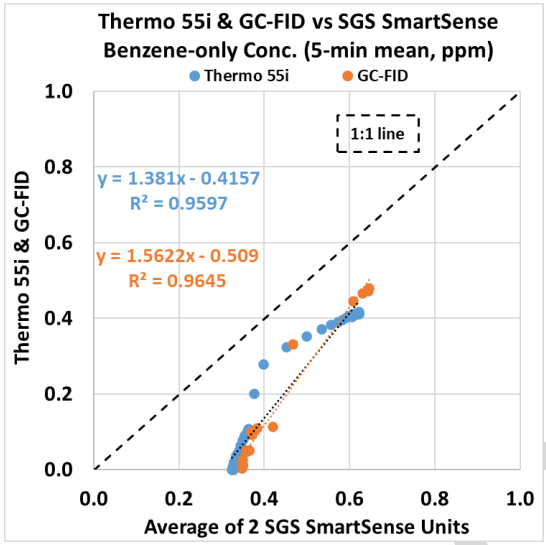
SGS SmartSense vs Thermo 55i vs GC-FID

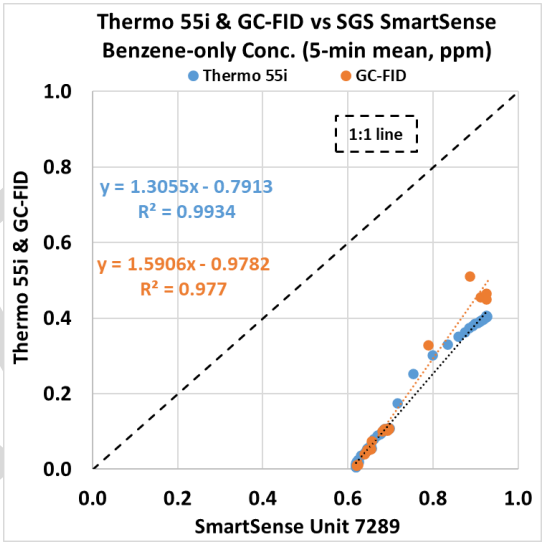
Initial Ramp

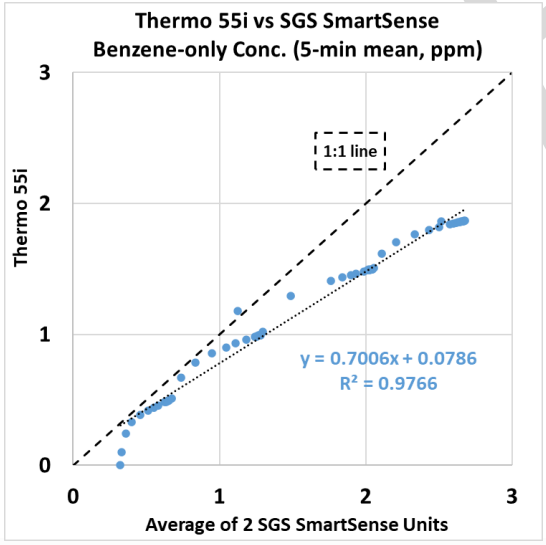
Final Ramp

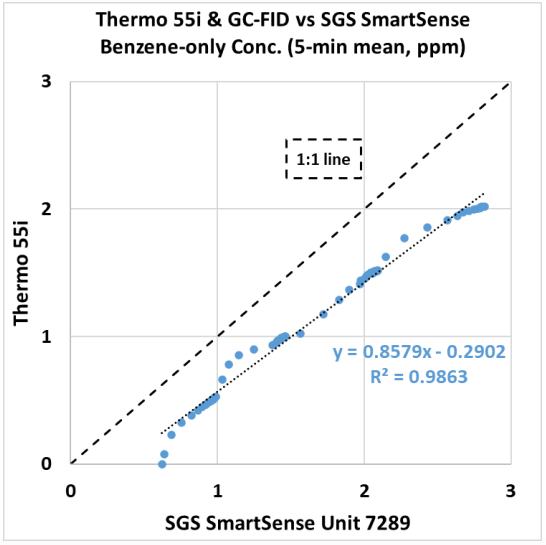
Low Ramp

High Ramp



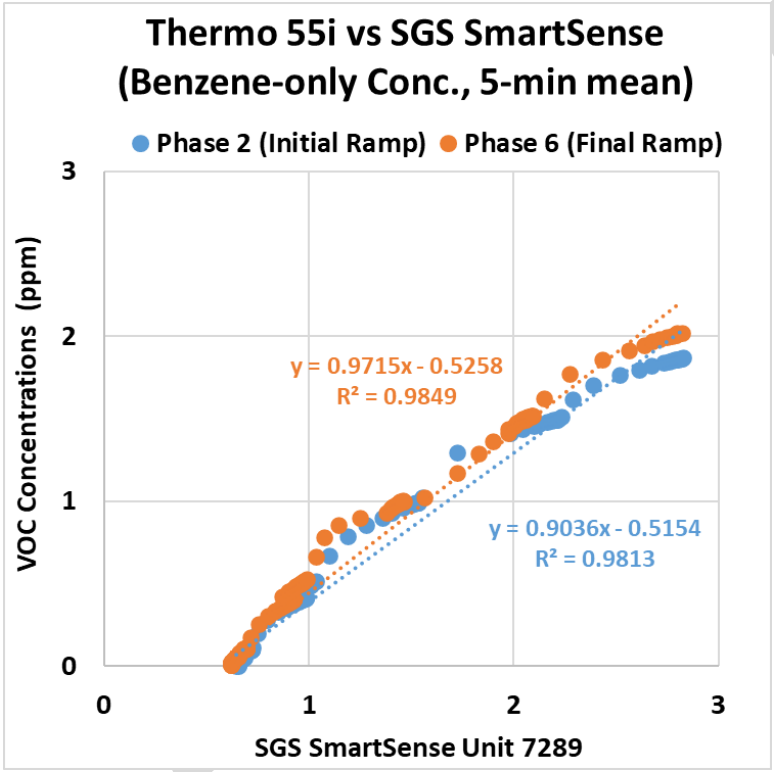






Short-Term Sensor Response Change: Benzene-only

- Short-term sensor response change is characterized as the change in reference-sensor regression between the initial and final concentration ramping experiments



- Combining data from both low and high concentration ramps of Benzene-only conc., the slope of the final concentration ramping was slightly higher, suggesting that the SGS SmartSense sensors on average became slightly less sensitive to unit changes in benzene-only concentrations compared to the initial concentration ramping, but the change was minimal.

Summary Statistics – Benzene-only

Initial Ramp (Units 7206 and 7289 only)

Sensors					Thermo 55i			GC-FID		
Nominal VOC Conc., ppm	Avg, ppm	Precision, %	IMV, %	SDL, ppm	Ref avg, ppm	Sensor Bias Error, ppm	Sensor Accuracy, %	Ref avg, ppm	Sensor Bias Error, ppm	Sensor Accuracy, %
0.015	0.33	100	200	Unit 7206: 0.08-0.27 Unit 7289: 0.03-0.09	0.02	0.31	-1647.6	0.01	0.31	-2388.7
0.05	0.34	100	200		0.05	0.29	-462.5	0.05	0.29	-457.8
0.1	0.36	100	200		0.10	0.26	-156.3	0.11	0.25	-124.7
0.4	0.62	100	117.6		0.41	0.21	49.9	0.47	0.15	68.9
0.5	0.62	99.9	109.6		0.49	0.12	75.4			
1	1.23	99.9	40.0		0.99	0.24	75.8			
1.5	2.03	99.9	17.3		1.50	0.54	64.1			
2	2.66	100	11.2		1.87	0.80	57.3			

Note: Unit 6555 did not function properly after the Phase 1 and was not included in these metrics.

Summary Statistics – Benzene-only

Final Ramp (Unit 7289 only)

Sensors					Thermo 55i			GC-FID		
Nominal VOC Conc., ppm	Avg, ppm	Precision, %	IMV, %	SDL, ppm	Ref avg, ppm	Sensor Bias Error, ppm	Sensor Accuracy, %	Ref avg, ppm	Sensor Bias Error, ppm	Sensor Accuracy, %
0.015	0.62	100	N/A	Unit 7289: 0.03-0.09	0.02	0.60	-2900.2	0.01	0.60	-2942.7
0.05	0.65	99.9	N/A		0.06	0.60	-976.2	0.05	0.60	-1021.3
0.1	0.70	100	N/A		0.11	0.59	-442.2	0.11	0.59	-438.0
0.4	0.93	100	N/A		0.41	0.52	-28.4	0.47	0.46	1.4
0.5	0.97	100	N/A		0.51	0.46	9.6			
1	1.46	99.9	N/A		1.00	0.46	53.9			
1.5	2.09	99.9	N/A		1.52	0.57	62.3			
2	2.84	99.9	N/A		2.02	0.82	59.6			

Note: Unit 6555 did not function properly after the Phase. Unit 7206 did not function properly partway through Phase 3. Both units were not included in these metrics.

Discussion

- **Data Recovery:** The SGS SmartSense sensor that functioned through all test phases (Unit 7289) showed 91% data recovery across the entire evaluation. Note that Unit 6555 was not functioning properly after Phase 1 testing and Unit 7206 was not functioning partway through Phase 3 testing.
- **Intra-model variability (IMV):** Moderate to high variability was observed among the SGS SmartSense sensors during Phase 2 testing.
- **Sensor Detection Limit (SDL):** The SDL of the SGS SmartSense sensors ranged from 0.07 to 0.50 ppm in the initial VOC ramp; the SDL of the sensors ranged from 0.03 to 0.27 ppm in the initial Benzene-only ramps.
- **Phase 1: Transient Plume Detection (3 units functioning)**
  - The SGS SmartSense sensors showed 100% plume detection recovery and detected the peaks about 10 minutes later than the Thermo 55i.
- **Phase 2**: **Initial Concentration Ramping (2 units functioning)**
  - ***Coefficient of Determination – VOC Blend*:** The SGS SmartSense sensors showed very strong correlations with the reference instruments for both low and high concentration ramps ($R^2 > 0.97$)
  - ***Coefficient of Determination – Benzene-only***: The SGS SmartSense sensors showed very strong correlations with the reference instruments for both low and high concentration ramps ($R^2 > 0.95$)

Discussion

- **Phase 3: Effect of Temperature and RH**
  - ***Extreme Conditions (2 units functioning):*** The SGS SmartSense sensors showed a decrease in mean VOC concentrations as T/RH increased from 5°C/20% RH to 20°C/40% RH, and then decreased further in mean VOC concentrations as temperature/RH was further increased to 35°C/80% RH.
  - ***RH Interference at Constant Temperature (2 units functioning) :*** In this particular test, the SGS SmartSense sensors generally showed a decrease of ~ 12-13% in VOC concentration as RH increased from 25% to 80% while temperature was maintained at 20°C.
  - ***Temperature Interference at Constant Relative Humidity (1 unit functioning):*** In this particular test, the SGS SmartSense sensors generally showed a VOC response moving in the opposite direction, i.e. the sensors' VOC reading increases when temperature decreases and vice versa, after steady-state temperature and RH conditions are realized. The average change of VOC concentrations between the initial and final 20°C/40% RH conditions was ~12%.
  - ***Temperature Interference at Constant Absolute Humidity (1 unit functioning):*** In this particular test, the SGS SmartSense sensors generally showed a VOC response moving in the same direction of temperature change. The average change of VOC concentrations between the initial and final 20°C with constant AH conditions was ~7.1%.

Discussion

- **Phase 4: Effects of Gaseous Interferents (1 unit functioning)**
  - **Ozone**
    - ***Responses to Ozone:*** The SGS SmartSense sensors VOC readings generally remained constant as ozone concentration increased from background value to ~ 400 ppb.
  - **CO**
    - ***Responses to CO:*** The SGS SmartSense sensors VOC readings generally remained constant as CO increased from background value to ~8 ppm.
  - **CO_2**
    - ***Responses to CO_2:*** The SGS SmartSense sensors VOC readings generally remained constant as CO_2 increased from background value to ~8,000 ppm.

- **Phase 5: Outdoor Simulation (1 unit functioning)**
  - The sensor's VOC values tracked well with the Thermo 55i VOC values when exposed to a combination of T, RH, ozone and VOC concentrations.
  - Overall, **VOC concentration** as measured by the Thermo 55i explained ~ 79% of the SGS SmartSense VOC readings in the ANOVA statistical test.
  - **Temperature, AH and Ozone** explained a small percentage (~8% combined) of the variance when T, AH and ozone are included in the ANOVA statistical test.

Discussion

- **Phase 6**: **Final Concentration Ramping (1 unit functioning)**
  - ***Coefficient of Determination – VOC Blend***: The SGS SmartSense sensors showed very strong correlations with the reference VOC monitor data in both the low and high concentration ramp experiments ($R^2 > 0.98$)
  - ***Coefficient of Determination – Benzene-only***: The SGS SmartSense sensors showed very strong correlations with the corresponding reference low benzene-only ramping data ($R^2 > 0.96$)
  - ***Short-term Sensor Response Change:*** In general, the slope of the final concentration ramping was higher, suggesting that the SGS SmartSense sensors on average became less sensitive to unit changes in VOC and benzene-only concentrations compared to the initial concentration ramping, nut the change was minimal.