COVER STORY

CO_2 Sensor Helps to Reduce the Risk of Covid-19 Transmission Indoors

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Indoor climate plays a key role in health protection, as pathogens remain in rooms for hours at typical air exchange rates in residential and office buildings. An increase in fresh air supply is recommended. To monitor and control the air quality, innovative CO_2 sensors like the new XENSIV™ PAS CO2 from Infineon provide precise, cost-effective, and space-saving solutions.

Current statistics, such as those of the U.S. Environmental Protection Agency (EPA), show that people spend almost 90% of their time indoors, while the concentrations of some pollutants indoors are often 2× to 5× higher than typical outdoor concentrations.[1] CO_2 concentration is a key indicator of air quality. At this point, it is worth noting that about 140 years ago, Max von Pettenkofer laid the foundations for current regulations relating to air quality with his studies on CO_2 levels. The higher the CO_2 value in a building, the less comfortable it becomes for the people inside. In poorly ventilated rooms, the CO_2 concentration increases rapidly. For example, in a space of about 4 m^2 occupied by only one person, the CO_2 value rises from 500 ppm (0.05%) to more than 1,000 ppm (0.1%) in just 45 minutes. At this level, the odorless and colorless gas can cause headaches, drowsiness, and poor concentration, often resulting in reduced productivity. From 2,000 ppm onward (0.2%), even the cognitive abilities of humans are influenced, and there is a significant risk to health at higher levels (**Figure 1**).

However, there are other health risks connected with indoor CO_2 concentration. If there is a high amount of exhaled CO_2 in the air, there is also a high number of aerosols. A high concentration of aerosols increases the risk of infection for everyone else in the room. Especially in times of Covid-19, this becomes crucial in offices, schools, shops, and the like. When a person infected with the coronavirus coughs, speaks, or sneezes, a spray consisting of droplets and aerosols is generated, which penetrates air in the room and then spreads. In the paper “Aerosol transmission of SARS-CoV-2,”[2] several researchers have shown that poorly or non-ventilated indoor spaces can increase the likelihood of aerosol transmission of Covid-19. Insufficient ventilation may lead to a long-range airborne transmission of the virus and opportunistic infection. A study done by TU Berlin[3] revealed that the indoor climate plays a key role in health protection, as pathogens remain in rooms for hours at typical air exchange rates in residential and office buildings (**Figure 2**). The sink rate and process of air renewal take considerable time. As such, an increase in the fresh air supply is recommended. To monitor and control the air quality, innovative CO_2 sensors like the new XENSIV™ PAS CO2 (**Figure 3**) from Infineon provide precise, cost-effective, and space-saving solutions. These can optimize the air quality in rooms for more healthy and productive indoor living and working conditions.

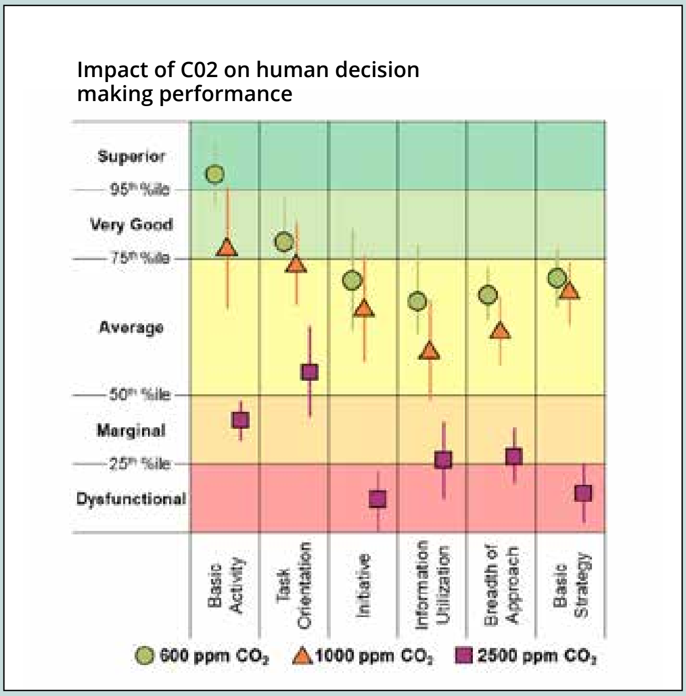

Figure 1: *CO_2 matters because levels of above 2,000 ppm significantly impact cognitive function.*

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In-person classroom and office work during the coronavirus pandemic raise concerns about aerosols and the risk of infection. Wherever you have a large number of people in a room, there is a considerable amount of exhaled air containing CO_2. The Federal Environment Agency of Germany and the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) published recommendations long before the coronavirus outbreak: In classrooms and offices, the CO_2 concentration should not exceed 1,000 ppm. By way of comparison, in the fresh air outside, the CO_2 concentration is 400 ppm. In this context, the idea of installing CO_2-measuring devices in classrooms and offices, as well as other indoor public spaces like gyms, bars, and restaurants, is about preventing the spread of the virus. It would, of course, be possible to measure aerosols in the air and sound the alarm if these become excessively high. But such measuring devices are complex and expensive. On the other hand, inexpensive and compact CO_2-measuring devices are now available that can warn against high concentrations of CO_2 in the air and thus also against high levels of aerosols. These could be used to indicate a potential increased risk of infection with coronavirus.

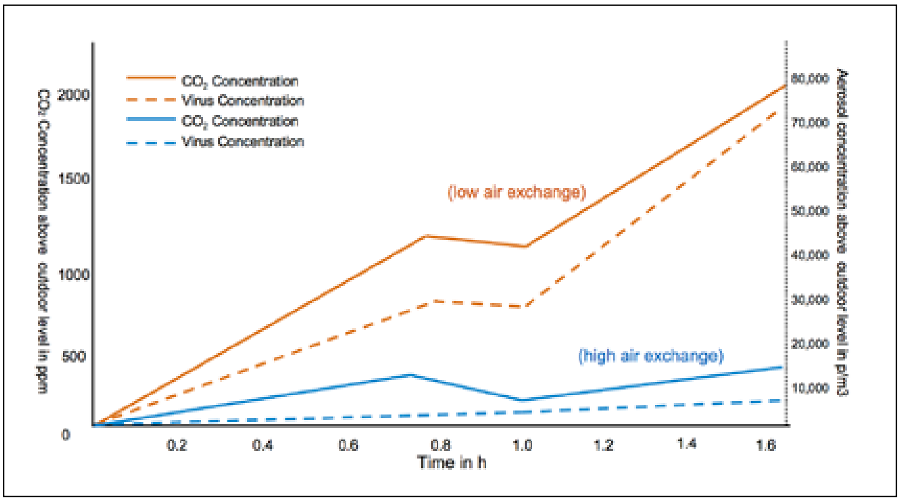

Figure 2: *The increase of the concentration of CO_2 (left axis) and aerosols (right axis) in a classroom over the duration of two lessons with a break*

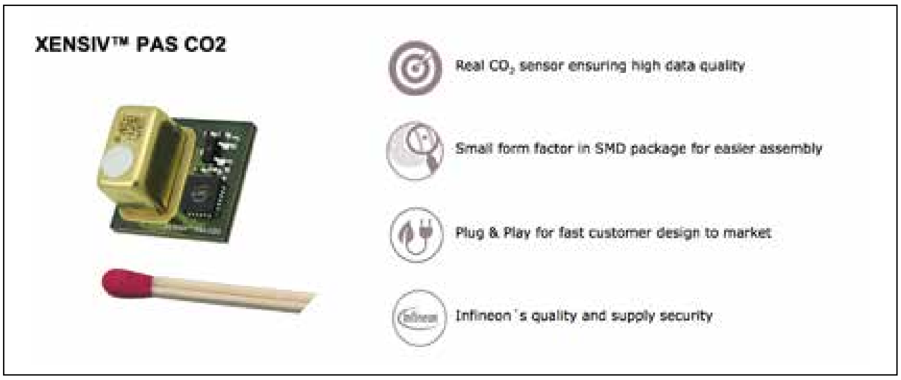

Figure 3: *The XENSIV™ PAS CO2 sensor measures only 13.8 × 14 × 7.5 mm.*

Reliable CO_2 monitoring is not only important with regard to Covid-19 but also beneficial to overall well-being and productivity when spending time indoors. CO_2 sensors can be used to measure the carbon dioxide concentration and thus the quality of indoor air (**Figure 4**). But in order to improve the surrounding air quality and, consequently, increase people's indoor comfort and productivity, more reliable and affordable CO_2 sensors are required. Currently, there are two options: sensors that are accurate but bulky and expensive and sensors that are small but inaccurate, providing grossly estimated values unsuitable for proper control. The XENSIV™ PAS CO2 sensor, in contrast, is ideal for a broad spectrum of applications, providing precise results in a compact format.

ENERGY AND COST SAVINGS THROUGH AIR CONTROL

A ventilation system does more than benefit human well-being. Effective air control in residential and commercial buildings can save energy, which at the same time reduces the corresponding costs and CO_2 emissions.

In the United States, families spend an average of about US$2,000 per year on energy. With a suitable upgrade, they could save about US$400 per year. Other sectors could likewise benefit from the use of air quality control based on reliable CO_2 measurements. Schools, hospitals, restaurants, and shops also have high energy requirements and associated high expenses. In total, countries like the U.S. spend more than US$400 billion every year on supplying all buildings with energy. They use about 74% of the electricity generated in the U.S., which accounts for about 40% of the country's total energy expenditure (**Figure 5**). With effective building automation that also controls ventilation, known as demand-controlled ventilation (DCV), the power consumption of U.S. buildings could be reduced by up to 20%, saving about US$80 billion a year in energy costs.[4]

If buildings are properly planned, constructed, and operated from the outset — for example, with DCV — the energy efficiency of buildings can be increased by up to 30% of the heating, ventilation, and air conditioning (HVAC) energy bill.[5] This would, in turn, make it possible to reduce the overall energy demand, which would solve the global problem of energy shortages on the one hand and reduce the threat to the environment on the other. One typical example: A U.S. school with an average size of about 7,000 m² shows a yearly HVAC energy consumption of about 5.6 USD/m².[6,7] Assuming 20% energy efficiency based on DCV, the savings is about US$8,000 per year. This translates to savings of 80,000 kWh (assuming 10 cents/kWh), which translates to 35 tons of CO_2 emission reduction. This is equivalent to the yearly CO_2 consumption of a forest with 1,600 trees.

POSSIBLE APPLICATIONS FOR CO_2 SENSORS

The data measured by CO_2 sensors can be used in many ways. In a DCV, HVAC systems use the values to adjust the air mixture in the room automatically to that of the outside air according to the targeted application requirements. This keeps indoor CO_2 concentration at a specific value — for instance, below 1,000 ppm according to the ASHRAE standard on ventilation and acceptable indoor air quality in residential buildings. Given the benefits of CO_2 sensing with regard to health and mitigation of infection risk, one can expect widespread adoption of CO_2 sensors in classrooms, offices, gyms, and bars, where the sensors will detect poor air quality. One example is the so-called CO_2 traffic light; the device warns the occupants of a high CO_2 level and therefore a high concentration of aerosols, which is a clear signal to air the room. These sensors can be organized in a sensor network connected to cloud solutions for data intelligence and remote access.

There are many other potential uses for CO_2 sensors. Small CO_2

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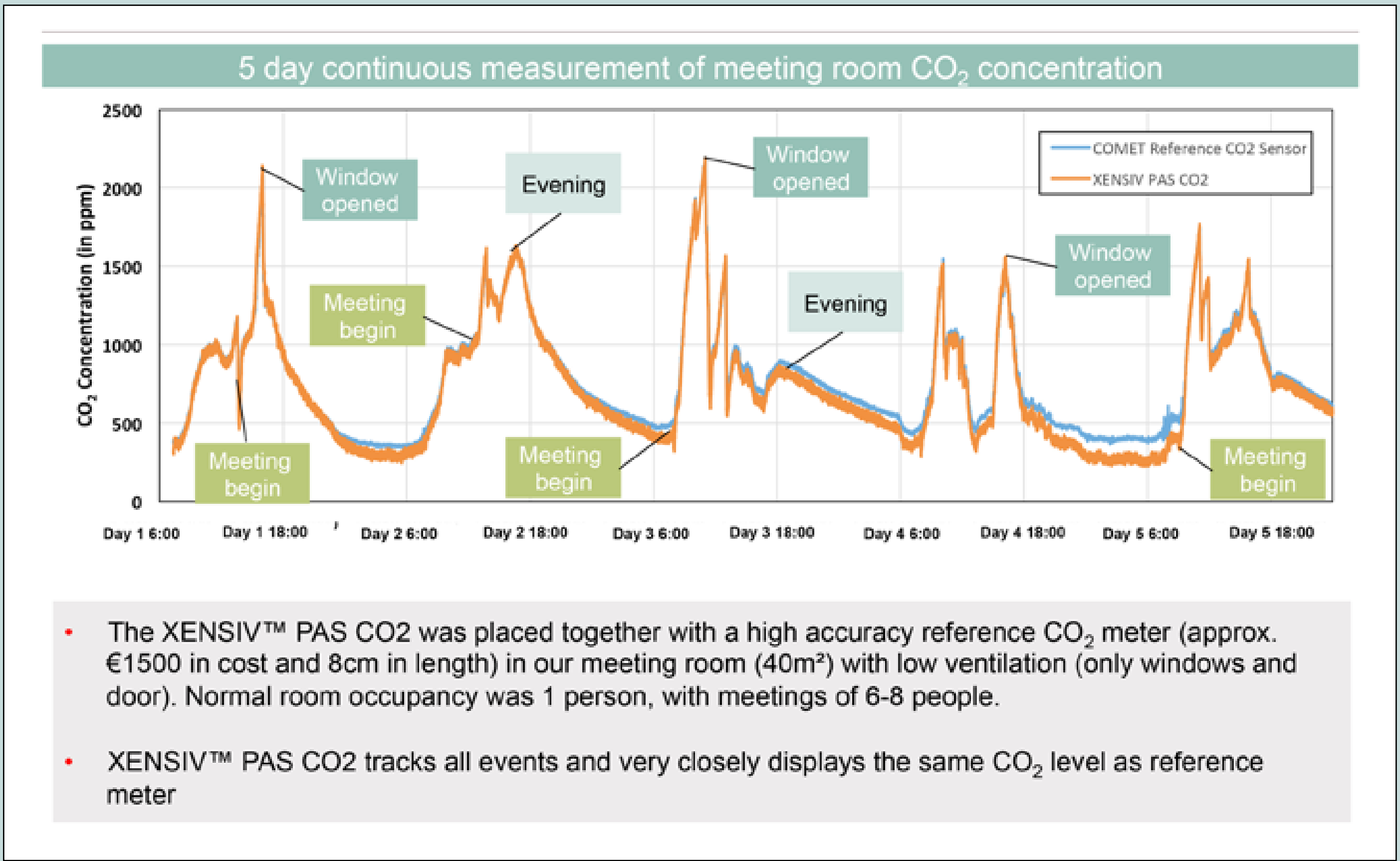

Figure 4: *The development of CO_2 levels in one of Infineon's meeting rooms*

sensors are suitable for applications such as smart home assistants and IoT devices like air purifiers and thermostats. Other applications could follow in the future, such as infant monitoring, food quality control, fitness tracking, and agriculture.

LIMITATIONS OF EXISTING SOLUTIONS

Non-dispersive infrared (NDIR) sensors are often used in building automation nowadays. They consist of an IR light source, a sample chamber, a spectral filter, and reference and absorption IR detectors, which is why they are relatively large and expensive. Although they provide true and accurate CO_2 measurements, their form factor makes them difficult to integrate, in turn making them unsuitable for installation in small IoT devices or smart home components.

The various indoor pollutants can also be detected by the so-called eCO_2 sensors, but unlike the NDIR sensor, they do not perform real measurements. Instead, they use algorithms to calculate an equivalent CO_2 value. These sensors deliver estimated values based on many assumptions, such as how many people — as the cause of an increasing CO_2 load — are present. With this method, the air quality is not always improved at the right moment, which means that the climate control system consumes an unnecessarily large amount of energy. There are currently no comparable solutions available on the market that both provide accurate and true CO_2 measurements and are small and cost-effective.

CO_2 SENSOR WITH PHOTOACOUSTIC SPECTROSCOPY

Thanks to its experience and leading position in microelectromechanical system (MEMS) technology, Infineon has succeeded in developing a new CO_2 sensor based on photoacoustic spectroscopy (PAS) (**Figure 6**). The PAS method is based on the photoacoustic effect, discovered by Alexander Graham Bell in 1880. Infineon owns a comprehensive and continuously growing patent portfolio on the PAS technology, from sensor design to system implementation. The method uses the fact that gas molecules absorb only light with a specific wavelength. In the case of CO_2, the wavelength is 4.2 µm. In rapid succession, light — i.e., energy — is supplied to the gas in exactly this wavelength via an infrared source with an optical filter. Because of rapid heating and cooling, this leads,

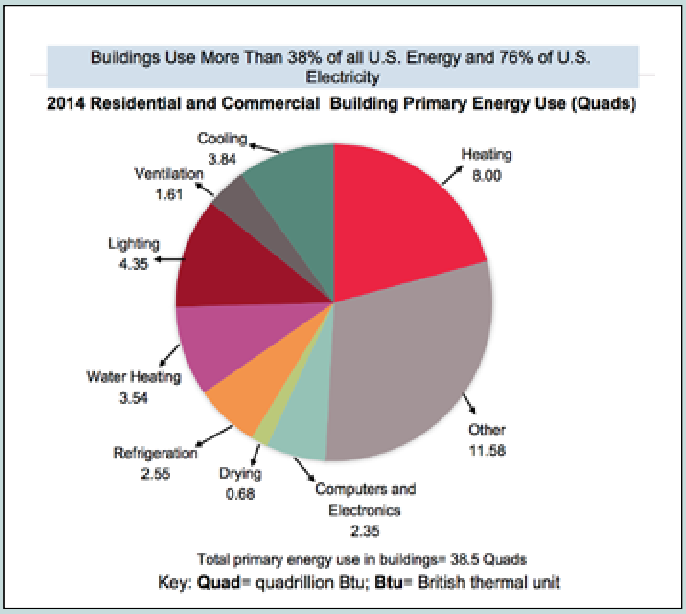

Figure 5: *Building energy accounts for 40% of total energy consumption in the U.S. and Europe.*

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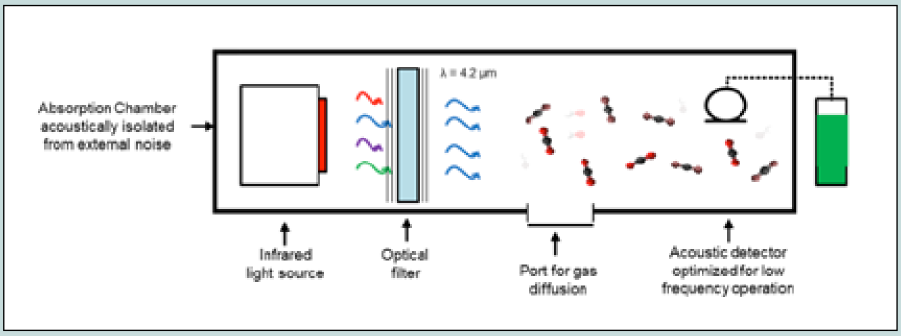

Figure 6: *The photoacoustic spectroscopy (PAS) principle* (Source: DOE, U. [2015]. Chapter 5: Increasing Efficiency of Building Systems and Technologies. Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities, 143–181.)

in turn, to thermal expansion and contraction, generating a pressure change that can be recorded by an acoustic detector optimized for low frequencies. The signal is then evaluated and used to draw conclusions about the amount of CO_2. The stronger the signal, the higher the CO_2 concentration. The highly sensitive MEMS acoustic device, which acts as a pressure sensor, is used as a detector, allowing for significant miniaturization.

The Infineon CO_2 sensor integrates a photoacoustic transducer with a detector, infrared source, and optical filter on a small PCB. The sensor uses a microcontroller for on-board signal processing, sophisticated algorithms, and a MOSFET for operating the infrared source.

A major challenge in developing a PAS-based CO_2 sensor was to push the performance of the detector to its limits and minimize system noise, i.e., to isolate the MEMS detector from external noise so that only the pressure change originating from the CO_2 molecules in the chamber is detected. The absorption chamber is acoustically isolated from external noise to provide accurate CO_2-sensing information; otherwise, the function of CO_2 detection would be significantly disrupted. While developing the solution, Infineon could benefit from its many years of experience in acoustics and related applications. The modeling of the MEMS microphone response, patented acoustic isolation of the diffusion port, and fast prototyping for validating the modeling results enabled an optimal system design.

Table 1: Key specifications of the PAS CO2 sensor

Operation range	400 ppm to 10,000 ppm
Accuracy	±30 ppm +3% of reading between 400 ppm and 5,000 ppm
Lifetime	10 years at 1 measurement/ minute
Operation temperature	0°C to 50°C
Relative humidity	0% to 85% (non-condensing)
Interface and compensation	I^2C, UART, and PWM
Supply voltage	12.0 V for the emitter and 3.3 V for other components
Average power consumption	11 mW at 1 measurement/minute
Package dimensions	13.8 × 14 × 7.5 mm

ADVANTAGES OF THE CO_2 SENSOR

Infineon has leveraged its state-of-the-art capabilities in sensors and MEMS microphones to develop a disruptive environmental sensing technology for CO_2. The XENSIV™ PAS CO2 (**Table 1**) is a real CO_2 sensor based on the PAS principle. The sensor uses Infineon's highly sensitive XENSIV™ MEMS microphone — which detects the pressure change generated by CO_2 molecules within the sensor cavity without picking up external noise. As output, it provides CO_2 concentration in parts per million. The data shows high-quality results even with the smallest pressure fluctuations. Accordingly, small amounts of gas are sufficient for an exact determination, which is why the size of the sample chamber could be designed to be suitably small.

XENSIV™ PAS CO2 offers an exceptionally small form factor that is 4× smaller (14 × 13.8 × 7.5 mm) and 3× lighter (2 grams) than the typical NDIR sensor, allowing for more than 75% space savings in customer systems. Furthermore, the majority of commercial NDIR sensors come with connectors that are not compatible with high-volume assembly standards and lead to a time-consuming manufacturing process. The XENSIV™ PAS CO2, on the other hand, is designed and offered (in tape and reel) with large-volume automatic manufacturing in mind, possessing surface-mount technology (SMT) capabilities for easy assembly and quick integration into customers' systems.

In short, the sensor provides high accuracy in a super-compact design, which makes it the right choice for HVAC control (DCV) applications enabling energy savings and compliance with major smart-building standards (e.g., LEED, WELL).

AVAILABILITY AND OUTLOOK

All sensor components are developed and designed in-house according to high-quality standards. Infineon will continue the development of PAS technology for further size reduction and cost optimization as well as performance adaption to other CO_2-sensing applications in industrial and consumer markets. Other gases could potentially be addressed by the PAS technology platform. Additionally, the Infineon/Cypress ecosystem will be leveraged to provide full-system offerings to the market, including sensing, processing, actuating, and connecting.

Prototypes of the new PAS CO2 sensor have already been tested and validated in key customer applications. A PAS CO2 evaluation kit is currently available for sampling. A complete suite of product evaluation boards (PAS CO2 evaluation board, Arduino-based Shield2Go board, and Adafruit feather-based PAS CO2 wing board based on the Infineon/ Cypress ecosystem), software libraries, and comprehensive documentation, including application notes, will also be available soon to support customers and accelerate the design-to-market time of the PAS CO2 sensor. Ultimately, the sensor will lead to significant improvements in indoor air quality and therefore in our health.

REFERENCES

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[5] DOE, U. (2015). An assessment of energy technologies and research opportunities. Quadrennial Technology Review. United States Department of Energy.

[6] *https://bit.ly/2SSu6HM*

[7] Typical energy cost is US$1.30/ft.² (in 2007).