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Low-cost sensors for indoor air quality: performance assessment in laboratory conditions

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1 Introduction

The availability of low-cost sensors for real-time measurement of indoor air quality (IAQ) is increasing over the years for the general population. If their functionalities are very promising, there is still a need to evaluate their metrological performances. This can be achieved in the field by collocating the sensors with reference instruments. Laboratory experiments offer the opportunity to assess the steady-state response of sensors in a controlled environment.

2 Materials/Methods

The study aims to perform both laboratory and field assessments of five different commercial IAQ monitors that include the measurement of CO_2 (carbon dioxide), TVOC (total volatile organic compounds) and PM (particulate matter). This paper presents the laboratory experiments. A 50-L glass chamber was used to conduct the experiments with a continuous airflow rate of filtered and humidified air. All the monitors were placed inside the chamber with additional small fans to homogenize the volume. The following reference instruments were also placed inside the chamber and used to compare the measurements: a photoionization detector for TVOC (ppbRAE), an optical particle counter (OPC) 1.108 Grimm Dust Monitor, and a Q-track (TSI) probe with NDIR sensor for CO_2. PM was generated both by incense burning and nebulization of saline aqueous solutions in a connected chamber. VOC and CO_2 were generated respectively by an isobutylene and a CO_2 reference gas cylinder. Different levels of concentrations were generated in the chamber. The steady-state response of each sensor over a minimum of 30 min was compared to the reference value. Reproducibility was also evaluated between duplicates of each sensor brand.

3 Results and Discussion

The empty chamber was devoid of both $PM_{2.5}$ and PM_{10} particles as assessed by the OPC for 8 hours. Apart for two sensors, the others showed a background concentration from 5 to 19 $\mu g/m^3$. CO_2 concentration was lower than atmospheric concentration, i.e. 263 ppm on average as assessed by the NDIR Q-Track probe. This was caused by the fact that the filtered air passes through a bubbler to humidify it trapping some CO_2 in the process. The bubbling process did not increase the relative humidity which was around 31%. The sensors have an inherent lower concentration limit of 450 ppm. However, except one sensor that also uses NDIR technology, all the others displayed unexpectedly high CO_2 equivalent concentrations between 1300 and 4000 ppm on average in the empty chamber. The same holds true for TVOC with unexpected high levels displayed by the sensors between 840 and 1100 ppb whereas the PID showed 107 ppb an average. A strong correlation was observed

between TVOC and CO_2 equivalent concentrations with the same slope for all MOS sensors (Fig. 1).

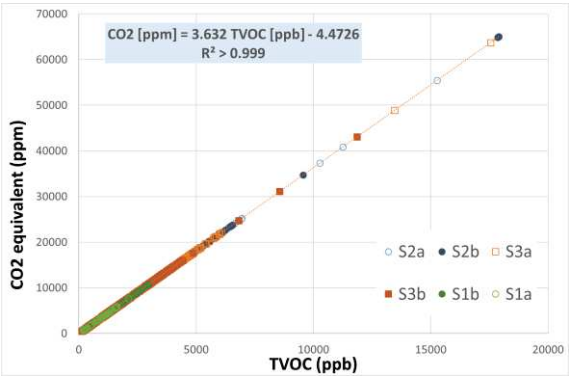

Figure 1. TVOC and CO_2 equivalent correlation.

When CO_2 was generated in the chamber at 640, 1000 and 1400 ppm, all sensors not using NDIR did overestimate the concentrations with slopes lower than 1 (Fig. 2).

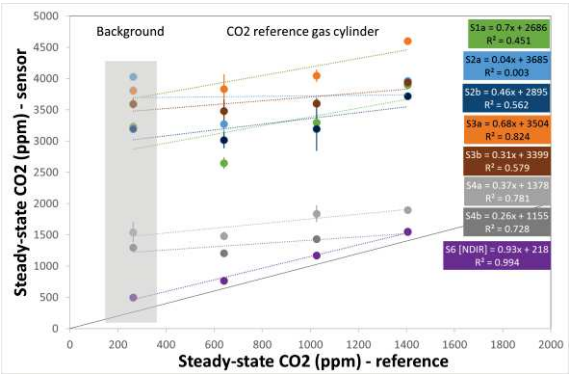

Figure 2. Steady-state sensor response to CO_2 reference gas.

The same kind of sensor response was observed with isobutylene generated concentrations from 500 to 1800 ppb (Fig. 3) with overestimated concentrations and slopes around 0.5.

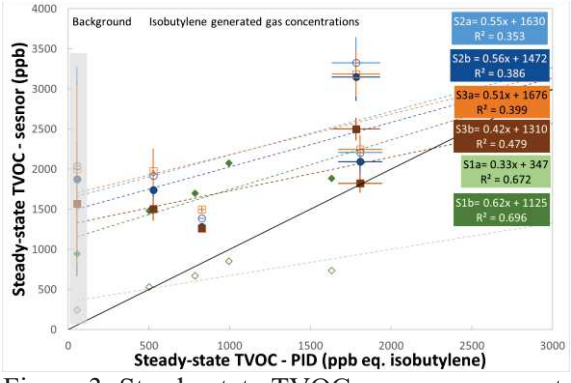

Figure 3. Steady-state TVOC sensor response to isobutylene reference gas. Sensors S4 and S6 were not equipped with TVOC detectors.

However, during incense burning experiments, TVOC concentrations up to 3000 ppb were achieved on the PID while the sensors displayed much higher values up to 18000 ppb. In that case, the slope of response was between 2.2 (S3b) and 4.5 (S2). The response of sensors changed according to the type of VOC mixture.

During incense burning, the generated PM concentration was too high and above the sensor specifications. A second set of experiments was conducted with the nebulization of various saline aqueous solutions to produce $PM_{2.5}$ concentration from 0.5 to 150 µg/m^3. A good correlation was observed for three sensors with $R^2 > 0.95$. Slopes were between 0.7 (S3) and 1.2 (S2). One sensor could not be directly compared to $PM_{2.5}$ reference concentration as it only displayed particle number (PN) concentration in Mpart/m^3. But a good correlation was observed. The performance of S1 sensor was poor for $PM_{2.5}$ measurements.

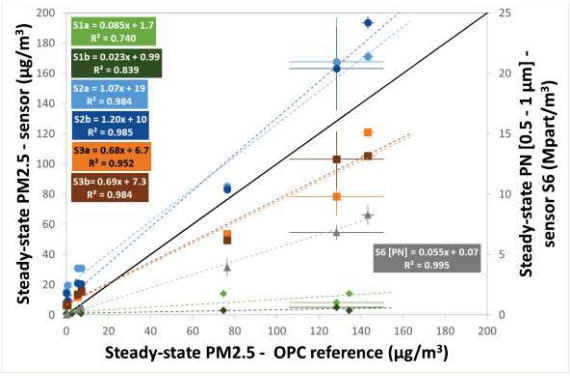

Figure 4. Steady-state sensor response to $PM_{2.5}$ generated from nebulization of salt solutions.

4 Conclusions

The performance varied between sensors and depended both on the target pollutants and the nature of the emission. A strong correlation was observed between CO_2 and TVOC measurements for the monitors without NDIR sensors. TVOC measurements displayed abnormally high concentrations during all the experiments, caused by unidentified interferences. The performance of monitors based on NDIR sensors was satisfactory for CO_2. For PM, all but one monitor displayed satisfactory correlations with the reference OPC with either over- or underestimation.

5 Acknowledgement

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