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.

2 TVOC and Indoor Air Quality
2.1 Definition of TVOC and Relation to Indoor Air Quality
The sum of VOCs1 corresponds to TVOC2 and is used as an indication for VOC contamination. VOC contamination is an established concept in regulatory and scientific literature. Note that the specific TVOC composition varies between different ambient indoor environments and indoor air is always composed of different volatile organic substances.3 Therefore, it is helpful to consider TVOC concentrations as statistical reference values which help to

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.
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.

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 Agency5

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.

<table>
<thead>
<tr>
<th>Level</th>
<th>Hygienic Rating</th>
<th>Recommendation</th>
<th>TVOC [µg/m³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Unhealthy</td>
<td>Situation not acceptable</td>
<td>10 000–25 000</td>
</tr>
<tr>
<td>4</td>
<td>Poor</td>
<td>Major objections</td>
<td>3 000–10 000</td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
<td>Some objections</td>
<td>1 000–3 000</td>
</tr>
<tr>
<td>2</td>
<td>Good</td>
<td>No relevant objections</td>
<td>300–1 000</td>
</tr>
<tr>
<td>1</td>
<td>Excellent</td>
<td>No objections</td>
<td>&lt;300</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Level</th>
<th>Recommendation</th>
<th>TVOC [µg/m³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside</td>
<td>Greatly increased (not acceptable)</td>
<td>&gt;3 000</td>
</tr>
<tr>
<td>Quality</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Significantly increased (only temporary exposure)</td>
<td>1 000–3 000</td>
</tr>
<tr>
<td>3</td>
<td>Slightly increased (harmless)</td>
<td>500–1 000</td>
</tr>
<tr>
<td>2</td>
<td>Average (harmless)</td>
<td>250–500</td>
</tr>
<tr>
<td>1</td>
<td>Target value</td>
<td>&lt;250</td>
</tr>
</tbody>
</table>

Table 2 IAQ levels for Europe according to WHO.6

2.2.3 RESET Standard for Indoor Air Quality8

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 CO₂ 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.

<table>
<thead>
<tr>
<th>IAQ performance target</th>
<th>TVOC [µg/m³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceptable</td>
<td>&lt;500</td>
</tr>
<tr>
<td>High Performance</td>
<td>&lt;400</td>
</tr>
</tbody>
</table>

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 System9

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 µg/m³, as shown in Table 4.

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).
9 LEED O+V: Existing Buildings v4.1: Indoor Environmental Performance.
2.3 Conversion of ppb TVOC (SGP30 Output) to \( \mu g/m^3 \)

In order to map the TVOC output of the SGP30 in ppb to \( \mu g/m^3 \), 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 \( \mu g/m^3 \) by applying the following equation:

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

where \( \rho_{gas\ mix} \), \( M_{gas\ mix} \), and \( c_{gas\ mix} \) 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 m\(^3\)/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 \( \mu g/m^3 \). 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 \( (c_{gas\ mix}) \) 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.

<table>
<thead>
<tr>
<th>TVOC Limit</th>
<th>TVOC [\mu g/m^3]</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;500</td>
<td></td>
</tr>
</tbody>
</table>

Table 4 Maximum average TVOC concentration according to LEED standard for green buildings.\(^5\)

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 ISO16000-29\(^10\) 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.\(^11\)

<table>
<thead>
<tr>
<th>VOC group/class</th>
<th>Representative</th>
<th>Mass ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturated hydrocarbon</td>
<td>n-octane</td>
<td>53%</td>
</tr>
<tr>
<td>Aliphatic hydrocarbon</td>
<td>m-xylene</td>
<td>47%</td>
</tr>
<tr>
<td>Unsaturated hydrocarbon</td>
<td>xylene</td>
<td>0.46%</td>
</tr>
<tr>
<td>Aromatic hydrocarbon</td>
<td>toluene</td>
<td>0.46%</td>
</tr>
</tbody>
</table>

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”.

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\(^11\) 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 SGP 30 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](image)

**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) 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, 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](image)

**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.

<table>
<thead>
<tr>
<th>Target Gas/ VOC</th>
<th>Chemical formula</th>
<th>Relative response $a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>TVOC complex real life mixture</td>
<td>C2H6OH</td>
<td>0.58</td>
</tr>
<tr>
<td>Ethanol</td>
<td>C2H4</td>
<td>0.3</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Date</th>
<th>Revision</th>
<th>Changes</th>
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<tr>
<td>February 22, 2019</td>
<td>1.0</td>
<td>First Release</td>
</tr>
<tr>
<td>November 11, 2019</td>
<td>2.0</td>
<td>Revision</td>
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</table>

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