VAISALA / APPLICATION NOTE

Infrared Sensor Technology and its Impact on HVAC CO_2 Measurement Accuracy

Modern ventilation systems recirculate indoor air in order to minimize the amount of energy required to treat outside air. Using carbon dioxide (CO_2) sensors as indoor air quality indicators helps to ensure a fresh outside air supply to building occupants while simultaneously optimizing energy consumption.

As energy-efficiency regulations become stricter, so do the requirements for CO_2 sensors. One of the forerunners in improving indoor air quality is the State of California. Its Building Standards Code sets performance criteria for CO_2 sensors: "CO_2 sensors shall be certified by the manufacturer to be accurate within plus or minus 75 ppm at a 600 and 1000 ppm concentration when measured at sea level and 25°C, factory calibrated or calibrated at start-up, and certified by the manufacturer to require calibration no more frequently than once every 5 years." This indicates the importance of carefully examining specifications when choosing a sensor – not all sensors will perform in line with expectations.

Operational Principle of Infrared CO_2 Sensors

Infrared sensors – also known as non-dispersive infrared (NDIR) sensors – dominate the HVAC CO_2 sensor market for obvious reasons. They are highly sensitive, selective, and stable. They have a long lifetime and they are insensitive to environmental changes. Moreover, the traditional challenges with this technology – relatively high cost and difficulty in miniaturization – have been overcome.

Carbon dioxide has a characteristic absorbance band in the infrared region at a wavelength of 4.26 µm. When passing infrared radiation through a gas containing CO_2, the CO_2 molecules absorb part of the radiation. The amount of radiation that passes through the gas depends on the concentration of CO_2 present. An infrared sensor incorporating an infrared source, a detector, and an optical path quantifies the phenomenon **(see Figure 1)**.

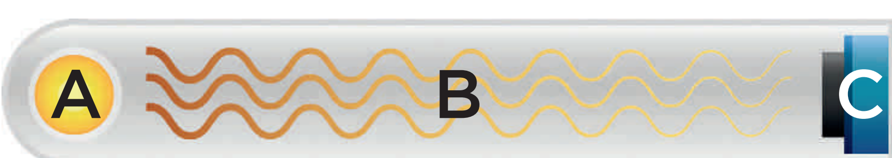

Figure 1.
Infrared absorption of CO_2 molecules can be detected with an infrared detector.
A: *Infrared source.* **B:** *Optical path.* **C:** *Detector.*

Basic performance criteria to check when choosing a HVAC CO_2 sensor:

- **Accuracy:** the proximity of the sensor reading to the true value
- **Measurement range:** the measurement-value limits the instrument is capable of reading
- **Sensitivity:** the minimum detectable CO_2 concentration, and also the minimum detectable concentration change
- **Selectivity:** the sensor's ability to specifically identify CO_2 in a gas mixture
- **Response time:** the length of time it takes for the sensor to respond to a change in CO_2 concentration
- **Stability:** expected time period for stable and reproducible CO_2 readings
- **Power consumption:** important for total energy usage, but also for measurement accuracy due to instrument self-heating
- **Ease of maintenance:** check both the specified calibration interval and the available calibration options, as well as their ease of use

Differences in Infrared CO_2 Sensors and Their Performance

After installation, HVAC CO_2 sensors can typically operate with little or no maintenance for years, even for their entire lifetime. Selecting a sensor capable of reliable and accurate measurements in the long-term is therefore important. Although all infrared CO_2 sensors share a common measurement principle, the technical solutions and measurement performance differ greatly. A well-trained HVAC professional will be familiar with the differences between the various sensor types and their performance.

Single-Beam Single-Wavelength Sensors

Single-beam single-wavelength sensors have a simple structure **(Figure 2)**, comprising an infrared source, a measurement chamber, and a detector.

Figure 2. Single-beam single-wavelength sensor.

The challenge with this type of sensor is its substantial long-term drift. The intensity of the miniature incandescent light bulb – a typical infrared source in CO_2 sensors – changes over time. In addition, dust and dirt may collect on the sensor surfaces. The sensor incorrectly interprets these changes as alterations in the CO_2 concentration, resulting in unreliable measurements in the long run.

To compensate for this inherent instability, some manufacturers employ the automatic background calibration method. The sensor records the lowest CO_2 reading within a given time period (typically several days) and readings are then rescaled assuming that the lowest recorded reading corresponds to fresh outside air (400 ppm of CO_2). Unfortunately this is not always the case, as building occupancy patterns influence indoor CO_2 levels. Facilities such as hospitals, retirement homes, residential buildings, and offices may have a round-the-clock occupancy, with lowest CO_2 levels of around 600-800 ppm. Repetition of the faulty rescaling leads to erroneous CO_2 readings, which in turn result in inadequate ventilation and lower indoor air quality. Moreover, in new buildings concrete carbonation can reduce the CO_2 concentration to well below 400 ppm, so automatic background correction doesn't work in that case either.

Dual-Beam Single-Wavelength Sensors

Dual-beam single-wavelength sensors **(Figure 3)** have a secondary infrared source to compensate for the infrared source drift. Curiously, manufacturers claim that as this secondary light source is seldom activated, it doesn't suffer from aging. The sensor structure is unnecessarily complex, and the secondary infrared source adds an extra potential failure

Figure 3. Dual-beam single-wavelength sensor structure.

point. Moreover, dust and dirt rarely accumulate evenly around the sensor. To conclude, this sensor structure is relatively unreliable.

Single-Beam Dual-Wavelength Sensors

Single-beam dual-wavelength sensors don't suffer from the drift issues that affect the performance of single-beam single-wavelength and dual-beam single-wavelength sensors. This technology, which is commonly used in expensive filter-wheel analyzers, measures not only at the absorption wavelength, but also at a reference wavelength where no absorption occurs.

Vaisala has packaged the single-beam dual-wavelength sensor into a compact structure that can be used in industrial transmitters. The reference is measured by placing an electrically tunable Fabry-Perot Interferometer (FPI) filter in front of the detector **(Figure 4)**.

Figure 4. A single-beam dual-wavelength sensor with an FPI filter in front of the detector.

The micromechanical FPI filter is electrically adjusted to switch between the CO_2 measurement wavelength and the reference wavelength. The reference measurement compensates for any potential changes in the infrared source intensity, as well as for dirt accumulation in the optical path, eliminating the need for complicated compensation algorithms.

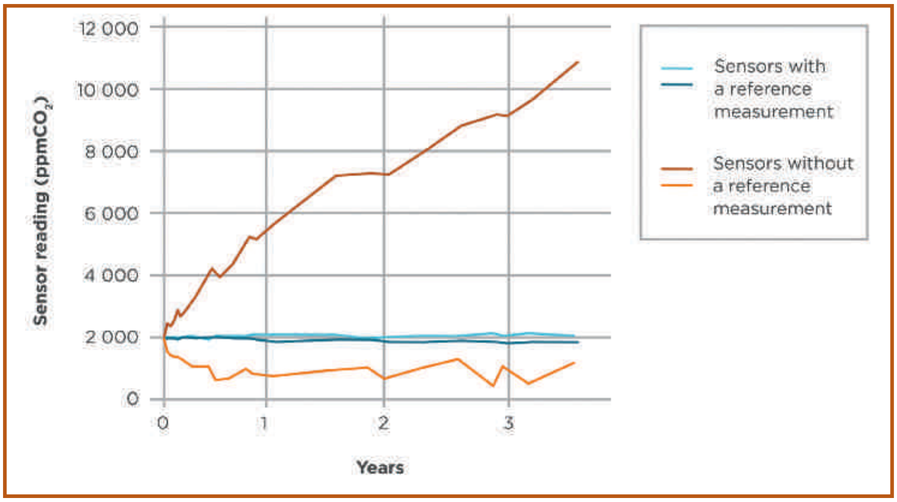

Figure 5: Long-term stability of Vaisala's single-beam dual-wavelength sensors (Sensors with a reference measurement) versus single-beam single-wavelength sensors (Sensors without a reference measurement)

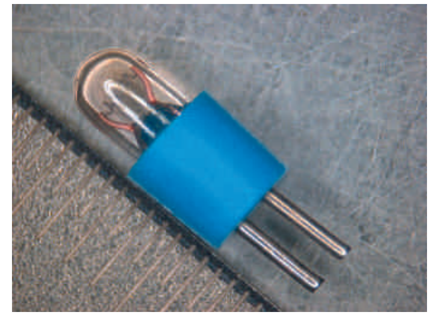

Figure 6. Miniature incandescent light bulb

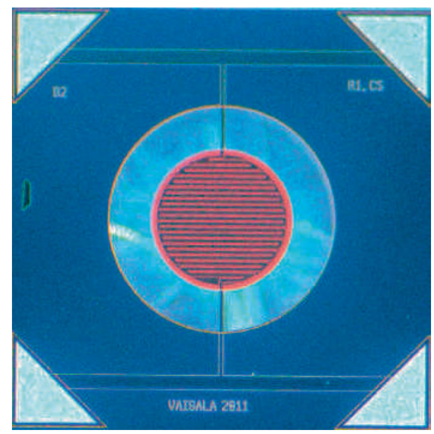

Figure 7: Vaisala-patented microglow, a silicon MEMS emitter infrared source.

Simple and cost efficient, the single-beam dual-wavelength sensor is highly stable over time, requiring minimal maintenance.

Figure 5 illustrates the difference in long-term stability between sensors that use a reference measurement (single-beam dual-wavelength sensors) and sensors that do not (single-beam single-wavelength sensors). The drift common in single-beam single-wavelength sensors originates from reduced infrared source intensity, resulting in too high CO_2 level indication. However, sensor drift can also result in too low readings.

Infrared Source – Performance from the Next Generation Technology

Miniature Incandescent Light Bulb

Most infrared CO_2 sensors use a miniature incandescent light bulb as the infrared source **(Figure 6)**, which are not the ideal source for sensors. Firstly, the initial light intensity varies greatly between units, making deployment challenging. Secondly, they suffer from inherent instability: tungsten evaporates from the thin filament and adheres to the glass surfaces, blackening the bulb walls. As the filament becomes thinner, output intensity gradually degrades. The long-term stability of sensors without a reference measurement (single-beam single-wavelength and dual-beam single-wavelength sensors) suffers greatly **(Figure 5)**. Other disadvantages include relatively high power consumption and limited lifetime.

Microglow

The next-generation infrared technology – microglow – solves many of the challenges that impact traditional infrared sources. The key advantages of microglow **(Figure 7)** are extended infrared source lifetime, reduced power consumption, uniform quality, and superior manufacturability at high-volumes.

Replacing the incandescent light bulb with microglow technology increases the sensor's operational lifetime by 50%, while power consumption is only 25% that of traditional infrared sources.

The high amount of heat generated by incandescent light bulbs limits their applicability in multiparameter transmitters measuring not only CO_2, but also humidity and temperature. As a temperature-dependent parameter, humidity can't be measured reliably in the proximity of a heat source. The uniquely low power consumption of microglow enables high-quality humidity measurement in the same transmitter enclosure as CO_2 measurement and also reduces the sensor warm-up time.

The intensity of microglow remains extremely stable throughout its lifetime **(Figure 8)**. Other benefits include short response time and superior manufacturability, as the chip can be automatically assembled directly on the component board.

Read more about microglow technology at www.vaisala.com/microglow.

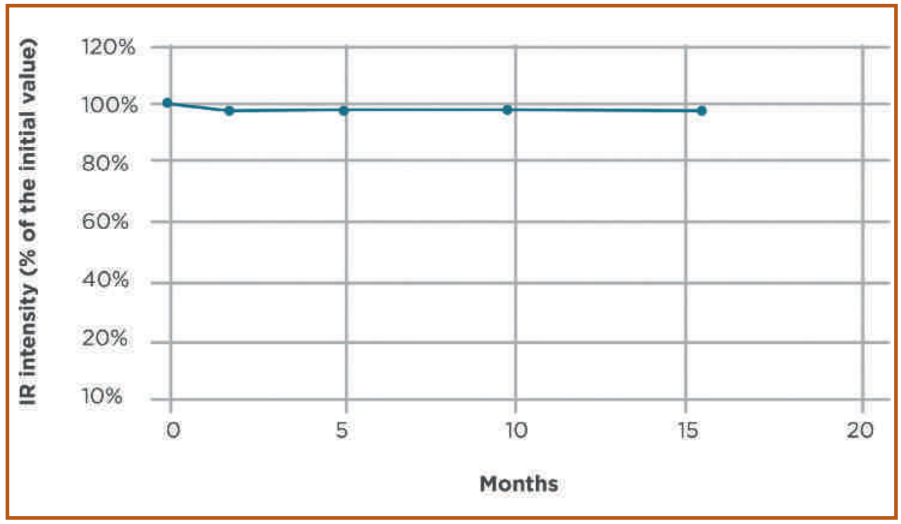

Figure 8. Microglow's superior long-term stability.

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