CO2 Assessment & Strategies

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Fresh Air Monitoring System

Studio 5

**Abstract**

CO₂ monitoring is crucial for air quality, classroom, and workplace safety. This report examines measurement strategies, use cases, implementation strategies, and ESP32-compatible sensors.

Indoor CO₂ levels range from 400 ppm (fresh air) to over 2,000 ppm (stale air affecting cognition). Selecting the right sensor is essential, with 0–5,000 ppm sensors ideal for air quality monitoring and higher ranges needed for industrial applications.

We compare CO₂ sensors, including SCD30, SCD4x, CCS811, and MHZ19, assessing accuracy, power consumption, and suitability. While CCS811 is affordable, it estimates rather than directly measures CO₂. The MHZ19 is similar where it offers a cheap price for an NDIR sensor at the expense of accuracy. The SCD30 and SCD4x series provide more precise readings, but each model in this range has varying usages.

Based on the following analysis, we recommend the best sensor for reliable monitoring, ensuring effective ventilation and maintaining healthy air quality.

**Technology Issues**

The purpose of the fresh air quality monitoring system (FAQMS) is to accurately monitor and display CO2 measurements for each room a module is placed in. Currently, users have reported inconsistencies with how data is recorded and its accuracy. Users have also reported distrust with data accuracy due to the inconsistent uploads and online status of our modules. One solution we’ve presented is using better LoRa modules (i.e. LilyGo v1.6.1) for more stable, simplified connectivity. However, we’ve discovered that the in-use CO2 sensors are a contributing factor to the quality of data.

**What CO₂ Does, Its Behavior, and Health Effects**

CO2 is a gas that plays an important role in the Earth’s atmosphere and other natural processes. CO2 is a natural byproduct of many activities, the most common indoor CO2 contributors are:

* Poor ventilation
* Presence of heaters/gas stoves
* Many people in the same location
* High outdoor CO2 levels
* Vehicle exhaust
* Cleaning chemicals and pesticides

Heavier than air, CO2 can accumulate in low-lying areas, where many public spaces tend to be located (e.g. main city streets, campus grounds, etc). Higher floors in buildings might offer slightly better air quality as they are farther from ground-level pollution sources, but this isn’t a guaranteed benefit. Regardless of weight, gases do not separate into layers in normal air, so the CO2 will diffuse and will not pool on the floor unless there is a consistent source or or large increase in CO2.

Whether CO2 pools near ground level or diffuses in the air we breathe, ensuring we understand the effects of varying CO2 levels is key to producing a system that can produce meaningful impact for our users.

**CO2 Levels & Health Effects**

The CO2 concentration in the air is a [good estimate for air quality](https://www.co2meter.com/en-nz/blogs/news/carbon-dioxide-indoor-levels-chart?srsltid=AfmBOorvyYaICOkb1wS6Cw5pztipWwxIeo1tdSAa6zm0xBeFGv_6olbJ):

| **CO2 Level (ppm)** | **Symptoms** | **Air Quality** |
| --- | --- | --- |
| 250-400 | Normal - refreshed, awake | Fresh outdoor air |
| 400-1.000 | Normal | Good indoor air quality |
| 1.000-2.000 | Drowsiness, reduced focus, slow | Heavy, uncomfortable (“stuffy”) air |
| 2.000-5.000 | Headaches, drowsiness, loss of attention, significantly poor concentration, increased heart rate | Stagnant, stale, “stuffy” air |
| >5.000 | Unsafe, potential asphyxiation over time, inability to perform work | Enclosed non-ventilated spaces (i.e. silos) workplace exposure limit in most areas |
| >40.000 | Permanent brain damage, coma, death | Severe oxygen deprivation |

**Deciding Sensor Type**

There are various types of sensors to measure CO2[3](https://done.land/components/data/sensor/airquality/):

* **NDIR (Non-Dispersive Infrared):** most accurate for indoor & industrial applications
* **Metal-Oxide Semiconductors (MOS):** compact home-monitoring devices
* **Electrochemical:** used in safety devices but have limited lifespan
* **Photoacoustic Spectroscopy (PAS):** used in scientific research with high accuracy
* **Tunable Diode Laser Absorption Spectroscopy (TDLAS):** uses laser light for industrial-grade analyzers

| **Type** | **Notes** | **Accuracy** | **Price** | **Quality** | **Best For** |
| --- | --- | --- | --- | --- | --- |
| NDIR | Balance of accuracy and cost | High | 💰💰💰 | High | Indoor monitoring, HVAC, industrial |
| MOS | Cheap, less reliable | Low | 💰 | Lowest | Low-cost, general monitoring |
| Electrochemical | More for CO than CO2 | Medium | 💰💰 | Low | Industrial safety, portable detectors |
| PAS | Slightly more expensive, but high-precision | High | 💰💰💰💰 | High | Indoor monitoring, science, high-precision monitoring |
| TDLAS | Expensive, highest-precision | Highest | 💰💰💰💰💰 | Highest | Industrial, scientific research |

In summary, from this table, **NDIR and PAS sensor types** are the best options for the scope of the FAQMS project. Although MOS sensors are cheaper and do the job, these sensors measure multiple unspecified substances and provide only an overall estimate. MOS sensors are also substantially affected by temperature and humidity. Their readings are somewhat random and may be influenced by many other factors.

NDIR sensors specifically measure the substance they were designed for and are known for their reliability and accuracy. NDIR sensors are widely used in high quality indoor air quality monitors[3](https://done.land/components/data/sensor/airquality/).

PAS sensors are also widely used in scientific research and lower end models are used for larger offices and industrial purposes. Although slightly more expensive than NDIR, the PAS offers more utility, stability, and accuracy for a wide range of users.

We’re currently using an NDIR sensor which works well enough, but the exact model we’re using has caused some issues for our users.

**Sensor Model Considerations**

Choosing the sensor *type* is not the only aspect we need to consider. There are many CO2 sensor models out there that offer benefits for varying applications.

For FAQMS, we want to deploy modules for indoor use that offer high accuracy for CO2 specific measurements and consistency while keeping costs low, options for development open, and footprint negligible. For the LoRa development board we’re using, there are a few options available[2](https://done.land/components/microcontroller/firmware/fromsomeoneelse/co2gadget/#supported-sensors) that are compatible. The MHZ19 NDIR sensor is used in our current modules and, from user reports and data insights, these readings have been concerning in terms of accuracy and consistency. Additionally, we have found that this sensor is impacted more by temperature and humidity and consumes more power compared to other similar options. Lastly, regular calibration is required which we cannot do during mid-semester and summer periods for our team.

After much deliberation, we have three options available:

| **Model** | [Sensirion SCD30](https://sensirion.com/products/catalog/SCD30) | [Sensirion SCD40](https://sensirion.com/products/catalog/SCD40) | [Sensirion SCD41](https://sensirion.com/products/catalog/SCD41) |
| --- | --- | --- | --- |
| **Technology** | NDIR | PAS | PAS |
| **Reading Range (ppm)** | 400-10,000 | 400-2000 | 400-5000 |
| **Cost (for 1 sensor)** | ~$31 | ~$28 | ~$34 |
| **Response Time** | ~20s | <10s | <10s |
| **Power Consumption** | Higher (~75mA) | Ultra-low (~3mA) | Ultra-low (~3mA) |
| **Environment Sensitivity** | Built in temp compensation, moderately affected by humidity | Advanced temp compensation, minimal affect by humidity | Advanced temp compensation, minimal affect by humidity |
| **Lifespan** | ~5 years | ~10 years | ~10 years |
| **Self-calibration** | Yes | Yes | Yes |
| **Best For** | High-accuracy CO₂ monitoring, greenhouses, industrial use | Indoor air quality, low-power, home applications | Low-power, HVAC, indoor air quality in larger spaces and offices |
| **Accuracy** | ±(30 ppm + 3% of reading) | ±(50 ppm + 5% of reading) | ±(40 ppm + 5% of reading) |

All 3 are suitable options for usage within the FAQMS. However, considering external expansion, calibration requirements, environment considerations, user requirements, and sustainability principles, I believe that using one of the SCD4x models would be most suitable.

Each model has a different measurement range. According to the [CO2 Meter Gas Specialists](https://www.co2meter.com/blogs/news/how-to-measure-carbon-dioxide), any sensor that can measure 0-1% (i.e. 400-10,000ppm) is applicable for indoor air quality measuring. However, the larger the range, the more inaccurate the readings can be (as seen in the Accuracy row above). Ranges up to 10,000ppm are more appropriate for industrial and greenhouse usage, which does not apply to our use case. A range of 400-2000ppm would be appropriate for our scope at this time, but would be too small a range when offering our product to users with larger rooms and/or higher occupancy (e.g. D206, external offices, etc). A range of 400-5000ppm would enable our system to be more accessible to a larger user audience and would allow for scalability.

**Summary**

If monitoring **indoor air quality** → 400–5,000 ppm (NDIR sensors are common)

If used in **greenhouses/agriculture** → 0–10,000 ppm (adjusting CO₂ levels for plant growth)

If for **safety/industrial applications** → 0–50,000 ppm or higher (detecting leaks or dangerous conditions)

If working in **special scientific applications** → 0–100% (medical, research, or industrial uses)

Although the SCD30 offers slightly higher accuracy, the SCD4x range offers many more benefits by a landslide. Additionally, the SCD30 is slightly more prone to environmental influences.

In conclusion, the SCD41 is most suitable for accommodating a larger user audience, accuracy, and scalability; however, the SCD40 is also suitable, though unable to read beyond 2000ppm.

**Resources**

2. [ESP32 Supported CO2 Sensors](https://done.land/components/microcontroller/firmware/fromsomeoneelse/co2gadget/#supported-sensors)

3. [Sensor Quality](https://done.land/components/data/sensor/airquality/#measuring-air-quality)

[SCD40 SCD41 CO2 Module](https://www.aliexpress.com/item/1005006326931355.html?aff_fcid=2ef7861a3840458faaace4a36754dcf4-1742244340142-06523-_DkcefZ7&tt=CPS_NORMAL&aff_fsk=_DkcefZ7&aff_platform=shareComponent-detail&sk=_DkcefZ7&aff_trace_key=2ef7861a3840458faaace4a36754dcf4-1742244340142-06523-_DkcefZ7&terminal_id=72a278dbcce14b74916333414b7af65b&afSmartRedirect=y)

[SCD4x Datasheet](https://sensirion.com/media/documents/48C4B7FB/66E05452/CD_DS_SCD4x_Datasheet_D1.pdf)

[CO2 Sensor LilyGo Tutorial with Co2 Sensor Recommendations](https://emariete.com/en/co2-meter-co2-gadget-low-power-with-lilygo-ttgo-t5-epaper-and-sensor-sensirion-scd41/)

[SCD30 Product Link](https://sensirion.com/products/catalog/SCD30)

[SCD40 Product Link](https://sensirion.com/products/catalog/SCD40)

[SCD41 Product Link](https://sensirion.com/products/catalog/SCD41)

“CO2 Sensors: SCD30/SCD4x | Data-Driven Engineering - APMonitor” [APMonitor](https://apmonitor.com/dde/index.php/Main/CO2Sensor#:~:text=These%20sensors%20measure%20CO%E2%82%82%20concentrations,and%20for%20comprehensive%20environmental%20monitoring)

“Adafruit SCD-40 and SCD-41 Overview” [Adafruit](https://learn.adafruit.com/adafruit-scd-40-and-scd-41/overview)

“CO2 Sensor Range: PPM and Percentage Compared” [CO2 Meter](https://www.co2meter.com/en-nz/blogs/news/co2-sensor-percentage-range-compared?srsltid=AfmBOormy0iLI3suBY-lf1rdsigN7aLs8QvcrKcW_iyxRpTPDeP9lSl5)

<https://www.co2meter.com/blogs/news/how-to-measure-carbon-dioxide>

“Carbon Dioxide Levels Chart” [CO2 Meter](https://www.co2meter.com/en-nz/blogs/news/carbon-dioxide-indoor-levels-chart?srsltid=AfmBOorvyYaICOkb1wS6Cw5pztipWwxIeo1tdSAa6zm0xBeFGv_6olbJ)

[Low Power CO2 Module Design](https://emariete.com/en/design-co2-meter-ultra-ultra-low-consumption/)

**Introduction**

High CO2 levels in learning environments have been linked to low testing performance.[[1]](#footnote-0) Because of this our team is building a CO2 monitoring system and in this research report I look at various CO2 sensors to fit our requirements.

Finding the right CO2 sensor is key to producing a product that is accurate, efficient and reliable. In this report I explore various different CO2 sensors, analysing their specifications in relation to our products requirements.

**Methodology**

To find the right CO2 sensor we must consider our project requirements:

1. Accuracy
2. Measure frequency
3. Compatibility with our existing technology (More below)
4. Easy to implement
5. Cost and availability

**Current Technologies**

We are currently using the LilyGo LoRa32 module and sending data using LoRa to The Things Network. The LilyGo LoRa32 module uses a ESP32 microcontroller, which supports communication protocols such as I2C, UART, and SPI.

**Sensor options**

I am exclusively considering NDIR (Non-Dispersive Infrared) CO2 sensors due to their proven accuracy, reliability, and long-term stability. NDIR sensor measures infrared light of a specific wavelengths. Using unique absorption bands specific to different gases concentrations can be calculated by the sensor. NDIR sensors are commonly used to detect CO2 [[2]](#footnote-1)

Additionally, I will only be considering sensors that are already test-boarded and readily available on the market. Designing custom PCBs or modifying sensors is outside the scope of this project, as it would require additional resources, time, and technical expertise beyond our current capabilities. While out of scope now this may be an option in future iterations.

| Sensor | Detection range | Accuracy | Interface | Power supply | Preheat time | Current consumption | Lifespan | Additional notes |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| [DFRobot](https://www.dfrobot.com/product-1549.html)  [Gravity](https://www.dfrobot.com/product-1549.html)  [Datasheet](https://wiki.dfrobot.com/Gravity__Infrared_CO2_Sensor_For_Arduino_SKU__SEN0219) | 400-5000 | ±(50ppm + 5% reading) | PWM | 5V | 1 min | 40ma avg  125mA peak | >5 years | No temp reporting  $100 |
| [CCS811](https://www.jaycar.co.nz/duinotech-arduino-compatible-air-quality-sensor-with-co2-and-temperature/p/XC3782?srsltid=AfmBOooYsq1Yv8P1DyN_OnbGL4Y8RWrGYjyjX1h9C-6fLYVr-3kf85E7)  [Datasheet](https://cdn.sparkfun.com/assets/learn_tutorials/1/4/3/CCS811_Datasheet-DS000459.pdf) | 400-8192  eCO2\* | Low | I2C | 3.3/5V | 20 min | 26mA | >5 years | Low Accuracy  $40 |
| [MH-Z19B](https://www.aliexpress.com/item/32946106807.html#nav-specification)  [Datasheet](https://www.winsen-sensor.com/d/files/infrared-gas-sensor/mh-z19b-co2-ver1_0.pdf) | 0-5000 | ±(50ppm + 5% reading) | UART, PWM | 5V | 3 min | Avg: <20mA, Peak: 150mA | >5 years | Temp reporting  $35 |
| [SCD-30](https://www.adafruit.com/product/4867)  [Datasheet](https://sensirion.com/media/documents/4EAF6AF8/61652C3C/Sensirion_CO2_Sensors_SCD30_Datasheet.pdf) | 400-10000 | ±(30ppm + 3%) | I2C, UART | 5V | 20 seconds | Avg: 19mA | 15 years | Temp/humidity reporting  $101 |
| [SCD-41](https://www.adafruit.com/product/5190)  [Datasheet](https://sensirion.com/media/documents/48C4B7FB/66E05452/CD_DS_SCD4x_Datasheet_D1.pdf) | 400-5000 | ±(40ppm + 5%) | I2C | 5V | 1 min | Avg: 17mA | >10 years | Temp/humidity reporting  $85 |

**Discussion**

Based on the criteria outlined, the following observations were made:

* The DFRobot Gravity is a versatile sensor however its PWM output high price makes it a not ideal option.
* The CCS811 offers ultra-low power consumption and can detect TVOCs but lacks the precision of dedicated CO2 sensors when our project requirements call for accuracy and high sensitivity.
* The MH-Z19B low cost and performance, making it a strong candidate for however lacks solid evidence to back up datasheet claims. So claims should be taken with a grain of salt. Warm up is also longer than others and requires calibration in outdoor fresh air.
* The SCD-30 provides great accuracy and additional temperature and humidity sensing, ideal for our project but it comes at a higher cost.
* The SCD-41 seems to hit a lot of our requirements, higher accuracy, ease to implement and long life however it does come at a higher cost.

**Conclusion**

After evaluating all these sensors I have decided based on accuracy, usability and reliability to choose the SCD-41. I do have to take into account the price of this sensor however, if the cost of the project is deemed too expensive then my second option would have to be the MH-Z19B but we would need to carefully consider the required calibration and warm up time in our project planning and design.

**Works Cited**

1. Mike. “NDIR Sensors Overview & Benefits - Duomo.” Duomo (UK) Ltd, 22 Sept. 2022, duomo.co.uk/ndir-sensors-overview-benefits/. Accessed 19 Mar. 2025.

2. Snezana Bogdanovica, et al. “The Effect of CO2 Concentration on Children’s Well-Being during the Process of Learning.” Energies, vol. 13, no. 22, 21 Nov. 2020, pp. 6099–6099, www.mdpi.com/1996-1073/13/22/6099, https://doi.org/10.3390/en13226099. Accessed 19 Mar. 2025.

1. (Snezana Bogdanovica et al.) [↑](#footnote-ref-0)
2. (Mike) [↑](#footnote-ref-1)