XENSIV™ PAS CO2: its contribution to the implementation of the WELL Building Standard™ and of the LEED rating system

Laurent Beaurenaut, Senior Principal for Environmental Sensors, Infineon Technologies

Abstract

This white paper demonstrates how Infineon's new CO_2 sensor XENSIV™ PAS CO2, based on photo-acoustic spectroscopy (PAS) technology, is compatible with the sensor requirement defined by the WELL Building Standard™ and the LEED rating system. The evidence presented is based on conceptual and experimental data. The document also provides a detailed analysis of the contribution of the sensor to the implementation of the WELL and LEED features.

Contribution to WELL:

WELL category			**Max. Points**
AIR	Precondition	A03 – Ventilation design	–
AIR	Optimization	A06 – Enhanced ventilation design	2
AIR	Optimization	A08 – Air quality monitoring and awareness	2
MATERIALS	Precondition	X01 – Material restrictions	-
MATERIALS	Optimization	X05 – Enhanced material restrictions	2
Total potential points			**6**

Contribution to LEED:

LEED category			**Max. Points**
Energy and Atmosphere	Prerequisite	Fundamental commissioning and verification	-
Energy and Atmosphere	Credit	Enhanced commissioning	6
Energy and Atmosphere	Prerequisite	Minimum energy performance	-
Energy and Atmosphere	Credit	Optimize energy performance	18
Material and Resources	Credit	PBT source reduction	2
Indoor Environmental Quality	Credit	Enhanced indoor air quality strategies	2
Total max. points			**28**

Table of contents

1 Scope

1.1 Introduction

On January 1, 2023, more than 45,000 WELL projects were registered around the world. The WELL Building Standard™ (WELL) is a rating system that focuses exclusively on the goal of making a positive impact on the comfort, health and wellbeing of occupants of buildings and their interiors [1]. The rapid adoption of WELL is not only explained by the appealing advantages that green buildings offer to a generation that spends 90 percent of its time indoors. It is also justified by the economic advantages and attractive returns on investment, such as increased property value, boosted productivity in the workplace, reduced health costs, reduced energy costs, etc.

LEED (Leadership in Energy and Environmental Design) is the world's most widely used green building rating system in the world [2], with about 180,000 registered projects on March 1, 2023 [3]. Available for virtually all building types, LEED certification provides a framework for healthy, highly efficient, and cost-saving green buildings, which offer environmental, social and governance benefits. LEED certification is a globally recognized symbol of sustainability achievement and leadership.

The purpose of this document is to demonstrate how Infineon's CO_2 sensor XENSIV™ PAS CO2 can contribute to the features defined by WELL and LEED. Because XENSIV™ PAS CO2 has been developed to serve high-volume air quality monitoring and ventilation applications, it is an optimal solution to enable the cost-effective implementation of WELL and LEED features.

This study is the result of a close collaboration with Habitech, the leading national Italian center for green building, renewable energy and innovation. Habitech is an accredited WELL performance testing organization and LEED proven provider. This paper addresses the following aspects:

- Suitability of PAS technology to sense CO_2, as confirmed by the International Well Building Institute (alternative adherence path granted).
- Evidence that XENSIV™ PAS CO2 is compatible with WELL and LEED requirements for sensors. This is backed up by performance data collected by the independent lab Dekra Testing and Certification GmbH.
- Analysis of the WELL and LEED features to which XENSIV™ PAS CO2 contributes, and mapping of those features to the sensor characteristics.

This document targets engineers and project managers developing air quality sensors and HVAC systems, WELL and LEED professionals and, more generally, green building enthusiasts.

1.2 Overview of the WELL Building Standard™

1.2.1 The green building reference

WELL is a performance-based system for measuring, certifying and monitoring features that impact human health and wellbeing. WELL is managed and administered by the International WELL Building Institute (IWBI), a public benefit corporation whose mission is to improve human health and wellbeing through the built environment [2].

WELL is grounded in a body of medical research that explores the connection between the buildings where people spend usually more than 90 percent of their time, and the impact on health and wellness. The WELL Building Standard™ version 2 (WELL v2) is a vehicle for buildings and organizations to deliver more thoughtful and intentional spaces that enhance human health and wellbeing.

WELL v2 includes a set of strategies – backed by the latest scientific research – that aim at improving human health through design interventions, operational protocols, policies, and fostering a culture of health and wellbeing. Built upon the pioneering foundation of the first version of the WELL Building Standard™ (WELL v1), WELL v2 draws expertise from a diverse community of WELL users, practitioners, public health professionals and building scientists around the world. Projects pursuing WELL certification are evaluated on the points earned in several categories. Based on the number of points obtained, a project receives one of the four WELL rating levels: Bronze (40 points), Silver (50 points), Gold (60 points) or Platinum (80 points). WELL v2 can be used for owner-occupied buildings or as WELL Core, i.e., the project owner rents/leases most of the space to one or more tenants.

1.2.2 Ten concepts

The WELL Building Standard™ establishes the performance requirements in ten categories, or concepts, related to occupant health and wellbeing in the built environment: Air, Water, Nourishment, Light, Movement, Thermal Comfort, Sound, Materials, Mind, Community.

1.2.3 Recertification

WELL certification is valid for three years and WELL ratings are valid for one year, at which point projects must undergo recertification or renewal to maintain their certified or rated status. During this process, the project is re-evaluated to verify that it continues to perform as designed. The requirements for retesting performance verified features depend on the extent of alterations made to the project since initial certification.

1.2.4 WELL performance tests

The WELL Building Standard™ is a performance-based system and every WELL project is verified through on-site testing of building performance. Performance verification entails a site visit by a performance testing agent who conducts performance tests, followed by a performance review by a Green Business Certification Inc. (GBCI) WELL reviewer to determine whether a feature has been achieved. The performance testing agent will ensure that the data collected during performance testing accurately represents the environmental and design conditions in the project at that time. For purposes of certification, performance testing must take place after construction is complete and after the project has successfully passed documentation review.

1.3 Overview of LEED® V 4.1

LEED - Leadership in Energy and Environmental Design - certification is a globally recognized symbol of sustainability achievement and leadership [5]. LEED rating system provides a framework for healthy, efficient, carbon and cost-saving green buildings.

LEED is a holistic system that doesn't simply focus on one element of a building such as energy, water or health, rather it looks at the big picture factoring in all of the critical elements that work together to create the best building possible. In fact, 35% of the credits in LEED are related to climate change, 20% of the credits directly impact human health, 15% of the credits impact water resources, 10% of the credits affect biodiversity, 10% of the credits relate to the green economy, 5% of the credits impact community and 5% of the credits impact natural resources. In LEED v4.1, a majority of the LEED credits are related to operational and embodied carbon.

To achieve LEED certification, a project earns points by adhering to prerequisites and credits that address carbon, energy, water, waste, transportation, materials, health and indoor environmental quality. Projects go through a verification and review process by GBCI and are awarded points that correspond to a level of LEED certification: Certified (40-49 points), Silver (50-59 points), Gold (60-79 points) and Platinum (80+ points).

Platinum	Gold	Silver	Certified

LEED was developed to address all buildings everywhere. The reference guides cover the following situations:

- LEED BD+C - Building Design and Construction New Construction and Major Renovation
- LEED ID+C - Interior Design and Construction
- LEED O+M - Building Operations and Maintenance
- LEED ND - Neighborhood Development
- LEED HOMES
- LEED Cities

1.4 Partnerships

To run this study, Infineon has partnered with recognized institutions whose credibility and expertise is well established in the industry:

- Habitech was commissioned to perform a multilevel analysis in order to map the features of the XENSIV™ PAS CO2 sensor to the requirements defined by WELL.
- Dekra Test and Certification GmbH was commissioned to test the XENSIV™ PAS CO2 sensor and provide an independent assessment of its performance.

1.4.1 Habitech and Greenmap program

Habitech

Habitech – the Energy and Environment District promoted by the Autonomous Province of Trento and recognized by the Italian Ministry of University and Research – is the leading national Italian center for green building, renewable energy and innovation: Habitech has operated since 2006 in these areas and strives for a market transformation toward sustainable solutions.

Habitech is a nonprofit organization and a network of more than 140 members which represents both private and public sectors: it is not only the point of reference for all of its members when it comes to R&D, innovation and sustainable practices, but it has also become a beacon for many other industries in Italy and abroad [6].

In 2007, Habitech, promoter and founder of the Green Building Council Italia Association, introduced the LEED certification system in Italy. Since then, Habitech has become one of the European leaders in sustainable construction, consulting with an innovative package of services for all LEED certification paths, and boasting the largest market share in Italy.

Habitech is an accredited **WELL performance testing organization** and a **LEED proven provider** [7].

Greenmap

Greenmap is the program developed by Habitech tailored for the industry. Greenmap fosters sustainability as a strategic level to innovation and development and supports the client's orientation toward their corporate mission. This involves the supply chain that contributes to the realization of products to increase awareness of resources, people and business cultures. It supports organizations in pursuing their strategic path to adopting sustainable criteria and practices as guiding principles.

The product feature mapping analysis conducted by Greenmap on XENSIV™ PAS CO2 was aimed at evaluating the contribution of the sensor to the "final product" of the supply chain process, i.e., the green building. During the mapping, the reference standards were examined in detail in order to determine the credits or features to which the sensor can contribute.

The green building approach involves the whole building, not just the individual products. However, the selected components play a fundamental role in the sustainability and certification goal of the building itself. All the products involved in a project can therefore contribute to credits as long as they conform with credits requirements.

With this analysis, we aim to create confidence backed by solid evidence about the benefits of using XENSIV™ PAS CO2 in the context of WELL.

1.4.2 Dekra Testing and Certification GmbH

Dekra offers a broad service portfolio with qualified and independent expert services ranging from vehicle inspection and expert appraisals to claims services, industrial and building inspections, safety consultancy, and testing and certification of products and systems, as well as training courses and temporary work [8].

Dekra Testing and Certification GmbH is an independent and unbiased service provider offering services regarding product tests and product certification for gas detectors [9].

1.5 Introduction to XENSIV™ PAS CO2

XENSIV™ PAS CO2 is a true CO_2 sensor based on the photo-acoustic spectroscopy (PAS) principle. It enables real-time measurements of the air quality of indoor environments and the implementation of energy-efficient strategies to maintain a healthy environment inside buildings.

This sensor integrates in a small form-factor module: a PAS transducer (detector, infrared source and optical filter); a microcontroller for signal processing and algorithms; and a MOSFET chip to drive the infrared source. The integrated microcontroller runs ppm calculations as well as advanced compensation and configuration algorithms.

The sensor uses a MEMS acoustic detector. The exceptional sensitivity of this acoustic detector coupled with the integrated PCB design reduces space requirements by more than 75 percent compared to commercially available real CO_2 sensors. Therefore, the XENSIV™ PAS CO2 sensor outperforms state-of-the-art NDIR sensors in terms of size and cost, without compromising on performance.

1.5.1 Principle of operation

The PAS principle works as shown in Figure 1. Pulses of light from an infrared source pass through an optical filter tuned specifically to the CO_2 absorption wavelength (λ = 4.2 µm). The CO_2 molecules inside the measurement chamber absorb the filtered light, causing the molecules to vibrate and generate a pressure wave with each pulse. This is called the photo-acoustic effect. The highly sensitive MEMS acoustic detector detects the pressure change generated by CO_2 molecules within the sensor cavity, and the microcontroller converts the output into a CO_2 concentration reading. In order to achieve a ppm reading that is as accurate as possible, the acoustic detector is optimized for low-frequency operation, and the absorption chamber is acoustically isolated from external noise.

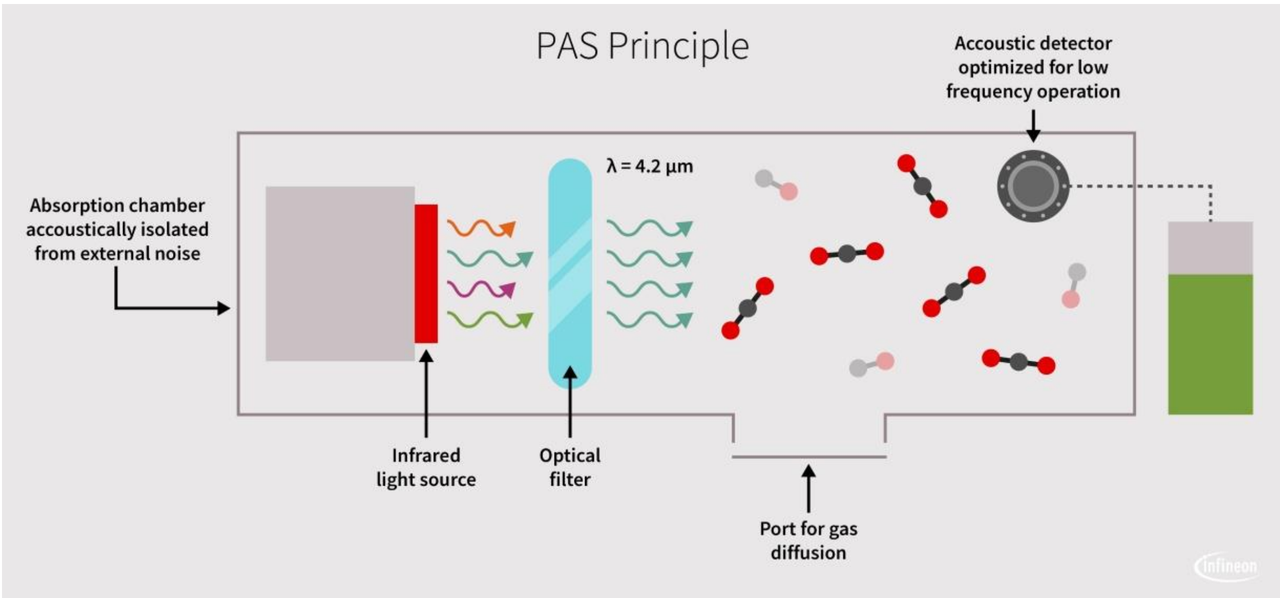

Figure 1 XENSIV™ PAS CO2 principle of operation

1.5.2 Practical use of CO2 sensors – an overview

In the context of this paper, there are two relevant use cases where CO_2 sensors can make an impact on air quality: air quality monitoring dashboards and demand control ventilation (DCV).

1.5.2.1 Air quality monitoring dashboard

A dashboard is defined in this paper as a system providing information to the building occupants about the CO_2 concentration inside the room. This is a passive system that does not lead to an actuation. Typically, such a system informs the occupants that it is time to ventilate the room in order to remove excess CO_2, for example by opening a window.

Multiple implementation and integration strategies exist for such an air quality monitoring dashboard function: for example, as a standalone module [10], into a wall-mounted sensor box [11], into a smart lamp [12], etc.

As a pilot project to protect its employees against the risk of COVID-19 transmission, between 2020 and 2022 Infineon deployed in its headquarters more than 100 CO_2 sensor units using XENSIV™ PAS CO2 in meeting rooms [13]. Real-time CO_2 concentrations were pushed to the cloud and available for individual rooms via an app or centralized on a dashboard (Figure 2).

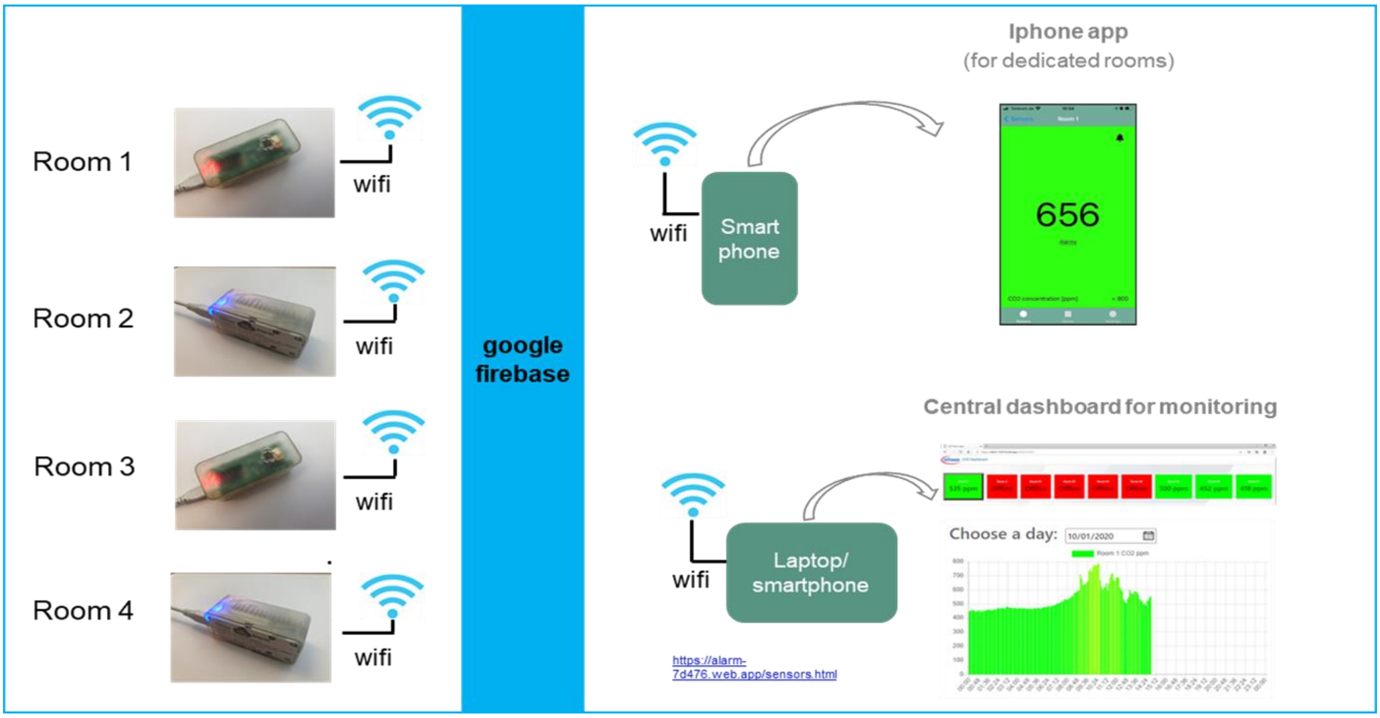

Figure 2 Air quality monitoring pilot project deployed at Infineon headquarters [12]

1.5.2.2 Demand control ventilation

DCV is a strategy that aims at ventilating a room only when CO_2 concentration exceeds a defined threshold. This approach is well established and defined in existing standards (e.g., ASHRAE 62-1 [14]) or in enforced legislation (e.g., California Building Code Title 24 [15]).

In a DCV system, the room ventilation is directly controlled by the sensors monitoring the CO_2 concentration (Figure 3). DCV has multiple advantages compared to conventional time-scheduled ventilation strategies: optimal air quality is maintained inside the room independently from occupancy, energy costs are significantly reduced, etc.

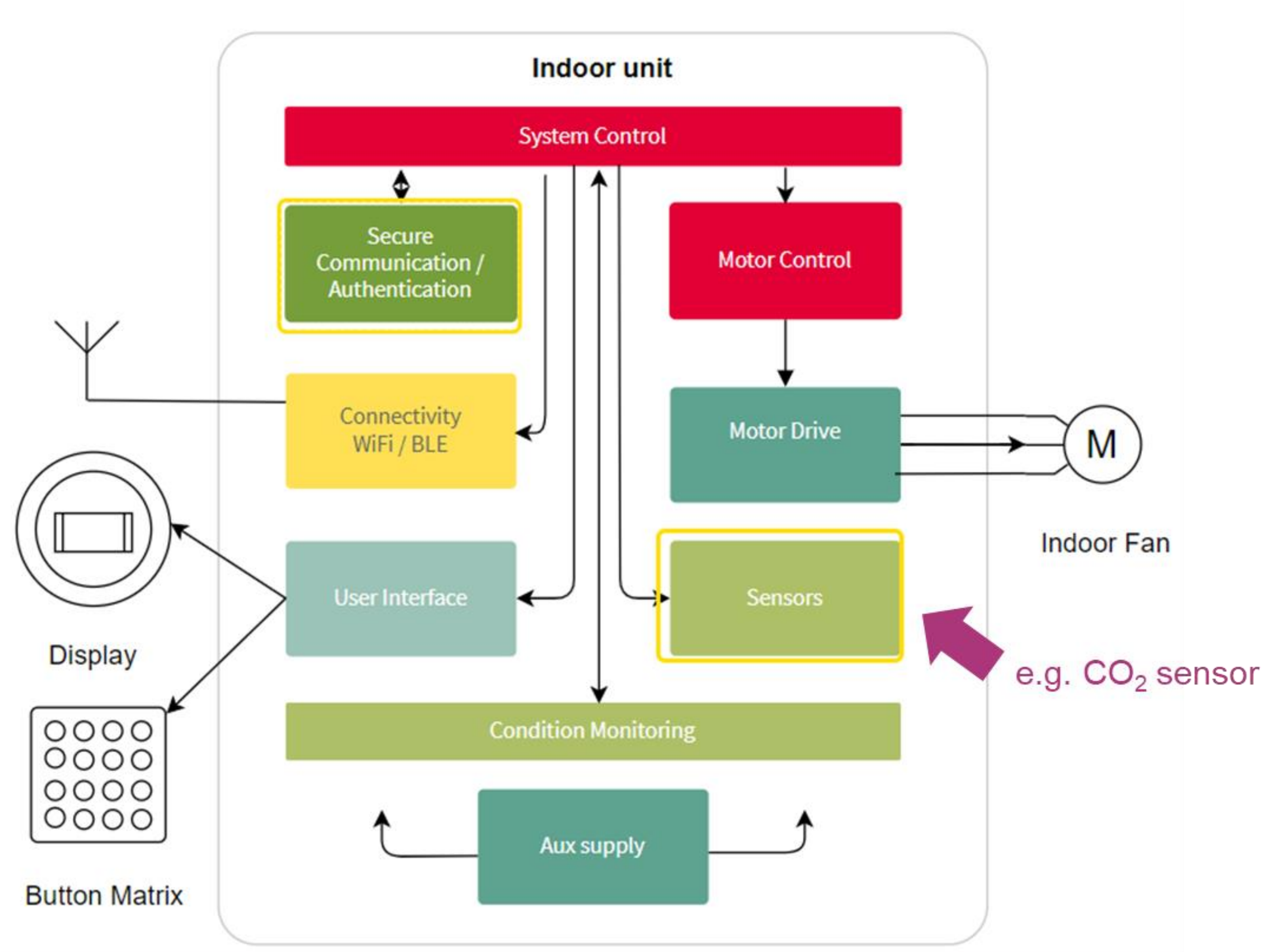

Figure 3 Simplified block diagram of an indoor unit as part of a residential aircon system

2 Compatibility of XENSIV™ PAS CO2 specification to WELL requirements

2.1 Alternative adherence path for the PAS sensing technology

The technical requirements for CO_2 sensors are described in the WELL Performance Verification Guidebook [16].

While WELL recognizes NDIR as state-of-the-art technology for CO_2 sensing, it also opens the door to alternative technologies and encourages an alternative adherence path (AAP) for other sensor types. The AAP shall include evidence indicating that the alternative sensor technology provides performance that is similar to or exceeds approved sensor technologies.

Three AAP (corresponding respectively to feature A03, A06 and A08) for the PAS technology have been submitted and accepted by the International Well Building Institute (IWBI) [17]. The decision of IWBI in favor of PAS technology has been motivated by the following arguments:

1. The PAS technology has been well established in the scientific community [17] to [22] for decades. PAS sensors are a credible alternative to NDIR, as they provide comparable performance while being smaller and more robust [23], [24]. Major sensor suppliers are now proposing PAS sensors to meet the most stringent requirements for indoor air quality monitoring [25], [26].
2. The specification of the XENSIV™ PAS CO2 is compatible with WELL technical requirements, as further discussed in Section 2.2.
3. Compliance with the WELL technical requirements has been verified by Infineon during product characterization. It has been validated by the independent organization Dekra Test and Certification GmbH (see below Figure 5).

2.2 Sensor characteristic requirement analysis

Table 1 summarizes the key requirements for CO_2 sensors derived from the WELL Performance Verification Guidebook.

Table 1 WELL technical requirements for CO_2 sensors

Parameter	Unit	Sensor Type	Range	Accuracy	Resolution
Carbon dioxide (CO_2)	ppm	Non-dispersive infrared	400 to -5000ppm	± 50 ppm ± 5 % at 400 to 2000 ppm	1 ppm

The following paragraphs discuss the compatibility of XENSIV™ PAS CO2 with those requirements.

2.2.1 Sensor type

PAS is a suitable alternative technology to NDIR (see discussion above on AAP).

2.2.2 Unit

As per its datasheet [27], XENSIV™ PAS CO2 delivers a digital measurement result in ppm. This is compatible with WELL.

2.2.3 Range

As per its datasheet, XENSIV™ PAS CO2 operating concentration range is specified as 0 to 32,000 ppm. The specified sensor range is therefore compatible with WELL.

2.2.4 Accuracy

As per its datasheet, XENSIV™ PAS CO2 accuracy is specified as +/-30 ppm +/-3% under the following conditions: rH = 30%, p = 1013 hPa, T_{amb} = 25°C, and $t_{sampling}$ = 1 measurement/min, CO_2 from 400 to 5000 ppm.

The specified sensor accuracy is therefore compatible with WELL.

2.2.5 Resolution

As per its datasheet, XENSIV™ PAS CO2 operating concentration range is specified to 1 ppm. The specified sensor resolution is therefore compatible with WELL.

2.2.6 Sampling rate

The WELL Performance Verification Guidebook requires that measurements shall be taken "at intervals not larger than 1 hour for radon and not larger than 15 minutes for other parameters". As per its datasheet, the sampling rate of XENSIV™ PAS CO2 is programmable from 1 measurement/5 s up to 1 measurement/hour. The default sampling rate of the sensor after reset is 1 measurement/60 s [28].

The specified sensor sampling rate is therefore compatible with WELL.

2.2.7 Recalibration interval

The WELL Performance Verification Guidebook requires that "all sensors measuring air quality parameters are recalibrated or replaced annually".

XENSIV™ PAS CO2 has been developed to operate for 10 years. As per its datasheet, the sensor specifies an annual drift of maximum 1% /year, with automatic baseline offset correction (ABOC) function activated. Based on this, the sensor will meet WELL accuracy targets for at least three years of operation without the need for recalibration. This is compatible with WELL.

2.2.8 Summary

XENSIV™ PAS CO2 is compatible with the requirements listed in the in the WELL Performance Verification Guidebook (Table 2).

Table 2 Compatibility of XENSIV PAS CO2 characteristics with WELL performance requirements

Parameter	WELL requirement	XENSIV™ PAS CO2	Compatibility
Sensor type	NDIR	PAS	Yes (AAP)
Unit	ppm	ppm	Yes
Range	400 to 5000 ppm	0 to 32,000 ppm	Yes
Accuracy	+/-50 ppm +/-5% [400 to 2000 ppm]	+/-30 ppm +/-3% [400 to 5000 ppm]	Yes
Resolution	1 ppm	1 ppm	Yes
Sampling rate	Less than 1 meas./hr	1 meas./min. or more	Yes
Recalibration interval	1 every year	1 every 3 years	Yes

2.3 Experimental validation of the XENSIV™ PAS CO2 compatibility with WELL requirements

2.3.1 Experimental validation at Infineon

2.3.1.1 Accuracy

During production, XENSIV™ PAS CO2 sensors are individually calibrated and tested end-of-line under exposure to CO_2. This ensures that every sensor produced by Infineon is compliant with the datasheet. The typical sensor response to a CO_2 concentration change is depicted in Figure 4:

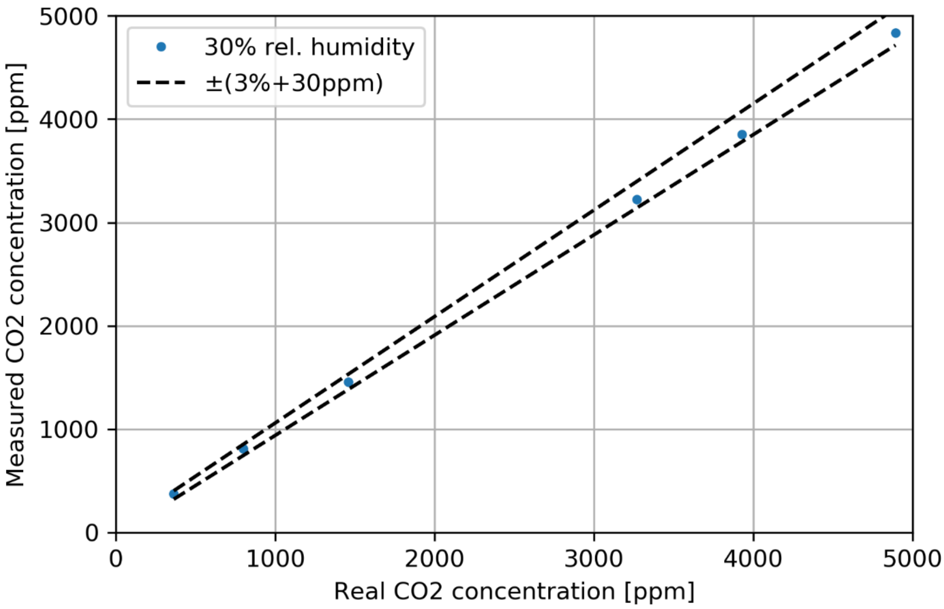

Figure 4 Typical XENSIV™ PAS CO2 sensor response to CO_2 concentration changes (VDD12 = 12 V, VDD 3.3 = 3.3 V, T_{amb} = 25°C, P = 1013 hPa and % rH = 30%)

It can be seen from Figure 4 that compliance with WELL requirements with respect to range and accuracy is achieved.

2.3.1.2 Automatic baseline offset correction

Because of the high sensitivity required to measure low gas concentrations, virtually all gas sensors are subject to drift during lifetime. Therefore, CO_2 sensors typically have a self-calibration mechanism to correct for it.

In order to correct slow drifts caused by aging during operation, the XENSIV™ PAS CO2 supports the ABOC function [29]. This self-calibration mechanism aims at correcting weekly the (minimal) offset errors resulting from aging. This ensures the accuracy ratings of the sensor are maintained over its lifetime.

Infineon has verified the functionality of the ABOC function by conducting extensive lab and field tests. Figure 5 shows the effectiveness of ABOC measured on multiple sensors which were operated over several weeks. The sensors were exposed to a regular indoor office environment and their output was logged continuously along with a high accuracy reference sensor and compared to WELL accuracy targets. Discontinuities in the sensor response occur every week. This corresponds to the sensor autonomously evaluating its offset error and readjusting its response accordingly.

With the use of ABOC, XENSIV™ PAS CO2 meets the requirements of WELL with respect to recalibration interval.

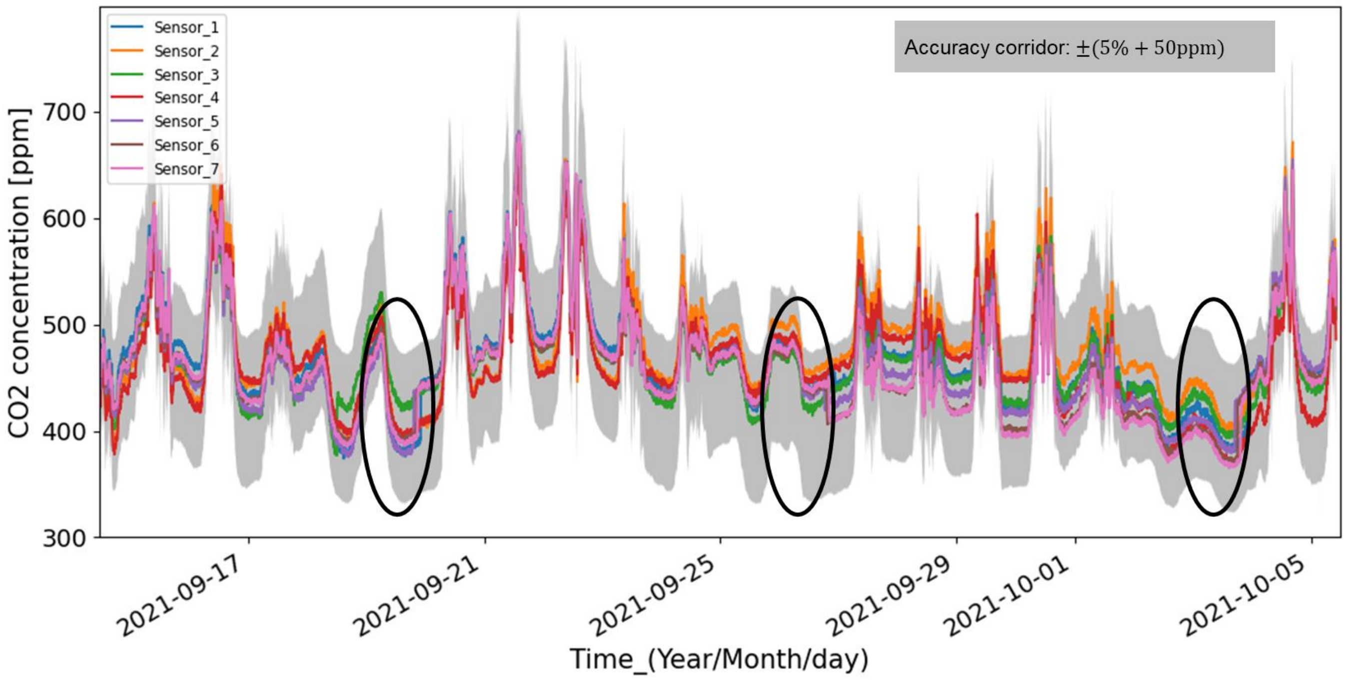

Figure 5 Verification of the ABOC self-calibration function of XENSIV™ PAS CO2

2.3.2 Experimental validation at Dekra

The performance of XENSIV™ PAS CO2 has been verified by independent lab Dekra Testing and Certification GmbH and the results compiled in a measurement [30]. Three Sensor2Go evaluation kits were used for the test (Figure 6).

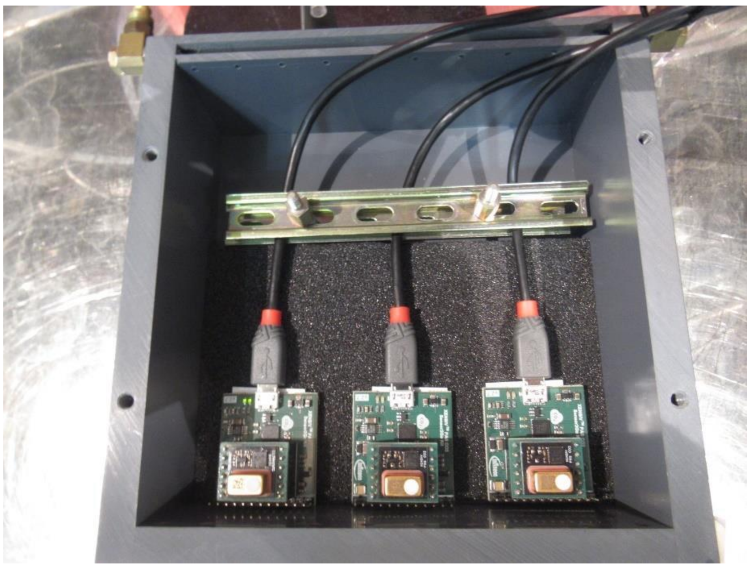

Figure 6 XENSIV™ PAS CO2 Sensor2Go evaluation kit mounted in test chamber and used for the performance tests

The response of the sensor (linearity test) has been tested at a relative humidity of 30% and an ambient temperature of 25°C. The sensor was exposed to a mixture of synthetic air and CO_2, whose concentration varied from 0 to 2000 ppm. It shall be highlighted that the setup introduces an uncertainty of +/-2% on the set CO_2 concentration, which should be added on top of the sensor native accuracy error.

Figure 7 shows the accuracy of the device under test (DUT) versus the WELL accuracy targets. It is therefore confirmed that the sensor fulfills the accuracy targets given by the WELL Performance Verification Guidebook

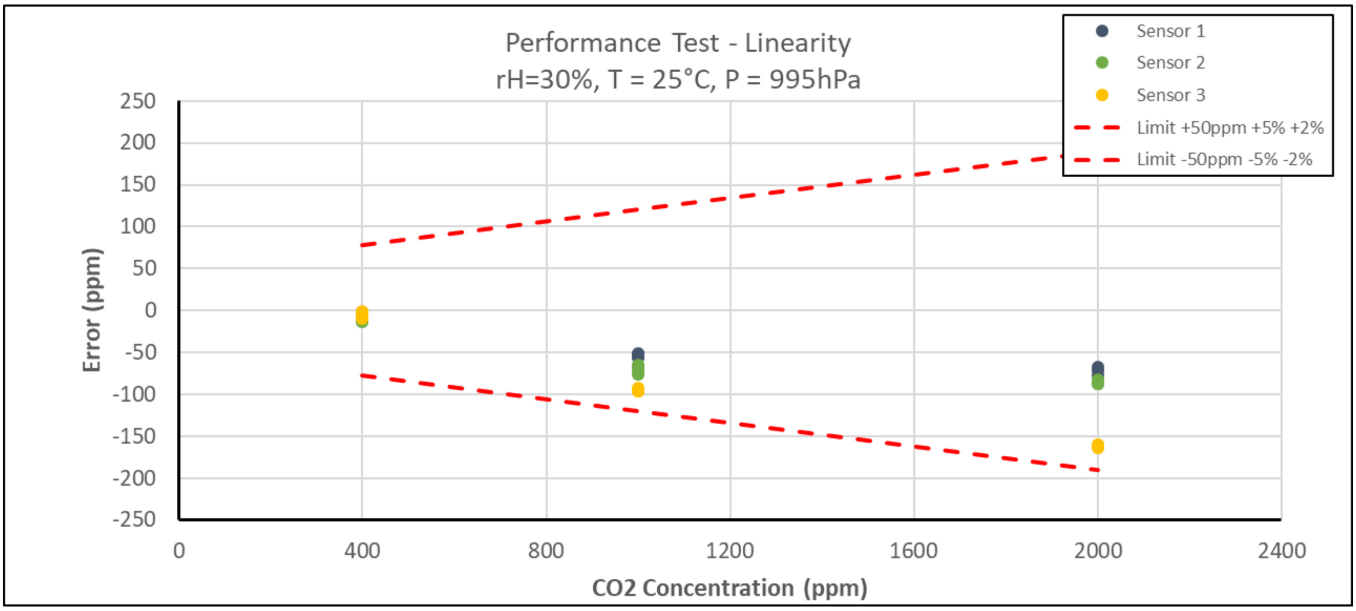

Figure 7 Results of the linearity tests performed by Dekra

2.4 Conclusion on compatibility with WELL requirements

Based on the evidence presented in this section (AAP, datasheet compatibility, experimental validation), it can be safely concluded that XENSIV™ PAS CO2 is compatible with WELL requirements for CO_2 sensors.

2.5 Discussion on boundary operating conditions

The WELL performance guide does not formally specify the operating conditions for the performance tests. This gives sensor suppliers freedom to define those conditions, in particular when specifying accuracy.

However, WELL defines indirectly boundary conditions for humidity and temperature through the thermal comfort features T01 (thermal performance) and T07 (humidity control).

After a careful review of those features, the following relevant operating range can be given as a guideline:

- Ambient temperature from 17°C to 32°C
- Relative humidity from 30% to 60%.

The XENSIV™ PAS CO2 operating range fully covers those two conditions.

3 Compatibility of XENSIV™ PAS CO2 specification to LEED requirements

Contrarily to WELL, LEED does not directly define requirements for CO_2 sensors, in terms of accuracy, measurement range, etc. Therefore, the compatibility of a given CO_2 a sensor to LEED requirements is subject to interpretation.

However, strategy 9 of feature “Enhanced indoor air quality strategies“ specifies that an alarm shall be issued if the sensed CO_2 concentration exceeds the setpoint by more than 10%. It also explicitly refers to ASHRAE 62.1-2016, Appendix D for the setpoint definition.

INFORMATIVE APPENDIX D
RATIONALE FOR MINIMUM PHYSIOLOGICAL REQUIREMENTS FOR RESPIRATION AIR BASED ON CO_2 CONCENTRATION

Oxygen is necessary for metabolism of food to sustain life. Carbon and hydrogen in foods are oxidized to carbon dioxide (CO_2) and water (H_2O), which are eliminated by the body as waste products. Foods can be classified as carbohydrates, fats, and proteins, and the ratio of carbon to hydrogen in each is somewhat different. The respiratory quotient (RQ) is the volumetric ratio of CO_2 produced to oxygen consumed. It varies from 0.71 for a diet of 100% fat to 0.8 for a diet of 100% protein and 1.00 for a diet of 100% carbohydrates [D-1]. A value of RQ = 0.83 applies to a normal diet mix of fat, carbohydrate, and protein.

The rate at which oxygen is consumed and CO_2 is generated depends on physical activity. These relationships are shown in Figure D-2 (see Reference D-2). The breathing rate is shown also. A simple mass balance equation gives the outdoor airflow rate needed to maintain the steady-state CO_2 concentration below a given limit.

$$V_o = N/(C_s - C_o) \quad \text{(D-1)}$$

where

V_o = outdoor airflow rate per person

V_e = breathing rate

N = CO_2 generation rate per person

C_e = CO_2 concentration in exhaled breath

C_s = CO_2 concentration in the space

C_o = CO_2 concentration in outdoor air

For example, at an activity level of 1.2 met units (1.0 met = 18.4 Btu/h· ft^2), corresponding to sedentary persons, the CO_2 generation rate is 0.31 L/min. Laboratory and field studies have shown that with sedentary persons about15 cfm (7.5 L/s) per person of outdoor air will dilute odors from human bioeffluents to levels that will satisfy a substantial majority (about 80%) of unadapted persons (visitors) to a space [D-3,D-4,D-5,D-6,D-7]. If the ventilation rate is to be held to 15 cfm (7.5 L/s) per person, the resulting steady-state CO_2 concentration relative to that in the outdoor air is

$$\begin{aligned} C_s - C_o &= N/V_o \\ &= 0.31/(7.5 \times 60 \text{ s/min}) \\ &= 0.000689 \text{ L of } CO_2 \text{ per L of air} \\ &\approx 700 \text{ ppm} \end{aligned}$$

40

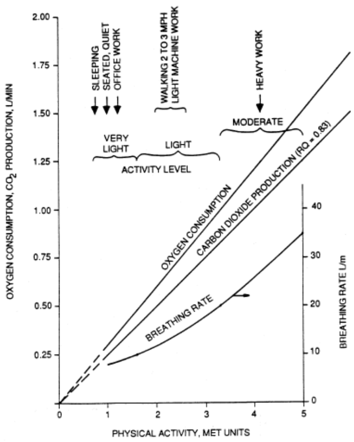

FIGURE D-2 Metabolic data.

Thus, maintaining a steady-state CO_2 concentration in a space no greater than about 700 ppm above outdoor air levels will indicate that a substantial majority of visitors entering a space will be satisfied with respect to human bioeffluents (body odor). A more detailed discussion of this relationship between CO_2 concentrations and the perception of bioeffluents, as well as the use of indoor CO_2 to estimate building ventilation rates, is contained in ASTM Standard D6245 [D-8].

CO_2 concentrations in acceptable outdoor air typically range from 300 to 500 ppm. High CO_2 concentrations in the outdoor air can be an indicator of combustion and/or other contaminant sources.

Figure D-3 shows the outdoor airflow rate required as a function of physical activity and steady-state room concentration. If the activity level is greater than 1.2 met, the required ventilation must be increased to maintain the same CO_2 level.

Also the decrease in oxygen content of the room air can be found from Equation D-1 when oxygen concentration is substituted for carbon dioxide concentration.

$$C_o - C_s = N/V_o \quad \text{(D-2)}$$

ANSI/ASHRAE Standard 62.1-2016

Figure 8 Appendix D of ASHRAE 62.1-2016

Out of this, two requirements can be reasonably derived:

- The sensor shall cover CO_2 concentrations comprised between 300ppm and 1200ppm.
- The sensor accuracy shall be better than +/-10% at 1200ppm.

XENSIV™ PAS CO2 is compatible with both of those requirements, and is therefore a suitable solution in the context of LEED.

4 XENSIV™ PAS CO2 contribution to WELL v2 features

WELL defines two categories of features: preconditions and optimizations. Failure to achieve a precondition in any concept will preclude the award of WELL certification. If all preconditions are satisfied, higher levels of certification award are possible based on the number of fulfilled optimizations.

The subsections below describe the features (preconditions and optimizations) to which XENSIV™ PAS CO2 contributes. The results below are based on the multilevel mapping analysis performed by Habitech [31].

4.1 Overview of the contributions to WELL

Table 3 Overview of the contributions of XENSIV™ PAS CO2 to WELL features

WELL category			**Max. Points**
AIR	Precondition	A03 – Ventilation design	–
AIR	Optimization	A06 – Enhanced ventilation design	2
AIR	Optimization	A08 – Air quality monitoring and awareness	2
MATERIALS	Precondition	X01 – Material restrictions	-
MATERIALS	Optimization	X05 – Enhanced material restrictions	2
Total potential points			**6**

4.2 WELL Feature analysis

4.2.1 A03 – ventilation design

Type of requirement

This requirement is a **precondition**.

Summary

This WELL feature requires projects to bring in fresh air from the outside through mechanical and/or natural means in order to dilute human- and product-generated air pollutants.

Description

Part 1 of this requirement aims at ensuring good indoor air quality through the provision of adequate ventilation.

WELL allows the freedom to select from multiple options to in order to fulfill this feature. Option 4 is relevant for CO_2 sensors.

Option 4: Ventilation monitoring

One of the following carbon dioxide thresholds is met in occupiable spaces:

a. 900 ppm or less.

b. Not more than 500 ppm above outdoor levels.

Verified by: Sensor Data

Note:
Refer to the Performance Verification Guidebook for information on sensor/testing requirements, required testing duration and compliance calculations.

Figure 9 WELL feature A03 (ventilation design), Part 1, Option 4

Mapping to XENSIV™ PAS CO2 characteristics

The requirements are well within the characteristics of the sensor as defined per its datasheet:

- Operating range: 0 to 32,000 ppm
- Accuracy: +/-30 ppm +/-3% for reading between 400 and 5000 ppm

4.2.2 A06 – enhanced ventilation design

Type of requirement

This requirement is an **optimization** (max. 2 points).

Summary

This WELL feature requires the implementation of advanced ventilation strategies that can achieve higher air quality levels and thus benefit human health and productivity.

Description

Part 1 of this requirement aims at expelling internally generated pollutants and improving air quality through an increased supply of outdoor air or increased ventilation efficiency.

WELL allows the freedom to select from four options to in order to fulfill this feature. Option 2 and Option 4 are relevant for CO_2 sensors.

Option 2: Demand control ventilation

For mechanically ventilated buildings, the following requirements are met in at least 90% of regularly occupied spaces:

a. A demand-controlled ventilation (DCV) system regulates the outdoor air ventilation rate to keep CO_2 levels less than the thresholds specified in the table below, at the maximum intended occupancy:

Tier	Threshold		Threshold	Points
1	900 ppm	OR	500 ppm above outdoor levels	1
2	750 ppm	OR	350 ppm above outdoor levels	2

b. Carbon dioxide is measured at the return air diffusers or in the breathing zone at least 3.3 ft away from doors, windows, air supply diffusers or occupants. At least one sensor is used for each occupancy zone (or per air handling unit, if a single zone is served by multiple air handling units). If the occupancy density/pattern/usage is substantially different in two adjacent areas, each area must be considered a separate zone.

Verified by: Letter of Assurance – Engineer

Letter of Assurance -Engineer

Option 4: Ventilation monitoring

One of the following carbon dioxide thresholds is met in occupiable spaces:

a. 750 ppm or less.

b. Not more than 350 ppm above outdoor levels.

Verified by: Sensor Data

Note: Refer to the Performance Verification Guidebook for information on sensor/testing requirements, required testing duration and compliance calculations.

Figure 10 WELL feature A06 (enhanced ventilation design), Part 1, Options 2 and 4

Mapping to XENSIV™ PAS CO2 characteristics

The requirements are well within the characteristics of the sensor as defined per its datasheet:

- Operating range: 0 to 32,000 ppm
- Accuracy: +/-30 ppm +/-3% for reading between 400 and 5000 ppm
- Interfaces: I^{2}C and UART, enabling communication with a microcontroller which is itself connected to the building management system.

4.2.3 A08 – air quality monitoring and awareness

Type of requirement

This requirement is an **optimization** (max. 2 points).

Summary

This WELL feature requires the ongoing measurement of contaminant data to educate and empower occupants about their environmental quality.

Description

This feature is aimed at informing and educating individuals on the air quality of their indoor environment. It consists of two parts. Part 1 (1 point) requires the installation of indoor air monitors.

1: Sensor requirements

The project deploys monitors with sensors that measure at least three of the following parameters in occupiable spaces in compliance with the requirements outlined in the Continuous Monitoring Protocols of the Performance Verification Guidebook:

a. $PM_{2.5}$ or PM_{10}.
b. Carbon dioxide.
c. Carbon monoxide.
d. Ozone.
e. Nitrogen dioxide.
f. Total VOCs.
g. Formaldehyde.

Verified by On-site Photographs , Letter of Assurance – Engineer

Letter of Assurance -Engineer

AND

2: Reporting & maintenance

The following requirements are met:

a. Data are submitted annually through the WELL digital platform.
b. Proof of calibration or replacement is submitted annually in accordance with the requirements of the WELL Performance Verification Guidebook.

Verified by On-going Data Report

Note:
Refer to the Performance Verification Guidebook for information on sensor/testing requirements, required testing duration and compliance calculations.

Figure 11 WELL feature A06 (air quality monitoring and awareness), Part 1

Note: The requirements on reporting and maintenance only apply to non-dwelling units.

Part 2 (1 point) is about the promotion of air quality awareness.

Part 2

Promote Air Quality Awareness (1 Point)

For All Spaces except Dwelling Units

> **Note:**
> Projects may only receive points for this part, if Part 1 is also achieved

Information about the air quality measured in Part 1 of this feature is made available to occupants as follows:

a. Data are presented through one of the following:

1. Display screens prominently positioned at a height of 3.6–5.6 ft with at least one display per 5400 ft^2 of regularly occupied space.
2. Hosted on a website or phone application accessible to occupants. Signs are present indicating where the data may be accessed at a density of at least one sign per 5400 ft^2 of regularly occupied space.

b. Data presented include one of the following:

1. Concentrations of the parameters measured.
2. Qualitative results of air quality (e.g., colored-coded levels).

Verified by On-site Photographs , Letter of Assurance – Owner

Letter of Assurance -Owner

Figure 12 WELL feature A06 (air quality monitoring and awareness), Part 2

Mapping to XENSIV™ PAS CO2 characteristics

The requirements are well within the characteristics of the sensor as defined per its datasheet:

- Operating range: 0 to 32,000 ppm
- Accuracy: +/-30 ppm +/-3% for reading between 400 and 5000 ppm
- Maximum drift per year: 1% (with ABOC function)

4.2.4 X01 and X05: materials-related features

The WELL materials concept aims at reducing human exposure, whether direct or through environmental contamination, to chemicals that may impact health during the construction, remodeling, furnishing and operation of buildings.

RoHS compliance is required in the following features.

Table 4 Materials-related requirements where RoHS compliance is required

WELL feature	Requirement	Scope
X01 – material restrictions (precondition)	Part 2: Restrict mercury	Newly installed fire alarms, meters, sensors, relays, thermostats and load-break switches
	Part 3: Restrict lead	Paints and electronics
X05 – enhanced material restrictions (optimization)	Part 1: Select compliant interior furnishings	Electrical and electronic products

Mapping to XENSIV™ PAS CO2 characteristics

XENSIV™ PAS CO2 is guaranteed to be RoHS compliant [32]. A detailed description of the sensor's material is available in the material content datasheet [33].

5 XENSIV™ PAS CO2 contribution to LEED v4.1 BD+C

LEED also defines two categories of features: prerequisite and credits. The subsections below describe the features (prerequisite or credits) to which XENSIV™ PAS CO2 contributes. The results below are based on the multilevel mapping analysis performed by Habitech.

5.1 Overview of the contributions to LEED

Table 5 Overview of the contributions of XENSIV™ PAS CO2 to the LEED features

LEED category			Max. Points
Energy and Atmosphere	Prerequisite	Fundamental commissioning and verification	-
Energy and Atmosphere	Credit	Enhanced commissioning	6
Energy and Atmosphere	Prerequisite	Minimum energy performance	-
Energy and Atmosphere	Credit	Optimize energy performance	18
Material and Resources	Credit	PBT source reduction	2
Indoor Environmental Quality	Credit	Enhanced indoor air quality strategies	2
Total max. points			**28**

5.2 LEED feature analysis

5.2.1 EA Prerequisite - fundamental commissioning and verification (LEED BD+C V4.1)

Summary

This feature aims at supporting the design, construction and eventual operation of a project that meets the owner's project requirements for energy, water, indoor, environmental quality and durability.

Description

Requirements

Commissioning Process Scope

Complete the following commissioning (Cx) process activities for mechanical, electrical, plumbing, and renewable energy systems and assemblies, in accordance with ASHRAE Guideline 0-2013 and ASHRAE Guideline 1.1–2007 for HVAC&R Systems, as they relate to energy, water, indoor environmental quality, and durability.

- Develop the OPR.
- Develop a BOD.

The commissioning authority (CxA) must do the following:

- Review the OPR, BOD, and project design.
- Develop and implement a Cx plan.
- Confirm incorporation of Cx requirements into the construction documents.
- Develop construction checklists.
- Develop a system test procedure.
- Verify system test execution.
- Maintain an issues and benefits log throughout the Cx process.
- Prepare a final Cx process report.
- Document all findings and recommendations and report directly to the owner throughout the process.

Figure 13 LEED feature: fundamental commissioning and verification

Mapping to XENSIV™ PAS CO2

Infineon contributes to the commissioning process providing information about the installation and the use of the sensor. The reference documents provide recommendations to ensure ideal operation, such as typical application scenarios, handling precautions, etc. For example, the sensor should be isolated from potential sources of disturbance in the end application.

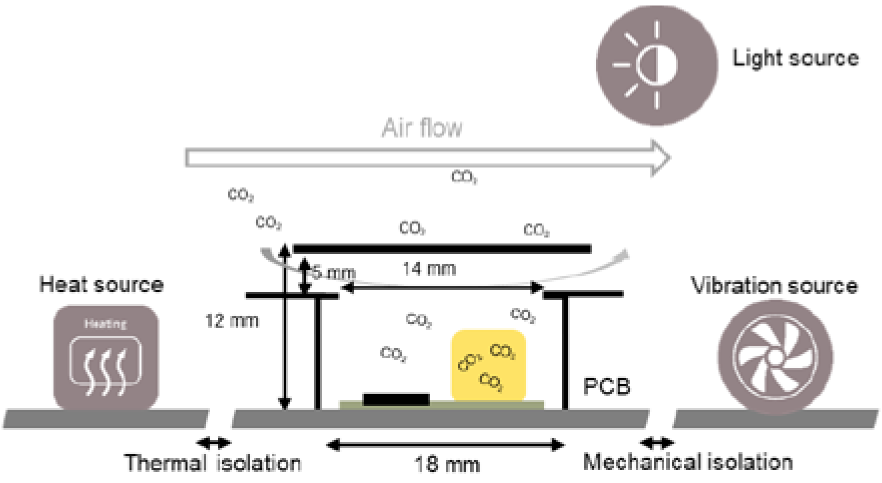

Figure 14 Preventive measures to be considered in the application using XENSIV™ PAS CO2

The reference documents of interest are:

- XENSIV™ PAS CO2 datasheet
- Application note: General design in guidelines for XENSIV™ PAS CO2 sensor [34]
- Application Note: Recommendations for board assembly of Infineon modules with land grid array terminations [35]

5.2.2 EA Credit – enhanced commissioning (LEED BD+C V4.1)

Summary

This feature aims at supporting the design, construction, and eventual operation of a project that meets the owner's project requirements for energy, water, indoor environmental quality, and durability.

Description

Requirements

Implement, or have in place a contract to implement, the following commissioning process activities in addition to those required under EA Prerequisite Fundamental Commissioning and Verification. Commissioning Authority Qualifications:

- The CxA must have documented commissioning process experience on at least two building projects with a similar scope of work. The experience must extend from early design phase through at least 10 months of occupancy;
- The CxA may be a qualified employee of the owner, an independent consultant, an employee of the design or construction firm who is not part of the project's design or construction team, or a disinterested subcontractor of the design or construction team.

Option 1. Enhanced Systems Commissioning (3-4 points)

Path 1: Enhanced Commissioning (3 points)

Complete the following commissioning process (CxP) activities for mechanical, electrical, plumbing, and renewable energy systems and assemblies in accordance with ASHRAE Guideline 0–2013 and ASHRAE Guideline 1.1–2007 for HVAC&R systems, as they relate to energy, water, indoor environmental quality, and durability. The commissioning authority must do the following:

- Review contractor submittals.
- Verify inclusion of systems manual requirements in construction documents.
- Verify inclusion of operator and occupant training requirements in construction documents.
- Verify systems manual updates and delivery.
- Verify operator and occupant training delivery and effectiveness.
- Verify seasonal testing.
- Review building operations 10 months after substantial completion.
- Develop an on-going commissioning plan.

Include all enhanced commissioning tasks in the OPR and BOD. OR

Figure 15 LEED feature: enhanced commissioning, Option 1, Part 1

Mapping to XENSIV™ PAS CO2

Infineon contributes to the commissioning process providing information about the installation and the use of the sensor. The reference documents provide recommendations to ensure ideal operation, such as typical application scenarios, handling precautions, etc.

The reference documents of interest are:

- XENSIV™ PAS CO2 Datasheet
- Application note: General design in guidelines for XENSIV™ PAS CO2 sensor
- Application Note: Recommendations for board assembly of Infineon modules with land grid array terminations

5.2.3 EA Prerequisite - Minimum energy performance (LEED BD+C V4.1)

Summary

This feature aims at promoting resilience and reduce the environmental and economic harms of excessive energy use that disproportionately impact frontline communities by achieving a minimum level of energy efficiency for the building and its systems.

Description

Requirements

Comply with ANSI/ASHRAE/IESNA Standard 90.1–2016, with errata or a USGBC-approved equivalent standard. ASHRAE 90.1-2016 Compliance pathways in Section 4.2.1.1 include compliance with all mandatory provisions, and compliance with one of the following:

- Prescriptive provisions of Sections 5 through 10
- Section 11 Energy Cost Budget Method
- Normative Appendix G Performance Rating Method. When using Appendix G, the Performance Cost Index (PCI) shall be less than or equal to the Performance Cost Index Target (PCIt) in accordance with the methodology provided in Section 4.2.1.1. Document the PCI, PCIt, and percentage improvement using metrics of cost or greenhouse gas (GHG) emissions.

Figure 16 LEED feature: minimum energy performance

Whereas mandatory provision 6.4.3.9 of standard ASHRAE 90.1-2010 stipulates [36]:

Mandatory provision *6.4.3.9 - Ventilation Controls for High-Occupancy Areas* of the technical standard ASHRAE 90.1-2010:
Demand control ventilation (DCV) is required for spaces larger than 50 m^2 and with design occupancy for ventilation of greater than 40 people per 100 m^2 of floor area and served by systems with one or more of the following:
a) an air-side economizer.
b) automatic modulating control of the outdoor air damper or
c) a design outdoor airflow greater than 1400 l/s.

Exceptions:
a) System with the exhaust air energy recovery complying with Section 6.5.6.1.
b) Multiple-zone systems without DDC of individual zones communicating with a central control panel.
c) Systems with a design outdoor airflow less than 600 l/s.
d) Spaces where the supply airflow rate minus any makeup or outgoing transfer air requirement is less than 600 l/s.

Figure 17 Mandatory provision 6.4.3.9 as per ASHRAE 90.1-2010

Mapping to XENSIV™ PAS CO2

XENSIV™ PAS CO2 contributes to the fulfillment of the mandatory provision 6.4.3.9 Ventilation Controls for High-Occupancy Areas of the technical standard ASHRAE 90.1-2010 by supporting the implementation of DCV.

The reference documents of interest are:

- XENSIV™ PAS CO2 Datasheet
- DCV implementation (see section 1.5.2.2)

5.2.4 EA Credit - optimize energy performance (LEED BD+C V4.1)

Summary

This feature aims at achieving increasing levels of energy performance beyond the prerequisite standard to reduce environmental and economic harms associated with excessive energy use that disproportionately impact frontline communities.

Description

Requirements

Analyze efficiency measures during the design process and account for the results in design decision making. Use energy simulation of efficiency opportunities, past energy simulation analyses for similar buildings, or published data (e.g., Advanced Energy Design Guides) from analyses for similar buildings.

Analyze efficiency measures, focusing on load reduction and HVAC-related strategies (passive measures are acceptable) appropriate for the facility. Project potential energy savings and holistic project cost implications related to all affected systems.

Choose one of the options below.

Option 1. Energy Performance Compliance (1–18 points except Schools and Healthcare, 1–16 points Schools, 1–20 points Healthcare)

Demonstrate a Performance Cost Index (PCI)1 below the Performance Cost Index Target (PCIt) calculated in accordance with Section 4.2.1.1 of ANSI/ASHRAE/IESNA Standard 90.1-2016, Appendix G, Table 4.2.1.1. For mixed use buildings, the required PCI shall be calculated by using an area weighted average of the building types.
Calculate the PCI, PCIt, and percentage improvement using metrics of cost and greenhouse gas (GHG) emissions. For each energy source serving the building, the GHG emission factors must be identical for the Baseline and Proposed building models.

LEED points are calculated based on the project percent improvement PCI below the PCIt using metrics of cost and GHG emissions. Total points have been divided equally between the metrics of energy cost and greenhouse gas emissions. Points are awarded according to Table 1 and Table 2.

Figure 18 LEED feature: optimize energy performance, option 1

Mapping to XENSIV™ PAS CO2

XENSIV™ PAS CO2 contributes to energy savings through the use of Demand Control Ventilation based on the monitored CO2 concentration (air flow rate is modulated on the basis of the monitored CO2 concentration. Reduction of the air flow rates during less occupied hours allows energy savings in ventilation and in air conditioning. The calculation of the energy performance can be through a dynamic energy model).

The reference documents of interest are:

- XENSIV™ PAS CO2 Datasheet
- DCV implementation (see section 1.5.2.2)

5.2.5 MR Credit – PBT source reduction (LEED BD+C V4.1 Healthcare)

Summary

This feature aims at reducing mercury-containing products and devices and mercury release through product substitution, capture, and recycling.

Description

Requirements

As part of the project's recycling collection system, identify the following:

- types of mercury-containing products and devices to be collected;
- criteria governing how they are to be handled by a recycling program; and
- disposal methods for captured mercury.

Applicable mercury-containing products and devices include, but are not limited to, lamps (such as linear and circular fluorescents, integrally ballasted and nonintegrally ballasted compact fluorescents and HIDs) and dental wastes (such as scrap amalgam, chair side traps, and separator wastes). In facilities delivering dental care, specify and install amalgam separation devices that meet or exceed the ISO-11143 standard. Comply with the mercury elimination requirements outlined below, from the 2010 FGI Guidelines for Design and Construction of Health Care Facilities, Section A1.3- 4b, Mercury Elimination.

- 4.2.1.1. New construction: healthcare facilities may not use mercury-containing equipment, including thermostats, switching devices, and other building system sources. Lamps are excluded.
- 4.2.1.2. Renovation: healthcare facilities must develop a plan to phase out mercury-containing products and upgrade current mercury-containing lamps to high-efficiency, low-mercury, or mercury-free lamp technology.

Figure 19 LEED feature: PBT source reduction

Mapping to XENSIV™ PAS CO2

XENSIV™ PAS CO2 contributes to this feature by being compliant to the RoHS Directive (Restriction of hazardous substances in electrical and electronic equipment).

The reference documents of interest are:

- XENSIV™ PAS CO2 Datasheet
- Material content datasheet
- Declaration of compliance to the RoHS Directive

5.2.6 EQ Credit – Enhanced indoor air quality strategies (LEED BD+C V4.1)

Summary

This feature aims at promoting occupants' comfort, well-being, and productivity by improving indoor air quality.

Description

Requirements

Comply with 3 strategies for 1 point or 6 strategies for 2 points

Strategy 9. Carbon Dioxide Monitoring

Monitor CO2 concentrations within all densely occupied spaces. CO2 monitors must be between 3 and 6 feet (900 and 1 800 millimeters) above the floor. CO2 monitors must have an audible or visual indicator or alert the building automation system if the sensed CO2 concentration exceeds the setpoint by more than 10%. Calculate appropriate CO2 setpoints using methods in ASHRAE 62.1–2016, Appendix D.

Figure 20 LEED feature: enhanced indoor air quality strategies, strategy 9

Mapping to XENSIV™ PAS CO2

XENSIV™ PAS CO2 contributes to this feature by being compliant to accuracy requirements for CO2 sensors as defined in ASHRAE 62.1:2019 (see section 3) and being able to communicate its sensed values via its digital interfaces to a host controller.

The reference documents of interest are:

- XENSIV™ PAS CO2 Datasheet

6 Conclusion

XENSIV™ PAS CO2 is a new generation of CO_2 sensor based on PAS technology, offering major advantages compared to state-of-the-art NDIR sensors: smaller size, higher mechanical robustness, support of highly efficient SMD manufacturing process, etc.

The results presented in this study demonstrate that XENSIV™ PAS CO2 is compatible with the requirements defined by the WELL Building Standard™ towards CO_2 sensors in terms of operating range, accuracy and resolution. Based on the expertise of Habitech, an accredited WELL performance testing organization and LEED proven provider, a detailed analysis of the contribution of the sensor to WELL features was provided.

Similarly, the compliancy of XENSIV™ PAS CO2 to LEED requirements and its contribution to LEED features was analyzed.

Because XENSIV™ PAS CO2 has been developed to serve high volume application, it provides an excellent cost/benefit ratio when used in the context of a WELL or LEED building concept.

7 Revision history

Table 6 Versions tracking

Reference	Description	Date
1.0	Creation	01.03.2023
2.0	LEED analysis added	08.03.2023

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