Total Volatile Organic Compounds (TVOC) and Indoor Air Quality (IAQ)

SGP30 TVOC and CO2eq Sensor

Preface

The SGP30 is a MOX based multi-pixel gas sensor capable of detecting small ambient concentrations of TVOC. The following document describes what TVOC is, lists possible sources, and explains how TVOC concentrations are related to indoor air quality. In real-life applications TVOC denotes a mixture of various abundant volatile organic compounds.
Therefore it is helpful to test TVOC sensor performance under laboratory conditions with so called TVOC proxies, e.g., defined by the ISO16000-29 norm for indoor air quality. This document explains what those ISO normed test gases are and shows that Sensirion's SGP30 gas sensor reveals similar performance for both the ISO-normed TVOC test gas and ethanol, respectively. This reasoning explains why ethanol is used for calibration and specification of the SGP30 TVOC sensor.

1 Introduction

The following document explains in **Section 2** the term of total volatile organic compounds (TVOC) and why this quantity is related to indoor air quality (IAQ) and the so-called IAQ levels. Since Sensirion's SGP30 gas sensor is responsive to a broad range of volatile organic compounds (VOC) and other gases relevant for indoor air quality, the present gas sensing technology is well-suited for monitoring TVOC concentrations and for translating those into IAQ levels. In order to meet Sensirion's high quality standards, each SGP30 sensor is calibrated upon production.

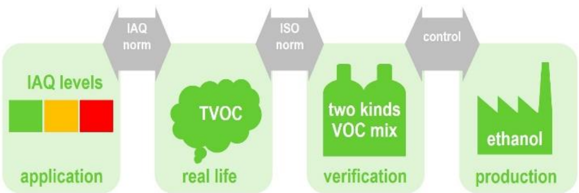

Figure 1 Added value chain of Sensirion's SGP30 gas sensor schematically shows the different verification steps from real-life indoor air quality application to verification in production.

Section 3 lists possible sources of VOCs and gives an overview of applications based on monitoring TVOC such as controlled air purification and ventilation enabled by SGP30 sensors.
Section 4 explains why Sensirion uses ethanol as target gas for calibration and why it serves as a reliable, accurate, harmless, and inexpensive proxy for TVOC by comparison with the ISO norm for indoor air quality.[1]

2 TVOC and Indoor Air Quality

2.1 Definition of TVOC and Relation to Indoor Air Quality

The sum of VOCs[2] corresponds to TVOC[3] and is used as an indication for VOC contamintation. VOC contamination is an established concept in regulatory and scientific literature. Note that the specfic TVOC composition varies between different ambient indoor environments and indoor air is always composed of different volatile organic substances.[4] Therefore, it is helpful to consider TVOC concentrations as statistical reference values which help to

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[1] Ref.: *Indoor air – test methods for VOC detectors, ISO16000-29:2104(E).*

[2] **VOC = Volatile Organic Compounds** includes all chemicals based on carbon chains or carbon rings with a vapor pressure larger than 0.01 kPa at room temperature, i.e., at 293 K or 20 °C." *Ref.: Council Directive 1999/13/EC of 11 March 1999 on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations.*

[3] **TVOC = Total Volatile Organic Compounds** includes the sum of all VOCs which elute between and including *n*-hexane and *n*-hexadecane on a non-polar capillary column.
Ref. (a): *DIN ISO 16000-6: Innenraumluftverunreinigungen (ISO 16000-6:2014), Beuth Verlag, Berlin.*
Ref. (b): *ECA (1997) (European Collaborative Action „Indoor Air Quality and its Impact on Man"): Total Volatile Organic Compounds (TVOC) in Indoor Air Quality Investigations. Report No. 19.*
Ref. (c): *Mølhave L, Bach R, Pederson OF, Environ Int 12:167–175 (1986).*

[4] Ref.: *Mølhave L, Clausen G, Berglund B, et al. (1997) Total Volatile Organic Compounds (TVOC) in Indoor Air Quality Investigations. Indoor Air 7:225–240.*

indicate indoor air quality. Several internationally accepted IAQ guidelines correlate TVOC concentrations with indoor air quality.[5–9]

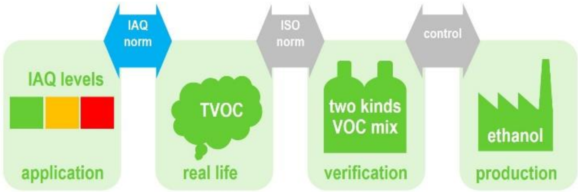

Figure 2 The *blue arrow* highlights the link between ambient TVOC concentrations and indoor air quality.

2.2 Standards for Indoor Air Quality (IAQ)

The following subchapters list a few relevant rating systems for indoor air quality and how indoor air quality can be determined from measuring TVOC concentrations.

2.2.1 IAQ Levels by German Federal Environmental Agency[5]

Following the human perception, the German Federal Environmental Agency translates TVOC concentration (parts per billion) on a logarithmic scale into 5 IAQ levels, as shown in **Table 1**.

Level	Hygienic Rating	Recommendation	TVOC [$\mu g/m^3$]
5 Unhealthy	Situation not acceptable	Intense ventilation necessary	10'000–25'000
4 Poor	Major objections	Intensified ventilation/ airing necessary	3'000–10'000
3 Moderate	Some objections	Intensified ventilation recommended	1'000–3'000
2 Good	No relevant objections	Ventilation/airing recommended	300–1'000
1 Excellent	No objections	Target value	<300

Table 1 IAQ levels and how they are related to TVOC concentration.[5]

Thereby the 5 stages or so-called IAQ levels extend from Level 1 (*excellent*) to Level 5 (*unhealthy*). Extended exposure to increased IAQ levels, i.e., to bad air, can affect the comfort, well-being, and health of building occupants. Poor indoor air quality is linked, e.g., to sick building syndrome, reduced productivity, and impaired learning in schools.

2.2.2 Air Quality Guidelines by the World Health Organization (WHO)[6]

The World Health Organization (WHO) released IAQ guidelines for Europe which are classified by means of TVOC concentration values. Different air quality classes and their corresponding class limits in TVOC concentration are listed in **Table 2**.

Level	Recommendation	TVOC [$\mu g/m^3$]
Outside quality classes	Greatly increased (not acceptable)	>3'000
4	Significantly increased (only temporary exposure)	1'000–3'000
3	Slightly increased (harmless)	500–1'000
2	Average (harmless)	250–500
1	Target value	<250

Table 2 IAQ levels for Europe according to WHO.[6]

2.2.3 RESET Standard for Indoor Air Quality[8]

RESET Air for Commercial Interiors is a continuous monitoring and communication standard for indoor air quality with the goal of raising public awareness of indoor air quality and its impacts on environmental aspects and occupant health. Goal of the standard is continuous monitoring of particulate matter (PM2.5), TVOC, and CO_2 concentrations. Since long-term exposure to VOCs can cause damage to the liver, kidneys and the central nervous system, the RESET standard formulates IAQ performance targets for an average daily exposure to TVOC concentrations, as listed in **Table 3**.

IAQ performance target	TVOC [$\mu g/m^3$]
Acceptable	<500
High Performance	<400

Table 3 IAQ performance targets for ambient TVOC concentration according to the RESET standard for indoor air quality.[8]

2.2.4 LEED Green Building Rating System[9]

LEED, or Leadership in Energy and Environmental Design, ist the most widely used green building rating system. It aims for providing a framework to create healthy, highly efficient, and cost-saving green buildings by providing globally recognized certifications. The LEED scoring function was developed based on the LEED TVOC limit of 500 $\mu g/m^3$, as shown in **Table 4**.

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[5] Bundesgesundheitsblatt – Gesundheitsforschung Gesundheitsschutz 2007, 50:990–1005, Springer Medizin Verlag 2007. (DOI 10.1007/s00103-007-0290-y)
[6] Air quality guidelines for Europe – Second Edition; hg. v. World Health Organization – WHO, Copenhagen (2000).
[7] Directive for the assessment of the indoor air, published by the working group on indoor air in the Ministry of Sustainability and Tourism (BMNT) and the Commission for Clean Air of the Austrian Academy of Sciences (KRL). Vienna (2014).
[8] RESET™ Air Standard for Commercial Interiors v2.0, 2018.
[9] LEED O+V: Existing Buildings v4.1: Indoor Environmental Performance.

TVOC Limit	TVOC [µg/m³]
TVOC limit	<500

Table 4 Maximum average TVOC concentration according to LEED standard for green buildings.[9]

2.3 Conversion of ppb TVOC (SGP30 Output) to µg/m³

In order to map the TVOC output of the SGP30 in ppb to µg/m³, as it is given by most standards, a gas mixture needs to be defined which represents a typical TVOC mixture for the application of interest. Based on this mixture, an average molar mass can be calculated which can be further used to directly convert ppb into µg/m³ by applying the following equation:

$$\rho_{\text{gas mix}}\left[\mu\text{g/m}^3\right] = \frac{M_{\text{gas mix}}\ [\text{g/mol}]}{V_{\text{m}} \times 1000\ \text{ppb}} \cdot c_{\text{gas mix}}\ [\text{ppb}]$$

where $\rho_{\text{gas mix}}$, $M_{\text{gas mix}}$, $c_{\text{gas mix}}$ are the mass concentration, the average molar mass, and the particle concentration of the defined gas mix and V_{m} is the molar volume (= 0.0244 m³/mol at 25 °C and atmospheric pressure).

The ppb-TVOC output of SGP30 is tuned for the gas mixture utilized by Mølhave *et al.*[4] featuring a composition of 22 VOCs at concentrations similar to those determined on average in residential indoor environments. The mean molar mass of this mixture is 110 g/mol and hence, 1 ppb TVOC corresponds to 4.5 µg/m³. However, it should be noted that this approach is a simplification only since real indoor gas compositions may vary significantly over time and from environment to environment. For conversions referring to different mixtures than that proposed by Mølhave *et al.*,[4] it is necessary to first determine the corresponding particle concentration ($c_{\text{gas mix}}$) based on the relative response of the SGP30 sensor (see **Table 6** for examples).

3 Indoor VOC Sources and Monitoring Applications

3.1 Typical Indoor VOC Sources

Figure 3 illustrates typical indoor VOC sources, as for example building materials such as carpets and floorings, furniture, paints, solvents, cosmetics, plastic products as well as gases being emitted by cooking and cleaning activities. The sum of those different VOC concentrations add up to a total concentration, i.e., TVOC which then directly relates to the IAQ levels, as shown in **Table 1**.

Figure 3 Illustration of typical indoor VOC sources.

3.2 Typical Applications for IAQ Monitoring

Several applications ask for monitoring IAQ levels by measuring TVOC concentrations. For example, the SGP30 sensors enable controlled air purification, filtering, and ventilation/airing triggered by measured IAQ levels according to high TVOC concentrations present. Furthermore, smart devices which are capable of detecting TVOC can help customers to improve air quality by understanding sources of bad air.

4 Test Gases Representing TVOC

4.1 ISO16000-29 Test Gases for VOC Detectors

The ISO norm for indoor air quality IS016000-29[10] provides standardized test methods for metal oxide based VOC detectors. The norm compares a simulated VOC mixed gas, with more than 40 individual constituents, to three different test gas mixtures. Listed test gases for TVOC are toluene, a two kinds of VOC mixed gas (listed in **Table 5**) and six kinds of VOC mixed gas.[11]

VOC group/class	Representative	Mass ratio
Saturated hydrocarbon Aliphatic hydrocarbon	*n*-octane	53%
Unsaturated hydrocarbon Aromatic hydrocarbon	*m*-xylene	47%

Table 5 Two kinds of VOC mixed gas is composed of *n*-octane and *m*-xylene, representing the two VOC classes of saturated and unsaturated hydrocarbons, respectively.

According to the ISO norm, the difference of indications between the simulated VOC mixed gas (more than 40 individual constituents) and the three different test gases toluene, the *two kinds of VOC mixed gas*, and *the six kinds of VOC mixed gas* are −18.1%, −1.6% and −0.46%, respectively. Considering reliability and lower costs of mixed gases with less components, the ISO norm quotes[10] that *"the **most suitable test gas** for metal oxide semiconductor detectors is the **two kinds of VOC mix**".*

[10] Ref.: *Indoor air – test methods for VOC detectors, ISO16000-29:2104(E).*

[11] According to ISO16000-29, the six kinds of VOC mix is based on the idea, that VOCs can be classified into seven kinds of groups, i.e., aromatic hydrocarbons, aliphatic hydrocarbons, terpenes, halides, esters, ketones, and aldehydes. Note that aldehydes are omitted due to their poor stability. For each of the other six groups, one representative was chosen, such as toluene, *n*-decane, *α*-pinene, *p*-dichlorobenzene, butyl acetate, and methyl *i*-butyl ketone.

4.2 Calibration of Sensirion's SGP30 TVOC Sensor with Ethanol

The SGP30 is a broadband VOC detector, which is capable of detecting various VOCs and therefore TVOC. Sensirion's SGP30 gas sensors are calibrated using ethanol since ethanol serves as a stable, reliable, and economical proxy for TVOC.

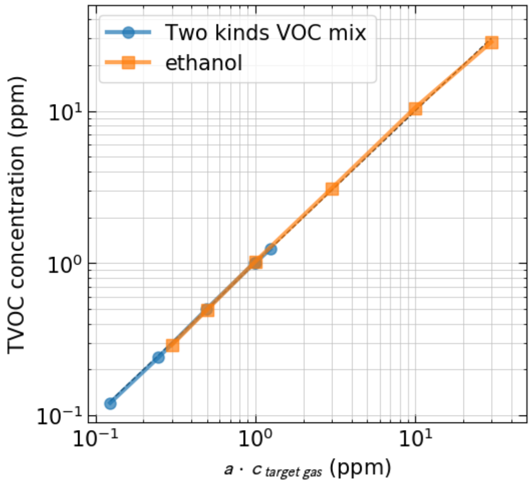

Figure 4 TVOC concentration versus target gas set concentration times the relative response factor *a* (see **Table 6**), measured for two different target gases: (a) ethanol and (b) the two kinds of VOC mix, which is according to ISO16000-29:2014(E)[10] the most suitable proxy for TVOC.

This can be verified by linking the SGP30 sensor response to ethanol with respect to the response to the ISO normed two kinds of VOC mix (see **Table 5**). According to the ISO norm for indoor air quality,[10] this two kinds of VOC mixed gas is a suitable test gas for simulating ambient TVOC concentrations. **Figure 4** shows the SGP30 response for different concentrations of ethanol and of the two kinds VOC gas mix, respectively. Within a large target gas concentration range, the SGP30 reveals a similar gain for both of those target gas compounds (compare similar slopes of both curves presented in **Figure 4**). That allows for calibration and testing with ethanol in production regarding real-life TVOC applications (**Figure 5**).

Figure 5 Production/calibration, verification, and application of SGP30 TVOC sensors. *Blue arrows:* SGP30 sensors are calibrated with ethanol, which serves as a reliable and economical proxy for TVOC.

Over a concentration range relevant for indoor air quality the TVOC concentration detected by SGP30 sensors when exposed to different ethanol concentration is directly proportional to the observed response for the two kinds of VOC gas mix of the ISO norm. Furthermore, this allows for directly converting between concentrations of the different test gases and ambient TVOC concentrations by employing the relative response factors *a* listed in **Table 6**.

$$c_{\mathrm{TVOC}} = a \cdot c_{\mathrm{target\ gas}}$$

Target Gas/ VOC	Chemical formula	Relative response *a*
TVOC	complex real life mixture	1
Ethanol	C_2H_5OH	0.58
Two kinds of VOC mix (*n*-octane + *m*-xylene)	C_8H_{18} + C_8H_{10}	0.3

Table 6 Relative response of SGP30 sensors to a (a) complex real-life mixture of TVOC (as represented by the Mølhave 22-compound mix),[4] (b) ethanol, and (c) two kinds of VOC gas mixture, according to the ISO indoor air quality norm.[10]

Revision History

Date	Revision	Changes
February 22, 2019	1.0	First Release
November 11, 2019	2.0	Revision

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