Compliance of Sensirion's VOC Sensors with Building Standards

Related to All Sensirion Products with a VOC Index Output

Preface

Metal-oxide (MOX) gas sensors such as Sensirion's SGP4x are a cost-efficient solution to continuously monitor indoor air quality. However, unlike the selective and quantitative measurements of a gas chromatograph coupled to a mass spectrometer (GC-MS), MOX sensors are limited to non-selective measurements of concentration ratios. Nonetheless, MOX sensors may fulfill the absolute TVOC concentration requirements of international building and health standards under defined conditions. These involve an equivalent concentration output, whose relation to the sensor's raw signal is valid under laboratory conditions as defined by the sensor manufacturer. It is expected that absolute measurements in the field will deviate from the true TVOC concentration.

This application note describes how Sensirion's VOC Index in IAQ monitors can be used to comply with standards like RESET® Air[1] and WELL Building Standard®[2]. First, the equivalence of the VOC Index to the ethanol concentration in parts per billion (ppb) under well-controlled laboratory conditions is established. Then the conversion of the ethanol concentration value to general TVOC in μg/m^3 according to the respective building standards is provided. **The laboratory tests do not need to be reproduced to comply with RESET® Air and WELL Building Standard®**.

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[1] RESET® Air is a registered trademark of GIGA. https://www.reset.build/standard/air
[2] WELL Building Standard® is a registered trademark of the International WELL Building Institute. https://standard.wellcertified.com/well

Contents

1 Introduction to TVOC

1.1 TVOC definition

Volatile organic compounds (VOCs) are molecules which are commonly found in indoor air environments, together with very volatile organic compounds (VVOCs) and semi-volatile organic compounds (SVOCs). The sum of all concentrations of single VOCs corresponds to the *total* VOC (TVOC) concentration which is used as an indication for contamination of indoor air.

TVOC is typically quantified either as a mass concentration in µg/m^3 or as a molar concentration in parts per billion (ppb). Typically, building standards define a safe threshold of average TVOCs in µg/m^3.

1.2 TVOC in real life

Although many indoor VOCs are harmful chemicals found in paints, furniture, and plastics, some contributors to TVOC can also be harmless and found in *e.g.* perfumes, food, and drinks. Assuming that the concentration of each individual VOC in the air is known, the true TVOC concentration can be calculated. However, this information does not reflect how harmful or harmless a specific TVOC concentration in a given indoor air situation is. This can be visualized by an analogy to colored liquids contained in three buckets. Once mixed, it is difficult to trace back the mixing ratio and the original color of each liquid, as shown in **Figure 1**:

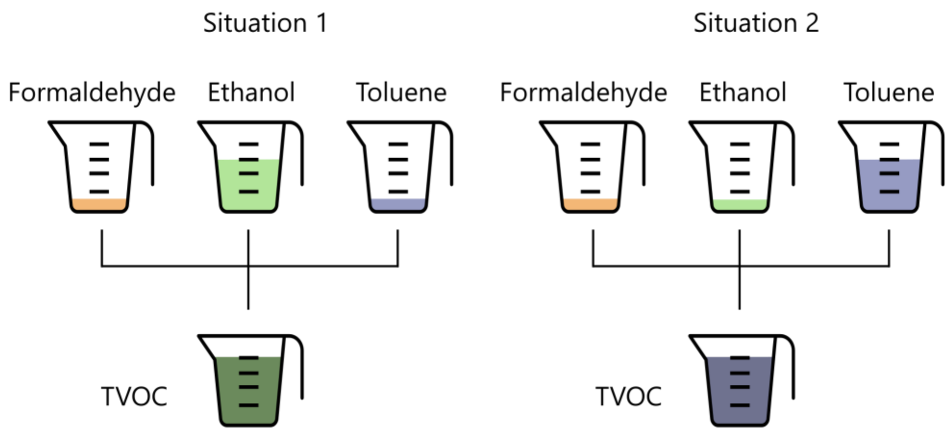

Figure 1. Schematic representation of TVOC where color and amount of the liquid represent type and partial pressure (concentrations) of VOCs respectively. While situations 1 and 2 have the same TVOC concentration, in situation 1 the TVOC value is dominated by harmless ethanol, while in situation 2 the main contribution to the same TVOC value comes from harmful toluene.

As an example, consider a 20 m^2 (~200 sq. ft) room initially filled with clean air. A dinner lasting 1 to 2 hours may increase the TVOC concentration by 10 ppm (**Figure 1**, situation 1). In this scenario, the high TVOC concentration is predominantly driven by harmless ethanol. Alternatively, consider the same 20 m^2 room initially filled with clean air. An open can of oil paint may also increase the TVOC concentration by 10 ppm (**Figure 1**, situation 2). In this scenario, the high TVOC concentration is predominantly driven by harmful toluene. In both cases, the TVOC concentration cannot inform us about individual VOCs present in the air nor how harmful a given situation is.

Distinguishing individual VOCs in indoor air would solve this problem. However, this is not a trivial task, as is discussed in the next section.

1.3 Measuring VOCs

1.3.1 Gas Chromatography – Mass Spectrometry (GC-MS)

GC-MS measures the concentration of individual VOCs present in the air, typically in **mass** concentration units: µg/m^3. The atmosphere can be analyzed on-line and in real time, by placing large and expensive laboratory-grade equipment in a room. For determining the TVOC level in a large number of rooms this is not commercially viable. To get a snapshot of the TVOC level in a room, absorber tubes are typically positioned in a room for a certain duration (typically hours). Then these tubes are sent to a specialized laboratory to perform first separation of the adsorbed gases (by means GC) and then their quantification (by means of MS). In this manner, GC-MS yields the exact amount for each constituent of the gas mixture collected during the exposure time of the absorber. While the cost per measurement of this method is much lower than for the real-time GC-MS analysis, and it is commonly performed during the commissioning of a new building, it is not a viable option for continuous monitoring nor for time-resolved detection of VOC events.

Online or off-line GC-MS enables the exact quantification of individual VOCs present in the air, as schematically represented in **Figure 2**.

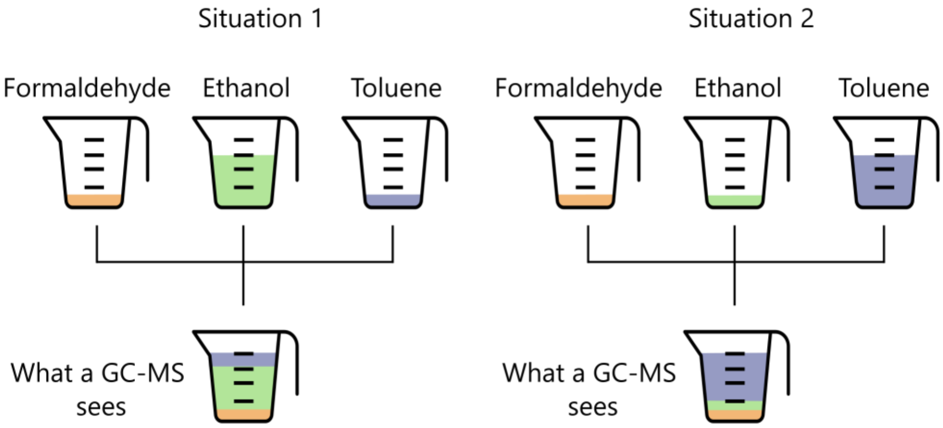

Figure 2. Schematic representation of GC-MS measurements of a VOC mixture. Note that information about type and concentration is still traceable, since GC-MS provides for each gas component an individual signal output.

1.3.2 Metal Oxide Gas sensors (MOX)

Metal Oxide Gas sensors measure the presence of oxidizing and reducing gases in the air, typically in **molar** concentration units: ppb. MOX sensors can continuously measure indoor VOCs, at low cost.

In short, the metal oxide material is exposed to indoor air, and the sensor electronically measures the presence of reducing gases which are mainly VOCs. Measurements can be performed up to several times per second.

Continuous measurement of VOCs is essential to monitoring indoor air quality over time. As opposed to single GC-MS measurements, MOX measurements enable the detection of events affecting indoor air quality.

However, VOC monitoring using MOX technology intrinsically has some disadvantages compared to GC-MS:

- A MOX sensor has typically **unknown** and **different selectivity** towards individual VOCs. While it is more selective towards certain VOCs, it can hardly identify them, as shown in **Figure 3**.
- A single MOX sensor generates a **single, aggregate output** for a VOC mixture. As a result, such MOX sensors cannot distinguish individual VOCs present in the air. This is schematically shown in **Figure 4** where the sensor observes the same gray color for two different gas mixtures in Variant 1 and 2.

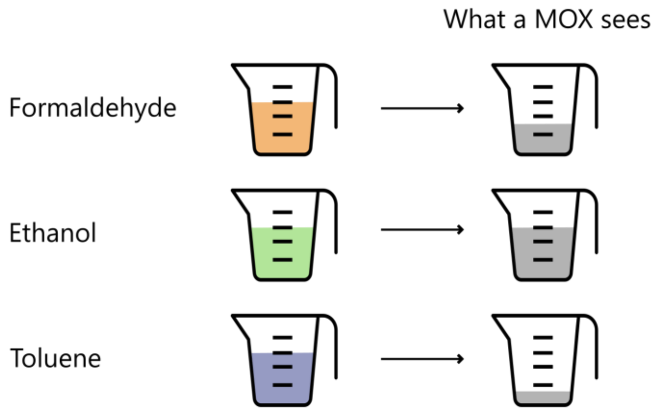

Figure 3. Schematic representation of the varying selectivity of a MOX sensor towards different VOCs.

While the sensitivity to individual VOCs can be characterized in well-controlled laboratory experiments, in real life MOX sensors typically provide a **non-selective single output** which is a sum of individual VOCs present in the air measured with unknown and different selectivity, as schematically represented in **Figure 4**.

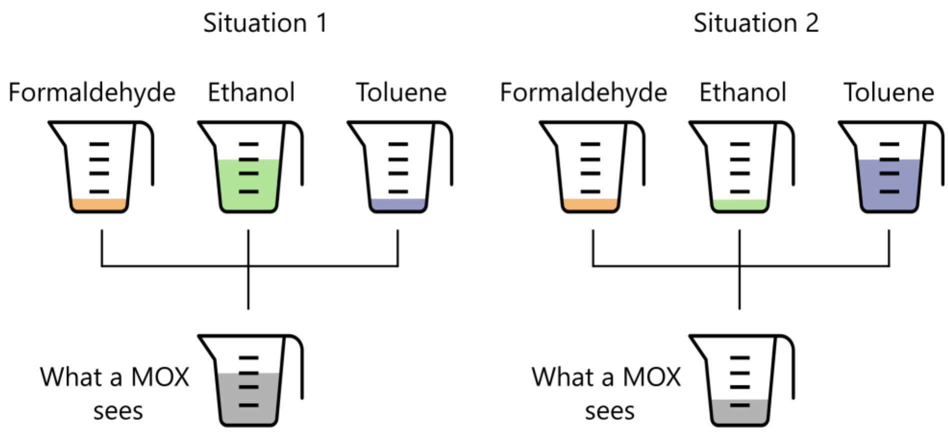

Figure 4. Representation of the non-selective single output of a MOX sensor exposed to a VOC mixture. Note that information about type (color) and concentration (amount) of the individual VOCs is not comprehensible anymore. Moreover, the TVOC value depends on the TVOC composition.

However, despite its above-mentioned limitations, MOX technology is an integral part of continuously monitoring air quality as required by building standards and it is the only commercially viable option available to date to continuously monitor indoor VOCs on a large scale. It yields immediate results and can easily be implemented into consumer products. The real-time feedback provided by MOX sensors empowers end-users to monitor their indoor air quality and assess the effectiveness of IAQ improvement measures.

2 Use of Sensirion's VOC Index in building standards

2.1 Converting Sensirion's VOC Index into $TVOC_{ethanol}$ ppb output

Considering the non-selective single output of MOX sensors, Sensirion recommends the use of the VOC Index as end-user output in IAQ devices. However, international building standards often rely on absolute TVOC concentrations. A detailed procedure to convert the VOC Index into equivalent TVOC concentration, which is only valid under laboratory conditions, is provided below. We recommend using the VOC Index algorithm specific tuning parameters optimized for indoor air quality monitoring applications, see **Table 1**.

To convert the VOC Index into equivalent TVOC, Sensirion recommends using ethanol as calibration gas. To train Sensirion's VOC Algorithm, the pre-defined learning sequence under a controlled laboratory environment shall be executed, as depicted in **Figure 5** left. The data shown herein were collected with the tuning parameters as stated in **Table 1**. This set of parameters is specifically suitable for IAQ monitors compliant with International Building Standards and aiming at displaying both short-terms events and long-term trends over the course of a few days to weeks.

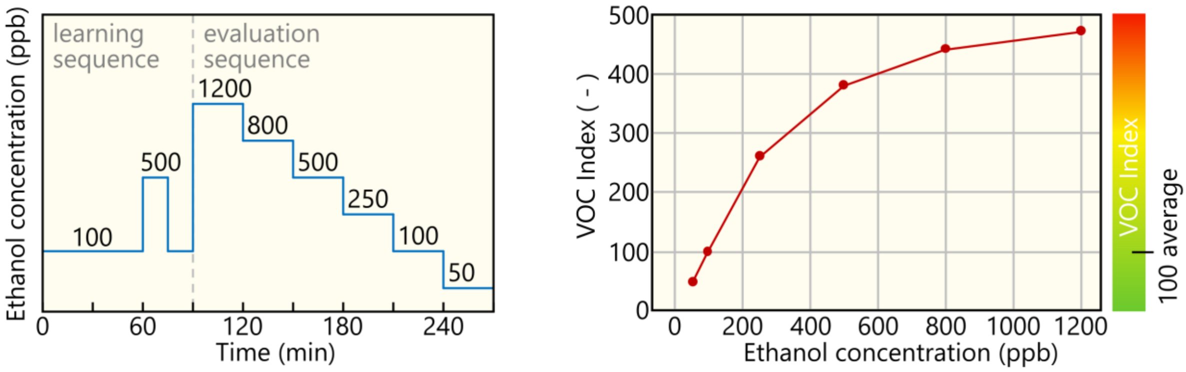

Figure 5. Standard testing sequence (left) and the resulting correlation thereof between VOC Index and ethanol concentration (right). This correlation can be further used as an approximation to convert VOC Index into concentration of TVOC. Note: tuning parameters as summarized in **Table 1** were used in this test.

Parameter	Symbol	Default Tuning Parameters	Specific Tuning Parameters for Building Standards	Unit
Average VOC Index	$\bar{x}_{\text{Index}}$	100	-	-
Normal learning time offset	t_{offset}	12	720	h
Normal learning time gain	t_{gain}	12	-	h
Maximum gating duration	t_{gating}	180	-	min
Initial standard deviation	σ_{initial}	50	-	-
Gain factor	f_{gain}	230	-	-

Table 1. Recommended parameter settings for the VOC Index algorithm when used in IAQ monitors compliant with international building standards. The normal learning time offset is different from the default values and should be set to 720 h to monitor trends on the timescale of weeks. Changing the normal learning time offset does not affect the time needed by the sensor to meet specifications.

The use of ethanol as calibration gas (**Figure 5** left) leads to a fixed relation between the VOC Index and ethanol concentration (**Figure 5** right), which is described in equation eq. 1:

$$\mathrm{TVOC}_{\mathrm{Ethanol}}\ [ppb] = (\ln(501 - VOC_{Index}) - 6.24) \cdot (-381.97) \qquad \text{eq. 1}$$

Where $\mathrm{TVOC}_{\mathrm{Ethanol}}$ is the ethanol equivalent of TVOC and is proportional to any other equivalents of TVOC *e.g.* to isobutylene as suggested by RESET® Air, or the Mølhave gas mixture[3] used in the WELL Building Standard®. In the following sections we provide the conversion factors between the $\mathrm{TVOC}_{\mathrm{Ethanol}}$ derived from equation 1 to the TVOC equivalents used in building standards.

2.2 Converting ethanol concentration into WELL Building Standard® compliant TVOC concentration

According to the Performance Guidebook v.2 of the WELL Building Standard®[4], performance of an IAQ monitor can be assessed by using ethanol as calibration gas and the Mølhave gas mixture to convert the ethanol concentration into the Mølhave equivalent of TVOC or $\mathrm{TVOC}_{\mathrm{Mølhave}}$. The conversion factor between $\mathrm{TVOC}_{\mathrm{Mølhave}}$ and $\mathrm{TVOC}_{\mathrm{Ethanol}}$ has been determined by measuring the sensor's response to the Mølhave gas mixture, consisting of 22 VOCs commonly found in residential indoor environments[3].

$$\mathrm{TVOC}_{\mathrm{Mølhave}}\ [\mathrm{ppb}] = 0.58 \cdot \mathrm{TVOC}_{\mathrm{Ethanol}}\ [\mathrm{ppb}] \qquad \text{eq. 2}$$

The TVOC concentration in µg/m[3] is calculated from the TVOC concentration in ppb according to the WELL Building Standard® guidelines, using equation 3:

$$\mathrm{TVOC}_{\mathrm{Mølhave}}\ [\mu\mathrm{g/m^3}] = 4.5 \cdot \mathrm{TVOC}_{\mathrm{Mølhave}}\ [\mathrm{ppb}] \qquad \text{eq. 3}$$

In summary, the TVOC in µg/m[3] is calculated from the VOC Index according to the WELL Building Standard® guidelines, using equation 4:

$$\mathrm{TVOC}_{\mathrm{Mølhave}}\ [\mu\mathrm{g/m^3}] = (\ln(501 - VOC_{Index}) - 6.24) \cdot (-996.94) \qquad \text{eq. 4}$$

Note: this approach is only a simplification since real indoor gas compositions may vary significantly over time and from environment to environment.

2.3 Converting ethanol concentration into RESET® Air compliant TVOC concentration

According to the RESET® Air[5] standard for Accredited Monitors, isobutylene can be used as a "middle ground" to convert ppb into µg/m[3] to assess the performance of an IAQ monitor, as shown in equation 5:

$$\mathrm{TVOC}_{\mathrm{Isobutylene}}\ [\mu\mathrm{g/m^3}] = 2.3 \cdot \mathrm{TVOC}_{\mathrm{Ethanol}}\ [\mathrm{ppb}] \qquad \text{eq. 5}$$

In summary, the TVOC in µg/m[3] is calculated from the VOC Index according to the RESET® Air guidelines, using equation 6:

$$\mathrm{TVOC}_{\mathrm{Isobutylene}}\ [\mu\mathrm{g/m^3}] = (\ln(501 - VOC_{Index}) - 6.24) \cdot (-878.53) \qquad \text{eq. 6}$$

Note: this approach is only a simplification since real indoor gas compositions may vary significantly over time and from environment to environment.

[3] Mølhave L, Bach R, Pederson OF, *Environ Int* 12:167–175 (1986). https://doi.org/10.1016/0160-4120(86)90027-9
[4] WELL Building Standard® is a registered trademark of the International WELL Building Institute. https://standard.wellcertified.com/well
[5] RESET® Air is a registered trademark of GIGA. https://www.reset.build/standard/air

2.4 Field data

Field data of Sensirion's VOC Index (left) over one month and the corresponding $\mathrm{TVOC_{Isobutylene}}$ and $\mathrm{TVOC_{Mølhave}}$ concentration according to RESET® Air and WELL Building Standard® (right) are shown in **Figure 6**.

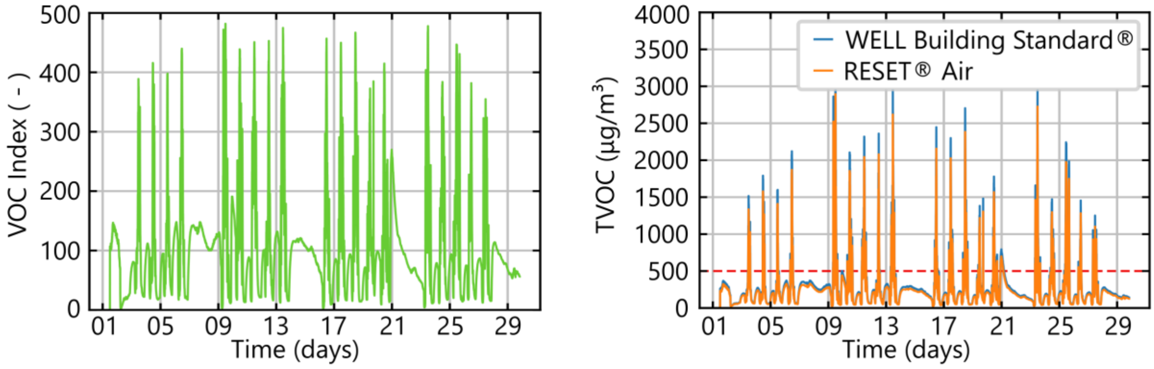

Figure 6. VOC Index (left) and corresponding $\mathrm{TVOC_{Isobutylene}}$ and $\mathrm{TVOC_{Mølhave}}$ concentration outputs according to RESET® Air and WELL Building Standard®, respectively (right).

2.5 Accuracy of Sensirion's VOC sensors, according to WELL Building Standard® requirements

WELL Building Standard® has accuracy requirements for continuously monitoring sensors[6]. The accuracy of Sensirion's VOC sensor in building environments is estimated by exposing the sensors to the varying VOC concentrations and recording their performance. The laboratory conditions presented in Section 2.1 can be used to perform this test.

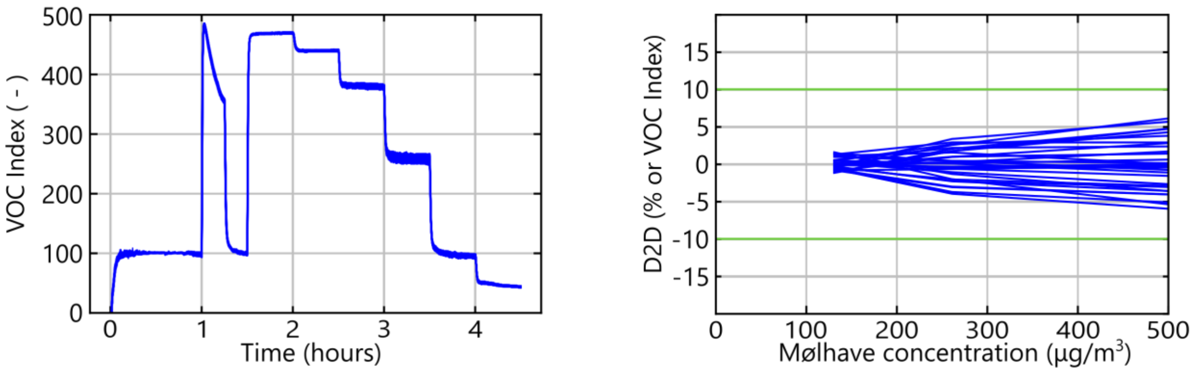

Figure 7. Repeated measurement of 30 sensors under the laboratory conditions presented in Section 2.1 (left). The corresponding device-to-device variation (D2D) is reported as a function of the Mølhave concentration.

The device-to-device variation (D2D) of Sensirion's sensors lies within ±10 VOC Index points in the range 0 to 500 µg/m³, as reported in **Figure 7**. From these measurements, the accuracy of Sensirion's VOC sensors can be generated as a function of Mølhave VOC gas mixture using eq. 4, as reported in **Figure 8**.

[6] WELL Performance Verification Guidebook, version Q4 2022. https://a.storyblok.com/f/52232/x/0364a6b272/well-performance-verification-guidebook_q4-2022_final.pdf

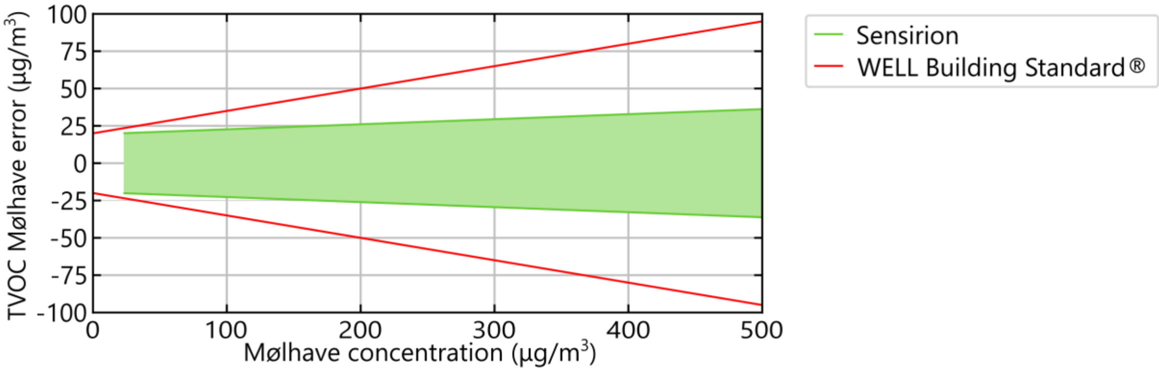

Figure 8. Accuracy of Sensirion's sensors, as a function of TVOC Mølhave concentration (green). The error is within the maximum allowed error according to the WELL Building Standard (± 20 µg/m^3 + 15% measured value).

The accuracy of Sensirion's VOC sensors lies within the requirements of the WELL Building Standard®, as shown in **Figure 8**.

3 Revision History

Date	Version	Pages	Changes
29 (March 2023)	1.0	all	Initial version
19 (September 2023)	1.1	all	Preface modification Correction of maximum gating duration Section 2.1 Addendum of Section 2.5

Important Notices

Warning, Personal Injury

Do not use this product as safety or emergency stop devices or in any other application where failure of the product could result in personal injury. Do not use this product for applications other than its intended and authorized use. Before installing, handling, using or servicing this product, please consult the data sheet and application notes. Failure to comply with these instructions could result in death or serious injury.

If the Buyer shall purchase or use SENSIRION products for any unintended or unauthorized application, Buyer shall defend, indemnify and hold harmless SENSIRION and its officers, employees, subsidiaries, affiliates and distributors against all claims, costs, damages and expenses, and reasonable attorney fees arising out of, directly or indirectly, any claim of personal injury or death associated with such unintended or unauthorized use, even if SENSIRION shall be allegedly negligent with respect to the design or the manufacture of the product.

ESD Precautions

The inherent design of this component causes it to be sensitive to electrostatic discharge (ESD). To prevent ESD-induced damage and/or degradation, take customary and statutory ESD precautions when handling this product. See application note "ESD, Latchup and EMC" for more information.

Warranty

SENSIRION warrants solely to the original purchaser of this product for a period of 12 months (one year) from the date of delivery that this product shall be of the quality, material and workmanship defined in SENSIRION's published specifications of the product. Within such period, if proven to be defective, SENSIRION shall repair and/or replace this product, in SENSIRION's discretion, free of charge to the Buyer, provided that:

- notice in writing describing the defects shall be given to SENSIRION within fourteen (14) days after their appearance;
- such defects shall be found, to SENSIRION's reasonable satisfaction, to have arisen from SENSIRION's faulty design, material, or workmanship;
- the defective product shall be returned to SENSIRION's factory at the Buyer's expense; and
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