Reliability of VOC emission chamber testing

– A round robin test with a synthetic resin floor coating, a parquet lacquer and a silicone sealant

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ABSTRACT The Association for the Control of Emissions in Products for Flooring Installation, Adhesives and Building Materials (GEV) organised a round robin test in 2020 with the purpose to update its list of recommended testing laboratories on the basis of test results. 43 laboratories from 15 countries received 3 test products, a synthetic resin floor coating, a parquet lacquer and a silicone sealant. The results of the GEV round robin test 2020 showed a similar variation of the results as in a previous round robin test of the GEV in 2017 without any significant improvement. The large variation of the results confirms the limited significance of single test results. This is why GEV discloses VOC emissions only in terms of broad emission classes. Within this limitation, the performance of 19 laboratories was rated to be good by GEV. Currently, a list of recommended testing laboratories for GEV emissions testing comprises 15 laboratories from 4 countries. These laboratories performed well in this round robin test and presented an appropriate accreditation according to ISO/IEC 17025.

Zuverlässigkeit von VOC-Emissionskammerprüfungen – Ringversuch mit Kunstharz-Bodenbeschichtung, Parkettlack und Silikondichtstoff

ZUSAMMENFASSUNG Die Gemeinschaft Emissionskontrollierte Verlegewerkstoffe, Klebstoffe und Bauprodukte e.V., GEV führte im Jahre 2020 einen Ringversuch durch, um auf der Grundlage der eingereichten Prüfergebnisse ihre Liste empfohlener Prüfinstitute zu aktualisieren. 43 Prüflabore aus 15 Ländern erhielten drei Prüfmuster, eine Kunstharzbodenbeschichtung, einen Parkettlack und einen Silikondichtstoff. Die Ergebnisse des GEV-Ringversuchs 2020 wiesen eine ähnliche Streuung der Prüfergebnisse wie bei einem früheren GEV-Ringversuch im Jahre 2017 auf. Die große Streuung der Ergebnisse bestätigt, dass einzelne Messergebnisse nur eine begrenzte Aussagekraft haben. Deshalb gibt die GEV die Emissionen nur in breiten VOC-Emissionsklassen an. Im Rahmen dieser Begrenzung wurden die Ergebnisse von 19 Teilnehmern von der GEV als gut bewertet. Eine Liste der für GEV-Emissionsprüfungen empfohlenen Prüfinstitute umfasst zurzeit 15 Prüflabore aus vier Ländern. Diese Labore hatten beim Ringversuch gut abgeschnitten und legten eine relevante Akkreditierung gemäß ISO/IEC 17025 vor.

1 Introduction

The *Association for the Control of Emissions in Products for Flooring Installation* (*Gemeinschaft Emissionskontrollierte Verlegewerkstoffe, Klebstoffe und Bauprodukte e.V.*, GEV) was founded in 1997. GEV developed the label EMICODE®. It allows manufacturers to show low product emissions of volatile organic compounds (VOCs). The VOC emissions are expressed in different emission classes. This voluntary label certifies low emissions of construction products. It is accepted as proof of low emissions by many certifiers of sustainable buildings, such as LEED, BREEAM and DGNB.

The complexity of the testing procedure is a challenge for the participating laboratories. This was shown by earlier round robin tests [1 to 3]. It is an essential goal of GEV to regularly repeat the round robin test. The intention is to maintain a high performance of the laboratories. 46 testing laboratories from 15 countries followed a call for voluntary participation in the 2020 round robin test and 43 of these reported test results:

- 22 laboratories from Germany,
- 4 laboratories from Italy,
- 2 laboratories each from China, Denmark, France, and Austria,
- 1 laboratory each from Belgium, Finland, the Netherlands, Poland, Portugal, Sweden, Spain, Switzerland, and the USA.

Among the 43 participating were

- 29 commercial testing laboratories,
- 6 public laboratories or research organisations,
- 8 industry laboratories.

Some of the laboratories carried out only parts of the test programme, in line with their specific interests.

2 Methodology

2.1 Organisation and preparation

Three products were used for this comparison: a synthetic resin floor coating, a parquet lacquer and a silicone sealant. The GEV testing method specifies measurements of VOC emissions after 28 days storage in a ventilated test chamber. For this round robin test, samples were selected which allowed the determination of significant emissions already after 3 days. This was essential for a robust statistical evaluation of the results. Pre-tests had confirmed the applicability of this procedure. The homogeneity of the testing material and its stability during the testing period were monitored. Three GEV member companies prepared the test samples, two companies distributed them to the participants.

The tests were performed in a period from October to mid-December 2020.

2.2 Test procedure

The participants had to test the three products according to the GEV testing method [4] with the following additional specifications:

- No pre-conditioning of the synthetic resin floor coating and of the silicone sealant (GEV testing method allows pre-conditioning as an option for surface treatment products).
- 3 days pre-conditioning of the parquet lacquer in a separate ventilated test chamber (GEV testing method specifies pre-conditioning as an option).
- Measurement of the emissions of VOC, SVOC (semi-volatile organic compounds), formaldehyde and acetaldehyde already after three days storage in a ventilated test chamber.

The GEV testing method [4] specifies details of test specimen preparation, test chamber conditions, air sampling and air sample analyses. Other procedural steps are based on EN 16516 [5].

2.2.1 Test specimen and test chamber

- Sample preparation for the synthetic resin floor coating: (300 ± 10) g/m² on a glass plate, surface structured with a B1 notched trowel.
- Sample preparation for the parquet lacquer: (150 ± 2) g/m² on a glass plate, with even surface.
- Sample preparation for the silicone sealant: application in a model of 3 mm layer thickness, 10 mm joint width.
- Loading of the test chamber: 0.4 m²/m³ for the synthetic resin floor coating and the parquet lacquer, 0.007 m²/m³ for the silicone sealant.
- Storage of the test specimen in the test chamber at (23 ± 1) °C, (50 ± 5) % relative humidity of the supplied air, (0.5 ± 0.025)/h air exchange rate.

2.2.2 Air sampling, analyses, reporting of results

VOCs and SVOCs were sampled from test chamber air with adsorption tubes that contained the polymer Tenax TA®. The tubes were analysed by gas chromatography (GC) with a mass selective detector (MSD) after thermal desorption (TD).

Formaldehyde and acetaldehyde were sampled with cartridges or adsorption tubes that contained silica gel which had been impregnated with 2,4-Dinitrophenylhydrazin (DNPH). The tubes or cartridges were analysed by high pressure liquid chromatography (HPLC) with a UV or a diode array detector after extraction with acetonitrile.

Most laboratories performed the test chamber air measurements as double or multiple determinations for internal QA/QC purposes. But only one test result had to be reported – the decision was left to the laboratories. The participants submitted their test results online via an input mask.

2.3 Statistical evaluation

QuoData GmbH performed the statistical evaluation of the reported test results according to ISO 13528 [6] which generally assumes a normal distribution of the data. This could be confirmed for specific data, such as the TVOC values, but not for all results, e.g., not for the *R* value. However, the *Q*/Hampel method as specified in ISO 13528 was used. This method requires only a unimodal distribution. QuoData GmbH had applied a kernel density estimation according to ISO 13528 to all data of the 2017 GEV round robin test using a proprietary software solution. No critical anomalies were observed, i.e., none of the evaluated data series showed a bimodal or even multimodal distribution. This demonstrated that the *Q*/Hampel method can be applied to data of a VOC emissions round robin test.

2.3.1 Assigned value (target value)

No objective true value is available for the tested samples. Therefore, a consensus value is calculated from the reported test results as robust, weighted arithmetic mean value. This is called "assigned value" in ISO 13528 [6] and it is taken as a substitute for the true value. It is the target value that should be achieved by the participating laboratories.

Following the *Q*/Hampel method, individual results are included with less weight in the statistical evaluation if they deviate from the mean value by more than 1.5 times the standard deviation – the larger the deviation, the less weight is given. For more details, see ISO 13528, Annex C.5.3 (Hampel estimator) [6]. As an example, test results deviating from the mean value by more than 4.5 times the standard deviation do not have any influence on the evaluation. If a laboratory did not report a specific parameter, then it could not be determined whether that laboratory saw an insufficient amount of that substance to report it, or whether the laboratory did not detect the substance at all. Therefore, no value was included in the evaluation in those cases. Consequently, the assigned value is not significantly influenced by missing or strongly deviating results and can be used as a convenient target value.

2.3.2 Standard deviation for proficiency assessment

No generic method specific standard deviation is known for this testing method. Therefore, the "standard deviation for proficiency assessment" was calculated from the reported test results as robust reproducibility standard deviation according to the *Q* method (ISO 13528, Annex C.5.2. [6]).

If the homogeneity test had shown a non-homogeneous distribution of the emissions across a total testing sample, then the standard deviation for proficiency assessment would have been expanded by the standard deviation caused by the inhomogeneity. This was not necessary in this case.

2.3.3 Standard and expanded uncertainty of the assigned value

The robust standard deviation is multiplied by 1.25 and divided by the square root of the number of the participants in the round robin test (see ISO 13528) to give the "standard uncertainty of the assigned value". This is generally assumed to be the best estimator for round robin tests. The "expanded uncertainty" (95 percentile) of the assigned value is given by multiplication by 2. Test results within this uncertainty of the assigned value are regarded to be close to the target value.

2.3.4 z score

This evaluation assumes that the reported test results follow a normal distribution, or at least a unimodal distribution. If the test results follow a normal distribution, then it can be expected that

- 68% of the test results are within 1 standard deviation of the target value,
- 95% of the test results are within 2 standard deviations of the target value,
- 99.7% of the test results are within 3 standard deviations of the target value.

Table 1 Results – TVOC and TSVOC value both (in toluene equivalents) according to GEV und EN 16516 (Clause 10.6.5), but the TVOC without acetic acid (for the interpretation of the z scores see Section 2.3.4)

Test sample	Weighted mean [µg/m³]	Expanded uncertainty of target value [%]	Relative standard deviation [%]	Participants with				Number results/ All participants
				z score +1 to -1	z score +1 to +2 & -1 to -2	z score +2 to +3 & -2 to -3	z score above +3 & below -3	
Resin coating TVOC	980	18	47	29	11	1	0	41 / 41
Parquet lacquer TVOC	550	21	56	32	7	0	4	43 / 43
Silicone sealant TVOC	1 340	23	58	29	12	0	0	41 / 41
Silicone sealant TSVOC	590	35	89	26	11	3	1	41 / 41

The z score is the difference of a single test result from the target value, divided by the standard deviation for proficiency assessment. This value can be larger or smaller than 0: A z score larger than 0 means, the test result is above the target value. And a z score smaller than 0 means, the test result is below the target value. The results were classified as specified in ISO 17043 [7] with one additional performance level:

- z score of +1 to −1
  The deviation of a test result from the target value is smaller than 1 standard deviation, i.e. within the 68% confidence interval. This is generally regarded as a good satisfactory result.
- z score of +1 to +2, or −1 to −2
  The deviation of test result from the target value is larger than 1 standard deviation, but smaller than 2 standard deviations, i.e. within the 95% confidence interval. This is generally regarded as a satisfactory result.
- z score of +2 to +3, or −2 to −3
  The deviation of a test result from the target value is larger than 2 standard deviations, but smaller than 3 standard deviations, i.e. within the 99.7% confidence interval. This is generally regarded as a questionable result.
- z score of +3 or larger or −3 or smaller
  The deviation of a test result from the target value is larger than 3 standard deviations. This is generally regarded as an unsatisfactory result.

All z scores refer to a single test parameter and a single sample in one testing laboratory. This tool is not designed to assign any type of score to a testing laboratory as a total.

2.3.5 Limitations of the statistical evaluation

This purely statistical evaluation is based on the reported test results of the participating laboratories. However, it may occur that the reported data do not allow a meaningful evaluation, even if the statistical procedures formally could be applied. No objective true target value is available. It is possible that a larger group of laboratories delivers wrong results either systematically or at random. As an example, some laboratories may fail with correct identification of the emitted VOCs. Other laboratories can experience difficulties to correctly quantify glycols and glycol ethers, see [3]. Therefore, a statistical evaluation should always be followed by a technical assessment and a plausibility check. This includes knowledge of substances that can be expected to be emitted during the chamber tests, as well as analytical challenges as discussed in an earlier study [3].

3 Results

Not all laboratories reported all requested parameters. Non-reported values were not replaced by substitute values but ignored in the evaluation.

3.1 Homogeneity and stability of the emissions

Eurofins Product Testing A/S performed homogeneity tests for selected VOCs on behalf of GEV for the VOCs with the highest emission rates. No homogeneity tests were conducted for sum parameters such as TVOC and *R* value. Three randomly chosen test items were analysed in single determination at the beginning of the round robin testing period (early October 2020) and three other items at its end. These were evaluated statistically by QuoData GmbH. As the heterogeneity standard deviation was not larger than 0.3 times the standard deviation for proficiency assessment, the test material was considered sufficiently homogeneous (see Annex B.2.2 in ISO 13528 [6]).

QuoData GmbH performed a statistical assessment of the stability of the testing material over time with a *t* test, taking into account the variance of the results of the homogeneity testing. The three early test items were compared with the three late ones. No statistically significant trend nor any instability was recorded for the investigated test parameters. Accordingly, the assessment of the laboratory test results by means of *z* scores was carried out without any restriction.

3.2 TSVOC and TVOC results

The TSVOC value (Total Semi-Volatile Organic Compounds) was not evaluated statistically for the synthetic resin floor coating and the parquet lacquer because the results of most testing laboratories were below the required determination limit of 5 µg/m³.

The TVOC value (Total Volatile Organic Compounds) was calculated in two different ways. In both cases, the contribution

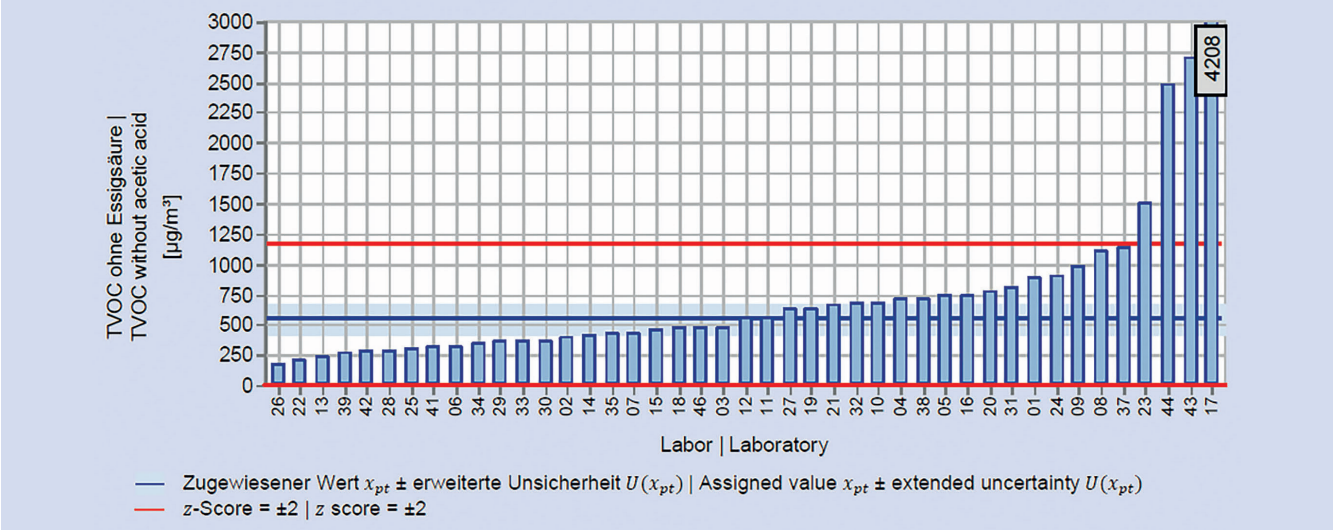

Figure 1 Distribution of results of TVOC (in toluene equivalents) without acetic acid for the tested parquet lacquer. *Graphic: QuoData GmbH*

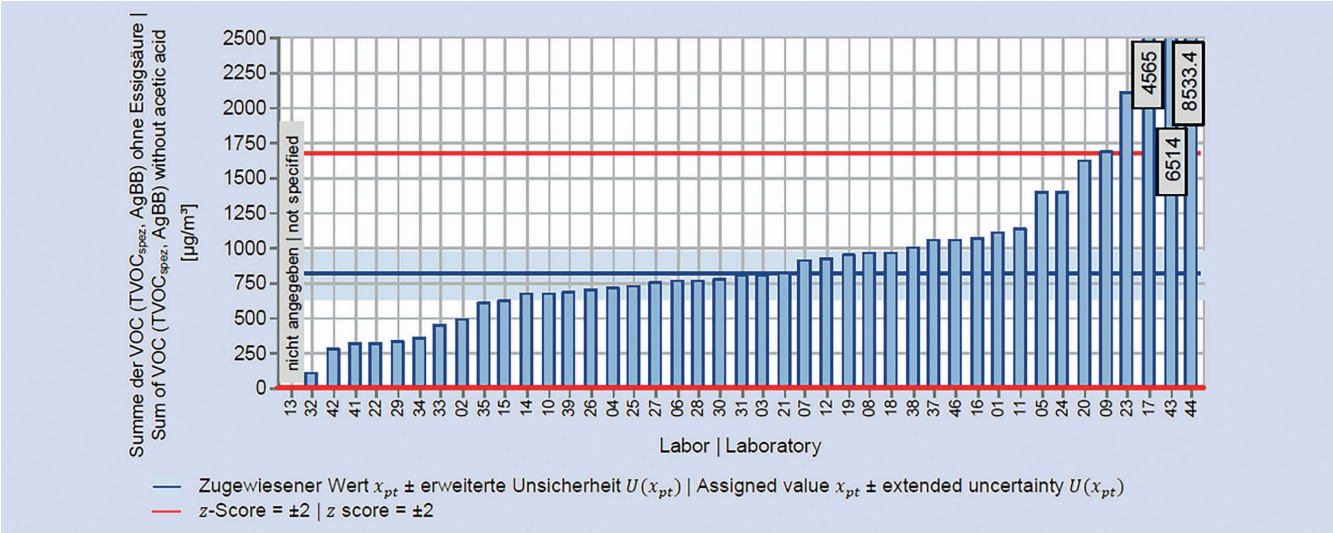

Figure 2 Distribution of results of $TVOC_{SPEZ}$, sum of VOCs, without acetic acid for the tested parquet lacquer. *Graphic: QuoData GmbH*

of acetic acid to TVOC was excluded from the calculation as specified by the GEV testing method. Results of acetic acid have not been included in that calculation due to the low reliability of that determination, see Chapter 4.1.

The TVOC value and the TSVOC value according to the GEV testing method [4] and EN 16516 (Clauses 8.2.6.2 and 10.6.5) [5] were determined in toluene equivalents, i.e. all single VOC substances were calculated with the response factor of toluene and summed, if above the reporting limit of 5 µg/m³ (see **Table 1** and **Figure 1**).

The „sum of the VOCs" according to EN 16516, Clause 10.6.8 [5], also called $TVOC_{SPEZ}$ value by AgBB, was determined such that

- all single VOC substances with a German LCI limit value (AgBB 2018) [8] were calculated with their respective substance specific response factor (LCI = lowest concentration of interest)
- all single VOC substances without a German LCI value and all non-identified VOCs were calculated with the response factor of toluene,

and (different to EN 16516) all values were summed for which the results in toluene equivalents were above the reporting limit of 5 µg/m³ (see **Table 2** and **Figure 2**).

3.3 Results of the R value without acetic acid

Individual VOC substances had to be quantified if the respective test result in toluene equivalents was at least 5 µg/m³ (reporting limit). Substances with a German LCI limit value (AgBB 2018) [8] had to be calibrated and quantified with their respective substance specific response factors. Then the *R* value was calculated as sum of all quotients of each individual test result and its respective German LCI value. Results of acetic acid have not been included in that calculation due to the low reliability of that determination, see Chapter 4.1 (see **Table 3**).

3.4 Results for single substances

The participants had not been informed about the substances to be analysed. Each participant had to identify and quantify the individual VOCs that were emitted under the specified testing conditions. Individual VOC substances had to be quantified if the

Table 2 Results – $TVOC_{SPEZ}$ value, sum of VOCs, according to EN 16516 (Clause 10.6.8), but without acetic acid (for the interpretation of the z scores see Section 2.3.4).

Test sample	Weighted mean [µg/m³]	Expanded uncertainty of target value [%]	Relative standard deviation [%]	Participants with				Number results/ All participants
				z score +1 to -1	z score +1 to +2 & -1 to -2	z score +2 to +3 & -2 to -3	z score above +3 & below -3	
Resin coating	940	20	50	30	10	0	0	40 / 41
Parquet lacquer	820	20	52	28	10	0	4	42 / 43
Silicone sealant	1200	24	60	27	9	3	1	40 / 41

Table 3 Results – R value without acetic acid according to GEV with German LCI values (AgBB 2018) (for the interpretation of the z scores see Section 2.3.4).

Test sample	Weighted mean [µg/m³]	Expanded uncertainty of target value [%]	Relative standard deviation [%]	Participants with				Number results/ All participants
				z score +1 to -1	z score +1 to +2 & -1 to -2	z score +2 to +3 & -2 to -3	z score above +3 & below -3	
Resin coating	0.7	16	42	27	11	3	0	41 / 41
Parquet lacquer	7	19	50	29	13	0	1	43 / 43
Silicone sealant	0.6	33	83	29	7	3	2	41 / 41

respective test result in toluene equivalents was at least 5 µg/m³ (reporting limit as specified in GEV testing method [4]).

The reported results were evaluated statistically only for those VOCs that had been found by many participants in relevant amounts. The results of formaldehyde and acetaldehyde were not statistically evaluated because almost all testing laboratories delivered either no results for these substances, or results below the reporting limit of 5 µg/m³ (see **Tables 4, 5** and **6**).

4 Assessment and discussion of the results

4.1 Acetic acid

It is well known that it is a challenge to determine acetic acid with the applied methodology. The adsorption tubes filled with Tenax TA® have only a low adsorption capacity for acetic acid and are quickly saturated. That is the reason why EN 16516 [5] states in a note to clause 8.2.1:

"A few VOCs like acetic acid are not quantitatively analysed under the conditions specified in this method. In this case, an alternative sorbent or series of sorbents or alternative conditions can be used to confirm a test result."

Alternative testing methodologies for acetic acid are specified in VDI 4301 Part 7 [9].

The present round robin test included only test results obtained by adsorption on Tenax TA®. In line with the GEV testing method, the contribution of acetic acid to TVOC and *R* value was excluded from calculation.

4.2 TVOC, $TVOC_{SPEZ}$ and TSVOC

The results did not show any improvement of the TVOC results compared to a previous round robin test of the GEV in 2017. The relative standard deviation from the weighted mean was 50 to 60% for the TVOC value in toluene equivalents and the sum of VOCs, the $TVOC_{SPEZ}$, but 90% for the TSVOC.

More than 70% of the participants delivered good satisfactory results with a z score between +1 and -1 for the TVOC value in toluene equivalents, and 60 to 70% for the sum of VOCs, the $TVOC_{SPEZ}$. Both were determined without the contribution of acetic acid. 60% of the participants delivered good satisfactory results with a z score between +1 and -1 for the TSVOC value.

The TVOC value in toluene equivalents is used historically and globally to assess the total emissions of products. Meanwhile, authorities and many labelling organisations in German speaking countries prefer to use the sum of VOCs for that purpose, the $TVOC_{SPEZ}$. This is justified by stating that the $TVOC_{SPEZ}$ value is closer to the real concentrations than the TVOC value in toluene equivalents. EN 16516 allows both ways of calculation. The significance of both parameters had been discussed in depth in an earlier study [3].

The impact of the both approaches is illustrated in **Figure 3**. The sum of VOCs, the $TVOC_{SPEZ}$, was compared with the TVOC in toluene equivalents (TE) for the parquet lacquer. The $TVOC_{SPEZ}$ was very similar to the $TVOC_{TE}$ for some laboratories (the ratio was around 1). But in most cases the $TVOC_{SPEZ}$ was higher, and the ratio of $TVOC_{SPEZ}$ to $TVOC_{TE}$ was in the range of 1 to 2, in few cases even almost 3 (see Figure 3).

Despite all its limitations, a TVOC value in toluene equivalents may be a significant parameter to survey total emissions where there is a similar composition of the emitted mixture of VOCs – e.g., for development purposes or for factory control, but without any ambition of health control. In the case of product evaluation, a TVOC value (calculated by whatever procedure) only can be an indicator whether "more" or "less" is emitted in total. This is of

Table 4 Results of individual substances, calibrated substance-specifically – Resin coating (for the interpretation of the z scores see Section 2.3.4).

Resin coating	Weighted mean [µg/m³]	Expanded uncertainty of target value [%]	Relative standard deviation [%]	Participants with				Number results/All participants
				z score +1 to -1	z score +1 to +2 & -1 to -2	z score +2 to +3 & -2 to -3	z score above +3 & below -3	
n-Propylbenzene (LCI # 1-8)	15	12	27	23	8	1	0	32 / 41
1,3,5-Trimethylbenzene (LCI # 1-10)	22	14	31	21	6	1	1	29 / 41
1,2,4-Trimethylbenzene (LCI # 1-11)	87	13	30	25	5	4	0	34 / 41
1,2,3-Trimethylbenzene (LCI # 1-12)	12	15	33	21	3	2	3	29 / 41
2-Ethyltoluene (LCI # 1-13)	19	14	31	22	6	0	2	30 / 41
Dipropylene glycol (LCI # 6-28)	102	37	73	17	5	2	0	24 / 41
1-Methoxy-2-propylacetate (LCI # 10-6)	25	15	31	20	6	1	0	27 / 41

Table 5 Results of individual substances, calibrated substance-specifically – Parquet lacquer (for the interpretation of the z scores see Section 2.3.4).

Parquet lacquer	Weighted mean [µg/m³]	Expanded uncertainty of target value [%]	Relative standard deviation [%]	Participants with				Number results/ All participants
				z score +1 to -1	z score +1 to +2 & -1 to -2	z score +2 to +3 & -2 to -3	z score above +3 & below -3	
Butylhydroxytoluol (BHT) (LCI # 5-2)	17	16	36	19	12	1	0	32 / 43
Dipropylene glycol mono methyl ether (LCI # 6-12)	270	35	80	24	3	2	3	32 / 43
Triethylamine (LCI # 12-11)	480	11	33	25	8	0	0	33 / 43

Table 6 Results of individual substances, calibrated substance-specifically – Silicone sealant (for the interpretation of the z scores see Section 2.3.4).

Silicone sealant	Weighted mean [µg/m³]	Expanded uncertainty of target value [%]	Relative standard deviation [%]	Participants with				Number results/All participants
				z score +1 to -1	z score +1 to +2 & -1 to -2	z score +2 to +3 & -2 to -3	z score above +3 & below -3	
Acetic acid (LCI # 6-1)	230	36	72	20	4	1	1	26 / 41
Octamethylcyclo-tetrasiloxane (LCI # 12-4)	47	33	74	22	8	1	1	32 / 41
Decamethylcyclo-tetrasiloxane (LCI # 12-12)	140	13	31	24	4	4	1	33 / 41
Dodecamethylcyclo-tetrasiloxane (LCI # 12-13)	55	22	49	23	5	2	0	30 / 41

special relevance for rating systems that do without evaluation of the individual VOCs, such as BREEAM and Green Star. The same applies to rating systems that have very short lists of target VOCs, such as the French VOC emissions label and CDPH.

GEV uses the TVOC in toluene equivalents as well, to compare products regarding the total emissions. GEV takes into account health related characteristics of the emissions for products labelled as EC1^{PLUS} by including the *R* value.

4.3 *R* value

The health impact of a potentially hazardous substance depends on its substance specific toxicity and on the exposure to this substance. Most times a mixture of VOCs is present. There is no toxicological cause-and-effect scheme available to describe interactions between the VOCs in such mixtures that is generally accepted and easy to handle. In a simplified approach, an additive effect is assumed, ignoring any possible reciprocally intensifying ("synergistic") or attenuating ("antagonistic") effects between the substances. Instead, the substance specific toxicity equivalents are evaluated separately and then summed.

LCI (Lowest Concentration of Interest) values have been specified for a large variety of volatile organic compounds (VOCs). LCI values are part of the product evaluation by several rating systems, such as the EMICODE testing method [4] and the German AgBB scheme [8]. Currently, the German list includes some 200 LCI values for individual substances. A harmonised EU list [10] includes some 160 agreed LCI values. These have been specified following a harmonised European procedure. Additive health effects are assumed for all VOCs with a concentration of at least 5 µg/m³ each. Then it is specified that the risk factor *R*, i.e., the sum of all R_i of the individual substances, must not exceed a limit value of 1.

$R_i = C_i / LCI_i$ with C_i = Concentration of an individual substance in air

R = Sum of all R_i = Sum of all quotients

This procedure is a cumulative assessment of the potential hazards of the emitted individual substances in a VOC mixture. It has the ambition to provide an indicative assessment factor (the *R* value) for the health risk potential of a tested product.

The results of the *R* value showed a relative standard deviation from the weighted mean of 40 to 80%. More than 70% of the participants provided good satisfactory results with a z score between +1 and -1 for the *R* value without the contribution of acetic acid.

4.4 Results of individual VOCs

The testing method covers a large variety of VOCs with very different chemical properties. EN 16516 [5], which is the basis of the GEV testing method, specifies only a general testing method to allow determination of emissions from a large variety of construction products. This procedure is appropriate for some of these VOCs, but less applicable to other ones. The testing laboratory has to adapt its own analytical procedures to the detected compounds that are visible in the chromatogram.

The results showed a relative standard deviation from the weighted mean of 40 to 80%. 30 to 70% of the participants produced good satisfactory results with a z score between +1 and -1 for the evaluated individual substances with significant emissions. Worst results were observed for propylene glycol, propylene glycol methyl ether, acetic acid, and octamethyl cyclotetrasiloxane.

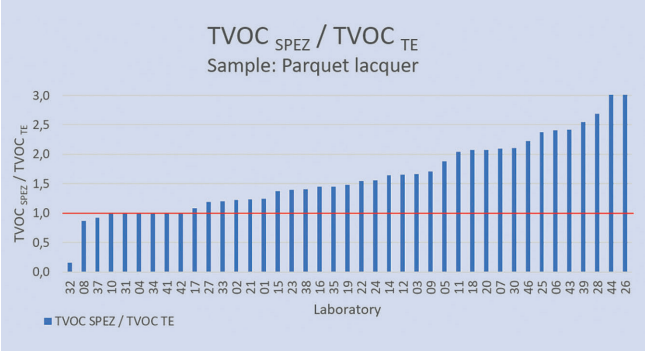

Figure 3 Ratio of $TVOC_{SPEZ}$ to TVOC in toluene equivalents (TE) for the tested parquet lacquer. *Graphic: Author*

The identification and quantification of glycols, glycol ethers and glycol esters can dominate the assessment of a product where these emissions occur. The determination of certain glycols and glycol ethers is difficult but possible. This was discussed in detail in an earlier study [3]. A number of laboratories had received special training on these substances. These laboratories showed better results in this round robin test.

An additional challenge is the fact that the composition of the VOC mixture is unknown in most cases of emissions testing. Information on real ingredients would be very helpful to allow correct identification and quantification, but this usually is not available to the testing laboratory.

4.5 Round robin tests as performance assessment of testing laboratories

Round robin test data can be used to assess the qualification of testing laboratories. One essential criterion is the number of reported satisfactory test data (i.e., with a z score between +2 and -2, or even between +1 and -1), but this assessment should be based only on those parameters for which a statistical evaluation is meaningful. These were in this round robin test:

- TVOC (EN 16516) without the contribution of acetic acid,
- Sum of VOCs ($TVOC_{SPEZ}$, AgBB) without acetic acid,
- TSVOC (EN 16516),
- *R* value without acetic acid,
- Individual substances with significant emissions, determined with substance specific calibration.

No objective true target value is available. It may occur that a larger group of laboratories delivers the wrong results systematically or at random, see Chapter 2.3.5. Therefore, a statistical evaluation should always be followed by a technical assessment and a plausibility check.

Another criterion is how many of the expected individual substances have been detected. An assessment of the performance of a testing laboratory can include information outside the round robin test as well, such as the degree of experience with testing for the EMICODE, testing capacity and delivery time.

19 participating laboratories fulfilled the requirements of GEV in this round robin test. An accreditation according to ISO/IEC 17025 [11] is very important for a positive rating of a testing laboratory, as this accreditation requires basic quality performance. But this accreditation needs to include specifically the GEV testing method or EN 16516 to be of value here. On this basis, GEV offers a list with recommended testing laboratories on its homepage, www.emicode.com. Currently 15 laboratories from

four countries are on that list. All laboratories that already were on that list before the round robin test in 2020 performed sufficiently well. No laboratory had to be deleted from the list.

5 Conclusions and outlook

The results of the GEV round robin test 2020 with 43 participants showed a similar variation of the results of TVOC, TSVOC, *R* value and of individual substances as in a previous round robin test of the GEV in 2017, without any significant improvement. The large variation of the test results confirms that single test results alone are not significant. This is why GEV discloses VOC emissions only in terms of broad emission classes.

The performance of 19 laboratories was rated as good by GEV. Currently, a list of recommended testing laboratories for GEV emissions testing comprises 15 laboratories from four countries. These laboratories performed well in this round robin test and presented an appropriate according to ISO/IEC 17025.

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