South Coast AQMD

AQ-SPEC

Air Quality Sensor Performance Evaluation Center

Air Sensors International Conference 2022

Session 4C: Indoor Sensing for Air Quality Control and Ventilation Applications

Development of ASTM Standard Test Methods for $PM_{2.5}$ and CO_2 Sensors Used for Indoor Air Quality Measurements

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Indoor Air Quality

- We spend ~90% of our time indoors
- Pollutants of recent pandemic-related concern for indoor air quality (droplets, aerosols, building crowdedness)
- $PM_{2.5}$
  - No indoor air quality standards for $PM_{2.5}$
  - Occupational standards only exist for PM_4
  - Indoor sources: improperly vented indoor combustion sources, dust resuspension, construction/fabrication activities, particle-producing activities near building air intake
- CO_2
  - ASHRAE recommends limits of 800 ppm for offices and 1,000 ppm in schools
  - Occupational standard of 5,000 ppm for workday average and 30,000 ppm for short-term exposure
  - Indoor sources: people breathing, improperly vented indoor combustion sources, combustion activities near building air intake

$PM_{2.5}$ and CO_2 Sensors

- $PM_{2.5}$ sensors use light-scattering technique
- CO_2 sensors mostly use nondispersive infrared absorption technique
- Well-suited for consumer, building, and vehicle applications
  - Low cost (~$100-1,000 USD range)
  - Low power
  - Low noise
  - Compact form factory
  - High time resolution
  - Range of aesthetic choices and interfaces
  - Some are smart-home / demand-control ventilation integrable
- Can provide feedback for indoor space ventilation or filtration actions (demand-controlled ventilation)
- Data quality can be a challenge
- Appropriate and widespread adoption of technologies into consumer and HVAC applications requires independent verification of sensor performance

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Generalized Standard Test Method Process

	Phase 1: Initial Concentration Ramp	Phase 2: Effect of T and RH	Phase 3: Interferent Testing	Phase 4: Temperature Cycling	Phase 5: Final Concentration Ramp
Purpose	Assess accuracy and correlation at constant climate with fresh sensors	Assess impact of indoor climates on accuracy	Assess impact of potential interfering pollutants on accuracy	Simulate accelerated non-specific aging of sensor	Assess *changes* in accuracy and correlation at constant climate with used sensors
For $PM_{2.5}$ Sensors:	•6 concentrations, 0-300 µg/m^3 •Response to power loss •Inorganic and organic particle type tested	•3 temperatures, 20-50°C •3 RH conditions, 40-80% •2 concentrations, 10-50 µg/m^3 •12 combinations required (plus 6 optional combinations)	•Use of Arizona Test Dust as interfering coarse PM •4 coarse PM concentration conditions, 10-150 µg/m^3	•Simulates a year's worth of cyclical environmental stress •143 temperature cycles from 10°C to 50°C, and back	•Repeat of Phase 1 •Minimum of 15 days must have elapsed since Phase 1 •Only inorganic particle type
For CO_2 Sensors:	•5 conc., 450-5000 ppm •Response to power loss	•3 temperatures, 20-50°C •3 RH conditions, 40-80% •2 conc., 1000-5000 ppm •12 combinations required (plus 6 optional combinations)	•Use of moisture as interferent species •5 RH conditions, 20-80%	•Simulates a year's worth of cyclical environmental stress •143 temperature cycles from 10°C to 50°C, and back	•Repeat of Phase 1 •Minimum of 15 days must have elapsed since Phase 1

Phase 1: Initial Concentration Ramp → Phase 2: Effect of T and RH → Phase 3: Interferent Testing → Phase 4: Temperature Cycling → Phase 5: Final Concentration Ramp

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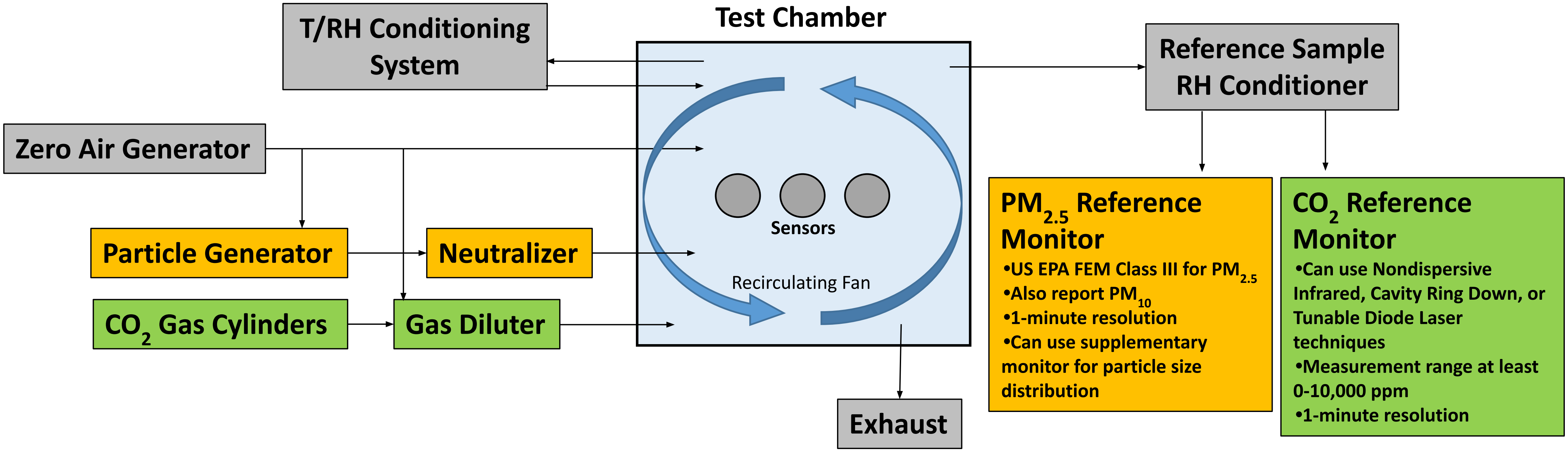
Testing Equipment Requirements

Specific to $PM_{2.5}$ sensors | Specific to CO_2 sensors



Phase 1: Initial Concentration Ramp → Phase 2: Effect of T and RH → Phase 3: Interferent Testing → Phase 4: Temperature Cycling → Phase 5: Final Concentration Ramp

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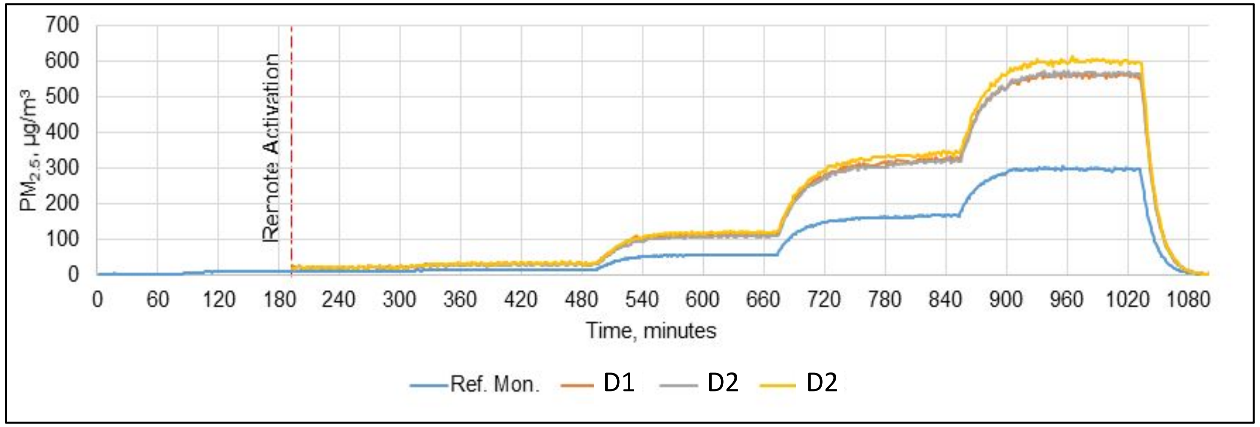
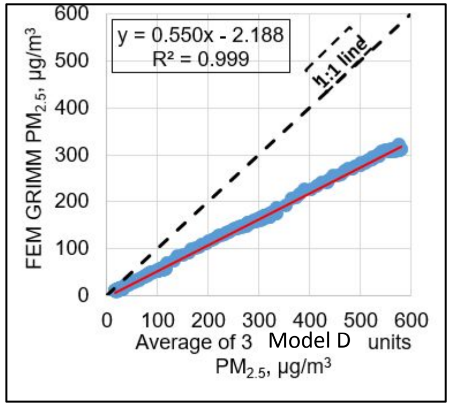
Phase 1 – Initial Concentration Ramp

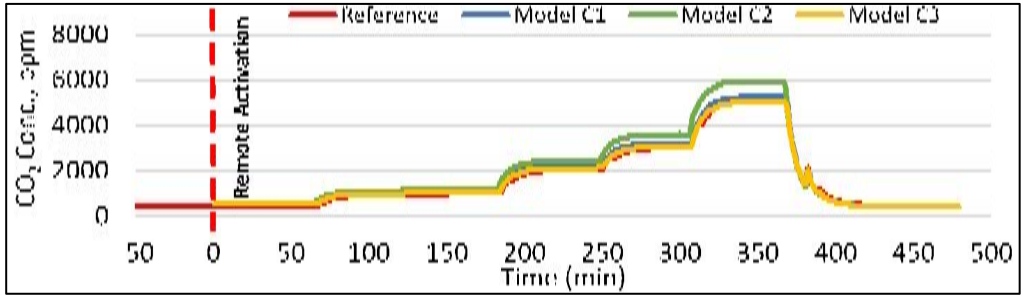
Level	Target $PM_{2.5}$ ($\mu g/m^3$)	Target CO_2 (ppm)
LOD	~0	--
Very Low	10	450
Low	15	1000
Medium	50	2000
High	150	3000
Very High	300	5000

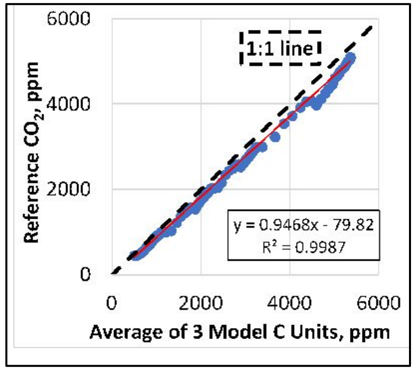




Conducted at constant 20℃ and 40% RH

- $PM_{2.5}$ substance: inorganic (NaCl) and organic (polystyrene latex) particles
- CO_2 substance: compressed CO_2 gas from ISO 17034 supplier





Phase 1: Initial Concentration Ramp | Phase 2: Effect of T and RH | Phase 3: Interferent Testing | Phase 4: Temperature Cycling | Phase 5: Final Concentration Ramp

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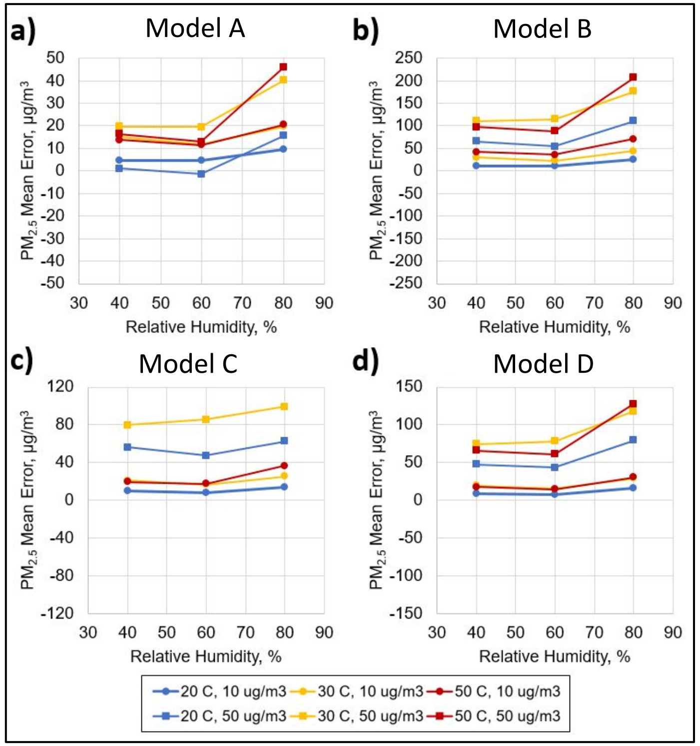
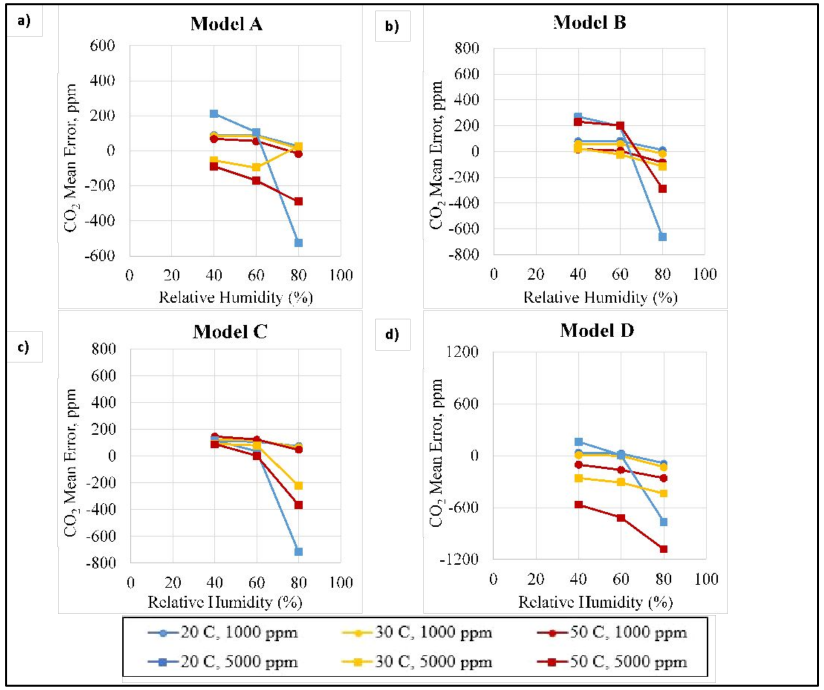
Phase 2 – Effect of T and RH

	Medium RH	High RH	Very High RH
Medium T	20°C 40%	20°C 60%	20°C 80%
High T	30°C 40%	30°C 60%	30°C 80%
Optional Cooking Environment T	50°C 40%	50°C 60%	50°C 80%

Conducted at two constant pollutant concentrations:

- 10 and 50 µg/m^3 NaCl for $PM_{2.5}$ sensors
- 1000 and 5000 ppm CO_2 for CO_2 sensors





Phase 1: Initial Concentration Ramp → **Phase 2: Effect of T and RH** → Phase 3: Interferent Testing → Phase 4: Temperature Cycling → Phase 5: Final Concentration Ramp

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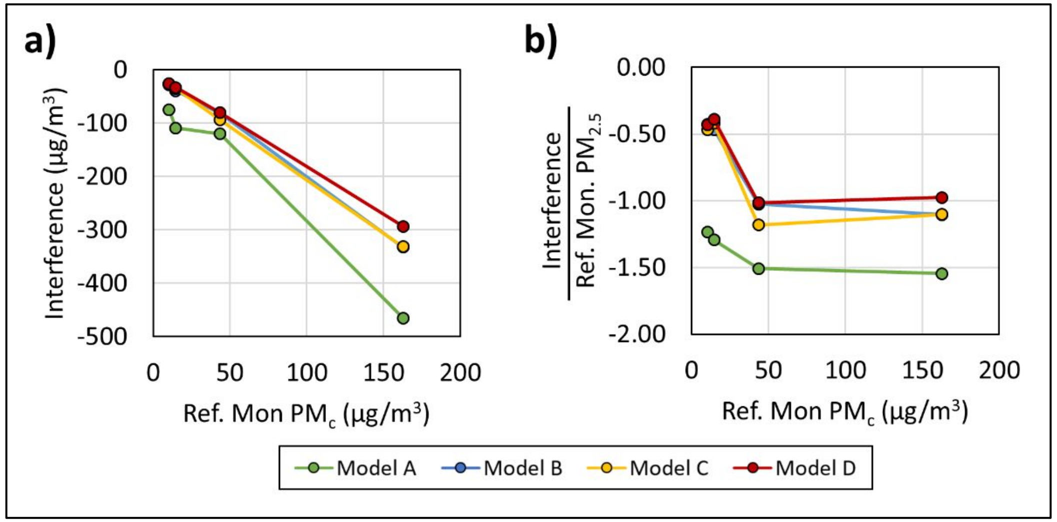
Phase 3 – Interferent Testing

Aspect	$PM_{2.5}$	CO_2
Conditions	20℃ and 40% RH	20℃ and 1000 ppm CO_2
Interferent	Coarse PM (between 2.5 and 10 µm)	Water
Interferent Reagent	ISO 12103-1 Grade A4 Coarse Arizona Test Dust	Water
Interferent Concentrations	10, 15, 50, 150 µg/m³	20, 40, 60, 75, 80% RH



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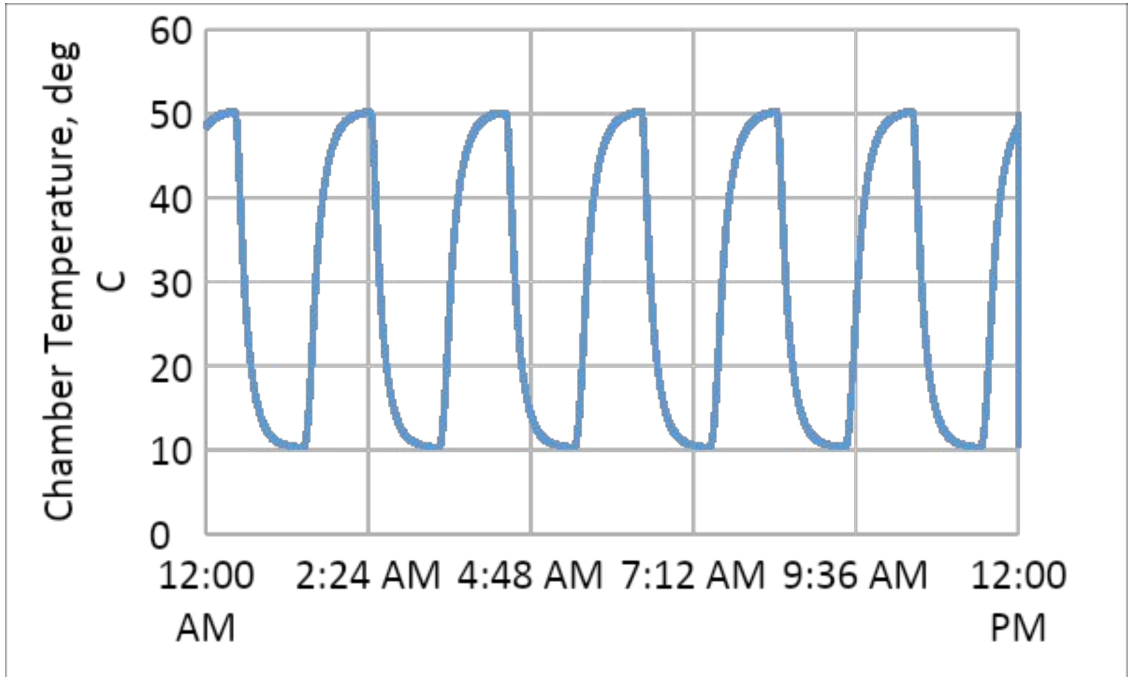
Phase 4 – Temperature Cycling

For both $PM_{2.5}$ and CO_2 sensors:

- Alternate T between 10℃ and 50℃ for 143 cycles
- Simulates 1 year's worth of non-specific aging
- No sensor data collected or analyzed from this phase
- Based on Coffin-Manson fatigue model

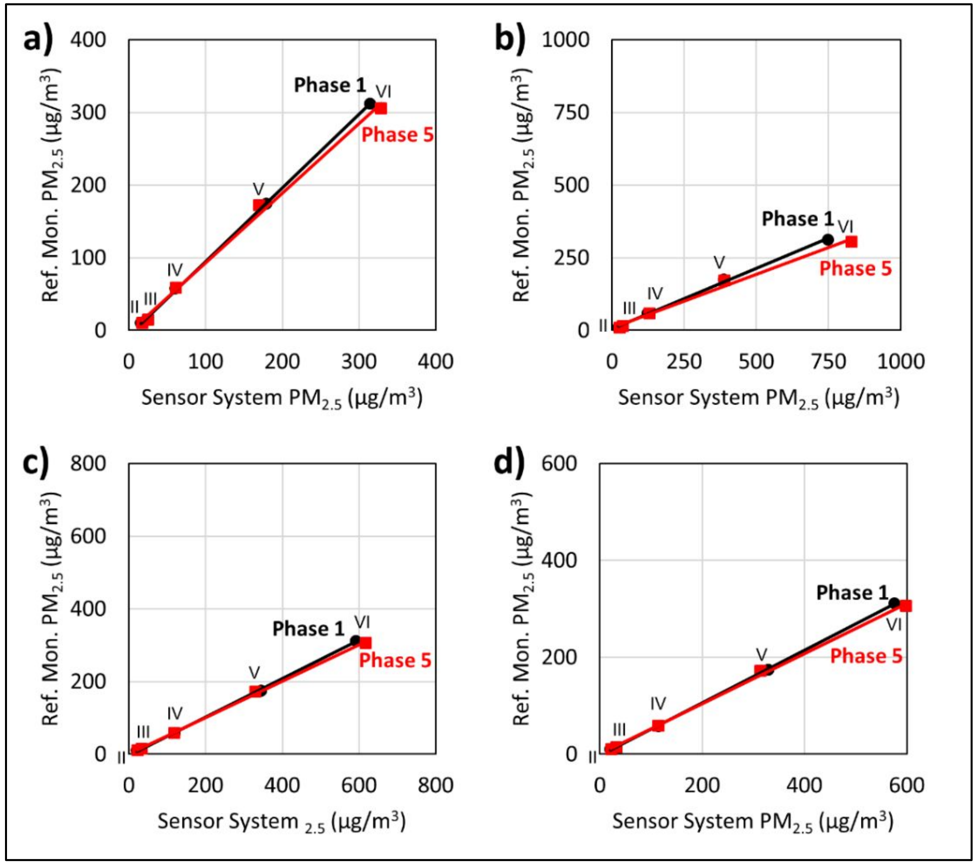
$$N_{\text{test}} = \frac{N_{\text{field}}}{\left(\frac{\Delta T_{\text{test}}}{\Delta T_{\text{field}}}\right)^{c}}$$



Phase 5 – Final Concentration Ramp

For both $PM_{2.5}$ and CO_2 sensors:

- Repeat Phase 1 to assess change in sensor response after being subjected to past series of tests
- Minimum of 15 days must pass between Phase 1 and this final test
- Looks for differences in sensor performance after subjected to series of exposure to climatic and interferent challenges, as well as accelerated non-specific aging



Phase 1: Initial Concentration Ramp → Phase 2: Effect of T and RH → Phase 3: Interferent Testing → Phase 4: Temperature Cycling → Phase 5: Final Concentration Ramp

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Conclusions

- Demand-controlled ventilation going to be more popular
  - More awareness and concern of indoor air quality
  - Energy-efficient building and home operations
  - Growing share of residential use of smart devices
  - New era of building crowdedness monitoring and disease transmission prevention
- $PM_{2.5}$ and CO_2 are important markers of indoor air quality, and sensor technology for these two pollutants is relatively mature and reliable compared to those for other pollutants
- These sensors are expected to be integrated into more buildings, HVAC systems, and automobiles
- Need rigorous, comprehensive, and traceable standard test methods to evaluate sensor performance
- ASTM $PM_{2.5}$ and CO_2 standard test methods serve this purpose

Test Standard Statuses

- $PM_{2.5}$
  - Test standard published in October 2021
    - D8405: "Standard Test Method for Evaluating $PM_{2.5}$ Sensors or Sensor Systems Used in Indoor Air Applications"
  - Participants requested for interlaboratory study
  - AQ-SPEC has proven ability to execute D8405 and can offer testing service under this test standard
  - Home Ventilating Institute (HVI) developing certification under this test standard
- CO_2
  - Laboratory testing and method development activities concluded
  - Test standard undergoing review, comment, and revision activities at ASTM subcommittee level

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