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ACCURACY OF CO_2 SENSORS

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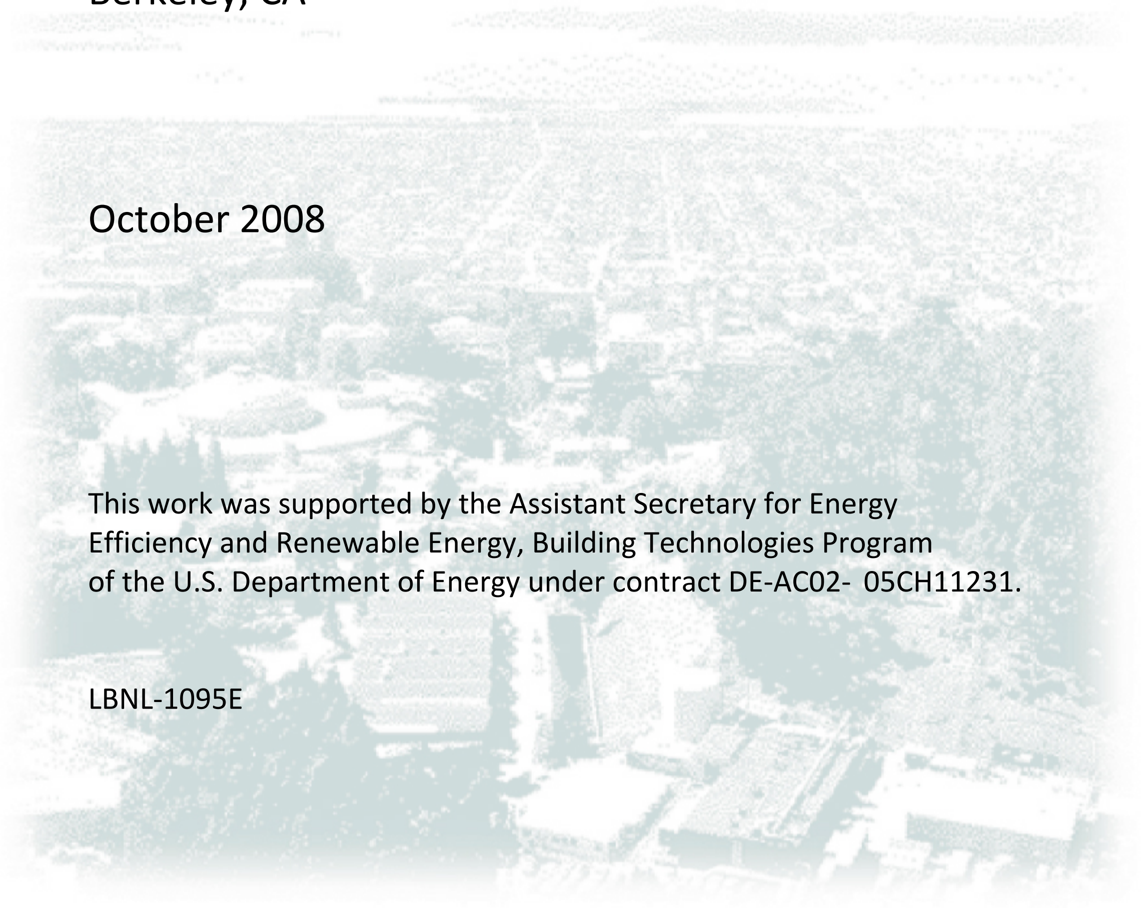

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Are the carbon dioxide (CO_2) sensors in your demand controlled ventilation systems sufficiently accurate? The data from these sensors are used to automatically modulate minimum rates of outdoor air ventilation. The goal is to keep ventilation rates at or above design requirements while adjusting the ventilation rate with changes in occupancy in order to save energy. Studies of energy savings from demand controlled ventilation and of the relationship of indoor CO_2 concentrations with health and work performance provide a strong rationale for use of indoor CO_2 data to control minimum ventilation rates[1-7]. However, this strategy will only be effective if, in practice, the CO_2 sensors have a reasonable accuracy. The objective of this study was; therefore, to determine if CO_2 sensor performance, in practice, is generally acceptable or problematic. This article provides a summary of study methods and findings – additional details are available in a paper in the proceedings of the ASHRAE IAQ'2007 Conference[8].

METHODS

Two different protocols were employed to assess the accuracy of 44 CO_2 sensors located in nine buildings within California. When possible, we used bags of CO_2 calibration gases to evaluate sensor performance at five CO_2 concentrations from 236 to 1180 parts per million (ppm). The data obtained were processed to obtain an offset error and slope or sensor gain error using a least-squares linear regression of measured CO_2 concentration verses "true" CO_2 concentration. If a sensor agreed exactly with the "true" concentration, then the offset error would be zero and the slope equal unity. This type of performance test was completed for 18 sensors from six buildings.

When a multi-point calibration was not possible, we performed a single-point calibration check of the building's CO_2 sensors using a co-located and calibrated reference instrument with an estimated accuracy of ±30 ppm.. The data were processed to obtain an absolute error, equal to the CO_2 concentration reported by sensor minus the true CO_2 concentration. We also calculated a percentage error equal to the absolute error divided by the true CO_2 concentration, multiplied by 100%. This type of sensor performance check was completed for 37 sensors located in seven buildings, including single point calibration checks in a few buildings where multi-point calibrations were completed. One limitation of the single point calibration data is that all of these data were obtained at CO_2 concentrations of 470 ppm or less.

All of the CO_2 sensors evaluated were non dispersive infrared sensors with a default measurement range of zero to 2000 ppm, although in some cases other ranges could be selected. The manufacturers' accuracy specifications ranged from ±40 ppm ±3% of reading to ±100 ppm over 5 years. Some sensors have a dual wavelength system detect and control for calibration drift, some used a single wavelength sensor and corrected for calibration drift with an algorithm assuming that the minimum measured concentration equals a reference value (e.g., 400 ppm). Most sensors sampled via diffusion, i.e., had no sample pump. The manufacturers' recommended calibration frequency ranged from every six months to every five years.

The sensor performance checks were all performed in commercial buildings located in California, selected without consideration of building age or type of CO_2 sensor. The buildings were used for healthcare, education, software industry, judicial, and state office applications. There were six brands of CO_2 sensors and multiple model types of some brands.

RESULTS

Figure 1 provides results from the multi-point calibration checks of CO_2 sensors. Offset errors ranged from –113 to +326 ppm. For 6 of 18 sensors, the offset error was greater than 50 ppm. The slope of the curve of measured versus true CO_2 concentration ranged from 0 to 1.35. For 6 of 18 sensors, the slope was more than 0.2 from the desired slope of 1.0. Based on the offset error and slope, Figure 2 provides CO_2 concentration measurement errors at true CO_2 concentrations of 600 and 1000 ppm. At 600 ppm, predicted errors ranged from –594 ppm to +537 ppm. For seven of 18 sensors, the predicted error at 600 ppm was greater than 100 ppm. For eight of 18 sensors, the predicted error at 1000 ppm was greater than 100 ppm. The accuracy of sensors of the same brand was highly variable. Data were insufficient for conclusions about the trend in sensor accuracy with a sensor age.

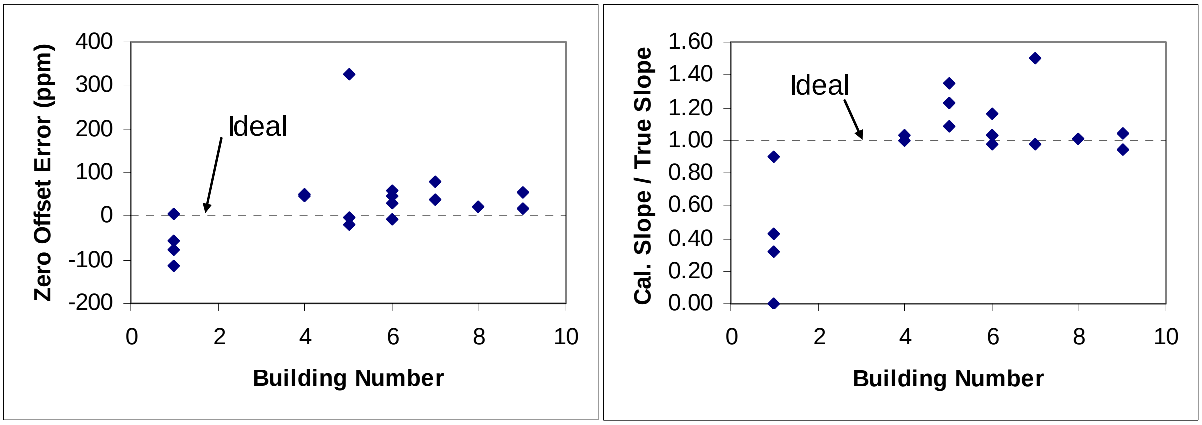

Figure 1. Zero offset errors and slopes from multipoint calibration checks of CO_2 sensors.

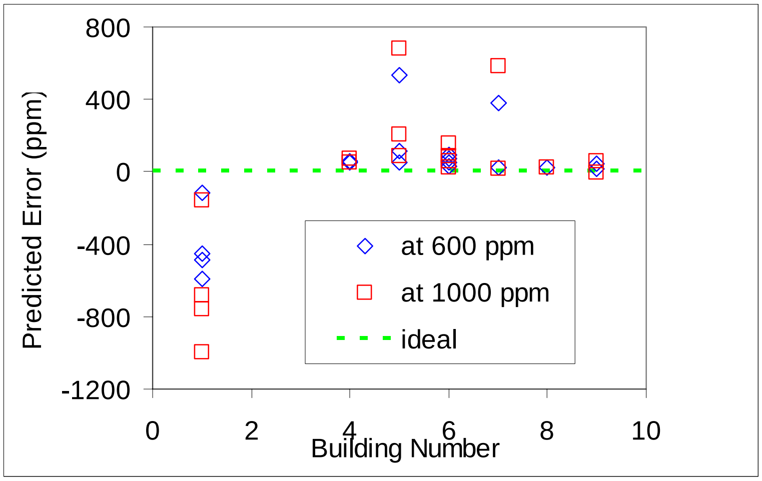

Figure 2. Predicted measurement errors at 600 and 100 ppm based on the slopes and zero-offset data obtained from multipoint calibration checks of sensor performance.

Figure 3 provide the results of the single point calibration checks of CO_2 sensors. Absolute errors ranged from – 378 to + 1013 ppm. The average and median of the absolute values of absolute error were 256 and 173 ppm, respectively. Percentage errors ranged from –100% to +258%. The average and median of the absolute values of percent error were 68% and 43%, respectively. These single point calibration checks occurred with low CO_2 concentrations, so percentage errors would likely be less at higher concentrations.

The errors were especially large from sensors in one in Building 2. Excluding the data from Building 2, the average and median of the absolute values of absolute error were 131 ppm and 76 ppm, respectively. Excluding the data from Building 2, the average and median of the absolute values of percent error were 31% and 18%, respectively.

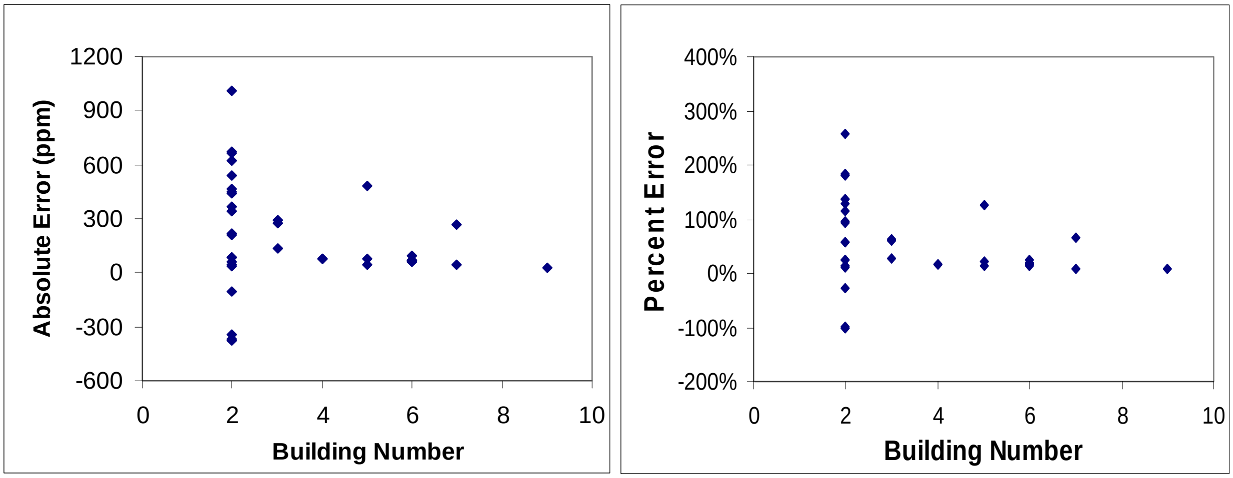

Figure 3. Absolute and percent errors from single point calibration checks of CO_2 sensors.

DISCUSSION

To place the results of this study in context, one must have an estimate of the required accuracy of CO_2 sensors. For demand controlled ventilation, at a minimum, one needs to be able to determine with reasonable accuracy the difference between peak indoor and outdoor CO_2 concentrations found in commercial buildings. We will assume that 20% accuracy is required for the subsequent discussion, but further research or analyses are recommended to better define the accuracy needed for effective demand controlled ventilation. The most representative source of CO_2 data from offices is a survey of 100 buildings by the U.S. Environmental Protection Agency (EPA). From this study, the minimum peak indoor-outdoor concentration difference was 55 ppm, the maximum was 777 ppm, the average was 310 ppm, and the median was 269 ppm. Consequently, 62 ppm (20% of 310 ppm) was selected as the minimum expectation for CO_2 measurement accuracy in offices. Based on our predicted error at 600 ppm from the multipoint calibration checks, seven of 18 CO_2 sensors would not meet this expectation, and many fail by a very large margin.

Classroom CO_2 concentrations tend to be higher than office CO_2 concentrations, thus, one might accept larger CO_2 measurement errors in classrooms. The most representative large data set is from a survey of 201 classrooms in California[9]. In this survey, a typical indoor-outdoor concentration difference was 600 ppm; thus, 20% of 600 ppm or 120 ppm was selected as a minimum expectation for CO_2 measurement accuracy in classrooms. Based on our predicted error at 1000 ppm from the multipoint calibration checks, eight of 18 CO_2 sensors would not meet this expectation, and several fail by a large margin.

Due to the small sample size, a formal statistical analysis of the relationship between accuracy and sensor manufacturer, design features, and sensor age was not warranted. From inspection of the data, no manufacturer or sensor type had a clearly superior accuracy. Based on an examination of plots, there was no clear relationship of accuracy with sensor age, although in the spot checks of sensor accuracy only three of 11 sensors with an age of two or fewer years had errors greater than 20%.

This study has important limitations. The sample of CO_2 sensors was small and a substantially larger study is needed to better determine typical sensor accuracy. The scope of this study scope was also very limited. The reasons for poor CO_2 sensor accuracy were not investigated. For example, based on the data collected, we cannot determine whether the identified accuracy problems are the consequence of technical limitations of low cost CO_2 sensors or due to failures of sensor users to maintain and calibrate sensors.

CONCLUSION

The study provides a strong indication that the accuracy of CO_2 sensors, as they are applied and maintained, in commercial buildings is frequently less than is needed to measure typical maximum values of one-hour-average indoor-outdoor CO_2 concentration differences with less than a 20% error. Thus, despite the small size of this study, we can conclude that there is a need for more accurate CO_2 sensors and/or better sensor maintenance or calibration procedures. Current users of CO_2 sensors for demand controlled ventilation are advised to frequently check sensor calibrations.

ACKNOWLEDGMENTS

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