

Odour testing of building products: Examinations for an on-going development of the test standard ISO 16000-28

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Abstract. VOC-emissions and their odours from building products and furnishings present indoors should not have an impact on personal well-being or health. Odours can be measured by applying the standard ISO 16000-28 'Indoor air – determination of odour emissions from building products using test chambers'. One of the described procedures is the assessment of perceived intensity using a comparative scale by a group of panellists.

In this paper, the perceived intensity sampling procedure and its evaluation method are investigated and shown to need improvement. New technical developments in the methodology used to increase the reproducibility of measurement results are discussed. Since odour tests are used for labelling, they have a major influence on the assessment of construction products, similar to the procedure of the German Committee for Health Evaluation of Building Products (AgBB).

In the original ISO standard, the evaluation is typically performed using a sampling container separated from the emission chamber. For a better sample presentation, an adapter was developed to connect the emission test chamber to the evaluation funnel and thus enable an odour assessment which is comparable to a direct measurement. The investigations show that losses of odourous substances can be greatly reduced, which is very desirable when seeking to obtain reliable results in odour measurement.

Another experimental series was carried out to reduce the measurement effort in the evaluation of perceived intensity. Application of the developed 'greater than or less than/equal to' query could be helpful here. The results show that the query mostly leads to the same result as the evaluation of the perceived intensity using the method according to the standard, but is much easier to perform.

Overall, the results can contribute to improving the acceptance of the evaluation of perceived intensity using ISO 16000-28 and to determining odours from building materials increasingly more precisely.

Keywords. Building material, odour, perceived intensity, odour adapter, VOC, emission test chamber

1. Introduction

Building products and furnishings used indoors should be low in emissions and hardly noticeable in terms of odours. This is a prerequisite of ensuring good indoor air quality and protecting the health and well-being of those who spend time in these rooms. It is often described in the literature that odour nuisance and the associated health complaints are among the most frequently mentioned impairments of indoor spaces (for example Mayer, 2013, VDI-Richtlinie 4302 Blatt 1, 2015; Umweltbundesamt 2020).

The use of low-emission and low-odour products is becoming increasingly important as the European Union's goal of achieving climate neutrality by 2050 (European Green Deal 2019) also focuses on the energy efficiency of buildings. With buildings accounting for 40% of the total annual energy demand, Member States have committed to enhancing building renovation ('Renovation Wave'). Furthermore, new buildings should be constructed to the nearly-zero energy standard (Directive 2012/27/EU, Directive 2010/31/EU). The building envelope is becoming increasingly airtight due to energy-efficient construction accompanied by better

thermal insulation of façades and securely closing windows and doors. If users try to ventilate unpleasant odours out of the room, e.g. by frequently opening windows, the buildings' heating energy demand inevitably increases (Panašková, 2012). In addition, the users' comfort can decrease due to falling room temperatures or undesirable drafts, which in turn can lead to health problems (Fisk & Seppanen, 2007). The testing and use of low-emission and low-odour products is therefore essential for healthy indoor air and energy-efficient building operation.

Odour emissions from building products can be measured with the well-known and accepted standard ISO 16000-28 'Indoor air - Part 28: - determination of odour emissions from building products using test chambers' (ISO 16000-28, 2020). This standard describes laboratory procedures for testing odour emissions from a building product placed in an emission test chamber by using a number of panel members. Applicability of the test methodology has been verified and documented in interlaboratory tests (Brosig et al., 2013a; Brosig et al., 2014; Brosig et al. 2015). However, although the method is proven in practice, incorrect measurements are still possible. Also, errors can occur due to a very complex measurement procedure and sample provision, so there is further need for research.

The German Environment Agency is currently funding the research project 'Low-odour and low-emission products for healthy indoor air - development of requirements for the Blue Angel for large-area products relevant to interiors' (research code: 3717 37 319 0) to further improve the procedure and the evaluation method and to measure and evaluate as many building products as possible using sensory techniques. These product tests will be used to improve the criteria of the Blue Angel. The Bundesanstalt für Materialforschung und -prüfung (BAM) and the University of Applied Sciences for Technology and Economics, Berlin (HTW) are conducting sensory tests and determining the emissions of elastic floor coverings and wood products. Proposals for further technical development of the process are also being investigated within this project. The evaluation method of the perceived intensity Π with the unit π (one criterion to evaluate the odour of a sample within the ISO 16000-28) and the sampling procedure are investigated in particular because they have a major influence on reproducibility of measurement results. In this abstract, these two topics are introduced, and the results presented.

2. Methods

In principle the method of ISO 16000-28 is used for the measurements. The specimen to be investigated for odour is placed in an emission test chamber

according to this standard. The emission test chambers and climatic conditions specified in ISO 16000-9:2006 (ISO 16000-9, 2006) and EN 16516:2020 (EN 16516, 2020) are the basis of the odour measurement procedure. Odour testing can thus be carried out together with analytical emission tests. The product loading factor i.e. the size of the test specimen in relation to the emission test chamber volume and the air volumetric flow rate flowing through the chamber, is specified by simulating actual room conditions. The product remains in the chamber for a specified period of time depending on the measurement requirements. Then, on the desired measurement day, the exhaust air from the chamber is evaluated by the panel members using either the criteria acceptability or perceived intensity Π . The hedonic note i.e. how pleasant or unpleasant an odour is perceived, can be added to the evaluation as a further measurement. In Germany, the Committee on the Health-related Evaluation of Construction Products is responsible for providing the foundation for the uniform evaluation of indoor building products (AgBB, 2021). For a measurement according to the AgBB-scheme, sensory testing and evaluation of the perceived intensity is carried out.

2.1 Measurement and evaluation of perceived intensity

The perceived intensity Π describes the strength of an odour perception and is evaluated with the help of a reference in order to minimise the influence of the subjective odour sensation on the measurement result. For this purpose, at least 6 different acetone concentrations in air (=reference odorant) are provided in an ascending order on the so-called comparative scale. The lowest perceived intensity i.e. the odour threshold of acetone, is set at 0 π , and the highest intensity for this specific testing procedure is set at 15 π . This covers the range of typical intensities of building products. The relationship between the given acetone concentrations and the perceived intensity is linear over this range (Müller et al., 2017). Panel members who have been trained in a 5-day procedure compare the acetone intensities with the intensity of the sample. The mean value of the sample intensity can be determined from the individual values. The method using the comparative scale has been described in detail in various publications (Panašková, 2014; Brosig, 2013b).

The procedure is well accepted, but training panel members is time consuming and the required accuracy of the measurement is high. Before the last revision of the standard ISO 16000-28 in November 2020, a minimum of 8 panellists was specified for testing the perceived intensity, and the accuracy of the evaluation, expressed by the 90% confidence interval, had to be $\pm 2 \pi$ (ISO 16000-28:2012). Since many measurements failed to achieve the required

accuracy, at least 12 to 15 panellists are now recommended to determine the perceived intensity and if the confidence interval requirement cannot be met (ISO 16000-28:2020), it has to be recorded in the test report.

However, the increased panellist number as recommended now, increases the measurement effort and costs for the already complex investigation. Even so, it may occur that the measurement fails to reach the confidence interval. Therefore, investigations have been carried out aiming to simplify the evaluation of the perceived intensity using the comparative scale.

An odour nuisance is altogether unacceptable according to the AgBB-scheme, if more than 30% of a non-trained large group of panellists evaluate an odour as unacceptable. Based on this and on health aspects, the AgBB sets a perceived intensity of 7 pi after 28 days as a preliminary evaluation criterion (AgBB, 2021).

This fact leads to the conclusion in our investigations that a building product is unsuitable for indoor use if more than 30% of panellists perceive the odour of a sample to be more intense than an acetone concentration of 7 pi offered for comparison. It is ultimately important to know whether a building product has a perceived intensity of ≤ 7 pi or > 7 pi on the 28th day of measurement in order to determine the sensory suitability of building products for indoor use. Knowledge of the exact value as determined by the reference method is not actually necessary.

To investigate this, the panellists are offered an acetone intensity of 7 pi at one of the funnels of the comparison scale in order to determine perceived intensity. They are asked to indicate whether a sample is perceived as less or equally intense (\leq) or of greater intensity ($>$) in comparison. The odour intensity of a sample is thus classified in one of two possible ranges.

This range query simplifies the task of panel members. The investigations should clarify whether the extent of tests can be reduced, e.g. provision of technology or whether and to what extent training is necessary. Brandt et. al (2021 and 2022a) have described the simplified method and provided the first results.

2.2 Development of sample presentation

To evaluate the sample air, it must be ensured that a sufficient and constant air flow rate of 0.6 to 1.0 l/s is made available to the panel members. This prevents ambient air from mixing with the sample air during smelling. Another requirement according to EN 16516 is to establish an air exchange rate in the range between 0.25 and 2.0 h⁻¹ in the emission test chamber (EN 16516, 2020). **Table 1** shows air flow rate results

from three different air exchange rates within this range in chambers of different sizes. Air flow rates of at least 0.6 l/s are printed in bold. It is obvious that even at the greatest permissible air exchange rate of 2.0 h⁻¹ a chamber size of 3 m³ has to be used to achieve the required minimum air flow rate. However, in practice smaller chambers are usually used for odour measurements, which is why the use of sample containers is necessary.

In the smaller test chambers normally used, sample containers are filled with sample air from the emission test chamber and presented to the panel for odour evaluation. The tested and ISO 16000-28 approved materials polyvinyl fluoride (brand name: Tedlar®) and polyethylene terephthalate (brand name: Nalophan®) serve as sample containers.

Table 1

Air flow rate at the outlet of emission test chambers of different sizes at different air exchange rates (bold: air flow rate of at least 0.6l/s, which allows direct measurement)

Size of emission test chamber	Air flow rate at the funnel in l/s		
	n = 0.5h ⁻¹	n = 1.0h ⁻¹	n = 2.0h ⁻¹
20m ³	2.78	5.56	11.11
4.7m ³	0.65	1.31	2.61
3m ³	0.42	0.83	1.67
1m ³	0.14	0.28	0.56
250l	0.03	0.07	0.14
125l	0.02	0.03	0.07
23l	0.00	0.01	0.01

As various studies show, the type of sample provision can influence the result of the odour measurement. The results of the perceived intensities can be different in direct evaluation compared to those from sample container-based evaluation because of the sample air changes in the sample container (Müller et al. 2011, 2016, 2017; Salthammer et al. 2016). Therefore, the use of direct sample provision should be preferred. The adapter presented here offers this possibility.

In sample container assessment, sample air is first collected in a sample container and then placed in a sample provision system for assessment by the panel (**Figure 1**).

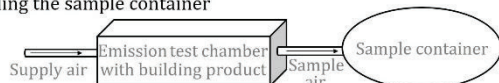
The adapter is connected to the emission test chamber and enables the collection and provision of sample air

in only one step (**Figure 2**). It is capable of buffering a sufficient amount of air for assessment by a single panel member and providing it at the moment of evaluation with a flow rate of 0.6 to 1.0 l/s.

Figure 1

Sample provision setup using sample containers according to ISO 16000-28 (two sub-steps)

1. Filling the sample container



2. Sample provision

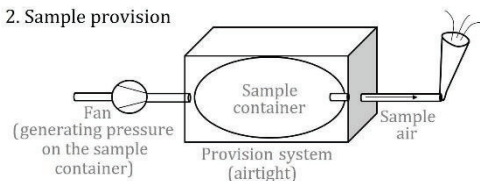
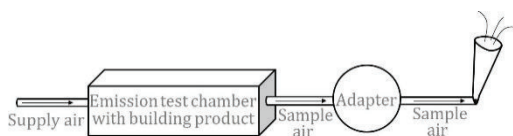


Figure 2

Filling and providing the sample using the adapter

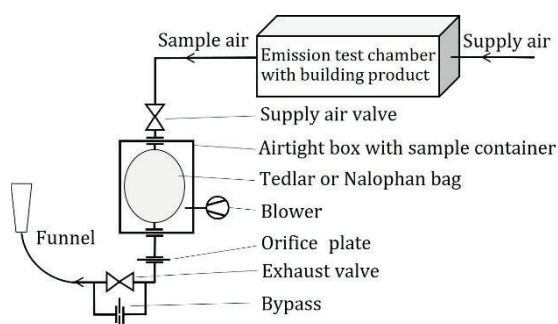


2.2.1 Adapter design and function. The adapter (described in literature at Brandt et. al, 2022b) consists of a sample container (Tedlar or Nalophan container) and the necessary accessories to allow alternating its operation between the filling process and sample air provision (**Figure 3**). During filling, the supply air valve is opened, and the exhaust air valve is closed. As soon as the sample container is filled, the excess air flows to the funnel via the bypass. This prevents the flow conditions in the emission test chamber from being affected. The adapter is connected at least one hour before sampling to flush the sample container sufficiently with sample air. During emptying i.e. at the time of sampling, the supply air valve is closed and the exhaust air valve is opened. The panel member can operate a blower with the help of a button, which exerts pressure on the sample container within the airtight box. This causes the sample container to empty towards the funnel. The blower speed can be controlled with the help of an orifice plate so that the desired constant volume flow rate (between 0.6 and 1 l/s) is provided at the funnel. The panel member can take sample air with a short breath several times for evaluation. At the end of sampling, the exhaust valve is closed, and the supply valve is opened to start the next filling process. During the emptying of the container, it must be ensured that the flow conditions in the emission test chamber are not influenced. This can be achieved by opening a sampling point to remove excess air.

The size of the sample container is about 15 l and is sufficient to provide sample air for evaluation by at least one panel member. Afterwards, the sample container is refilled ready for the next person to evaluate. The exact frequency of how quickly the adapter becomes available for the next panel member depends on the air exchange rate of the emission test chamber. For very small chambers, this may well take several minutes.

Figure 3

Adapter setup and positioning

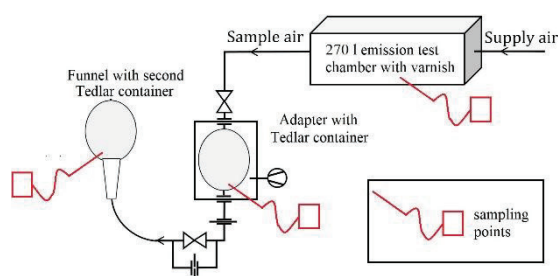


2.2.1 Experimental tests with the adapter. To test and prove applicability of the adapter, analytical and olfactory tests were carried out.

With analytical measurements of volatile organic compounds (VOCs), the sample air provided to the panel members when using the adapter is tested. It should be checked that the air has the same composition as when sampling directly. **Figure 4** shows the measurement setup for sampling the air from the adapter.

Figure 4

Sampling points for analytical measurements



For the VOC measurement, the adapter was connected to a 270 l chamber that contained a lacquer sample with various volatile organic components added artificially and operated with an air exchange rate of 1.0 h⁻¹. An approx. 20 l Tedlar container was used, which had been baked out at 80 °C for 4 hours according to the requirements of ISO 16000- 8. The container was then rinsed with sample air for 24 hours. For sampling, Tenax tubes were loaded with sample air from the emission test chamber and from

the container in the adapter. Directly afterwards, the adapter and its container inside was refilled with fresh sample air. Another completely empty Tedlar container of the same size, which had also been baked at 80 °C for 4 hours and rinsed with sample air for 24 hours, was placed over the funnel. An emptying procedure was then carried out with the help of the blower (as described in 2.2.1). Thus, the sample air flowed out of the container in the adapter into the second Tedlar container and filled it with sample air.

Tenax tubes were loaded from this second container filled with sample air. The sampling volume was 1 l each at a flow rate of 100 ml/min. Two- to three-fold analyses were always carried out. The substances were determined using thermodesorption and gas chromatography coupled with mass spectrometry measurements (TDS/GC/MS).

Olfactory measurements performed here are aimed at checking whether similar results have been achieved in an evaluation using the adapter, as in the direct evaluation. Several tests were carried out from which an investigation of the lacquer sample mentioned above is presented here as an example. The emission test chamber used was the 44 l CLIMPAQ (Chamber for Laboratory Investigations of Materials, Pollution and Air Quality), which is widely used in Northern Europe and is supplied with conditioned air (temperature and humidity according to ISO 16000-28) by an air conditioning system. The chambers comply with the requirements of ISO 16000-9 (ISO 16000-9, 2020). Loading was selected so that a distinct odour could be detected. All components that come into contact with sample air are made of glass or stainless steel. For direct evaluation, the air from the CLIMPAQ is fed directly to a glass funnel at a flow rate of 0.9 l/s.

For an evaluation using the adapter, the air flow is diverted and channelled to the adapter. The sample container made of Nalophan was rinsed with sample air for one hour before the test. The flow rate at the funnel was also set to 0.9 l/s for the sampling.

The study comprised the determination of the perceived intensity and the hedonic note by 9 trained panel members based on ISO 16000-28. The minimum size of 12 panel members required by the standard could not be met when performing the measurements due to the Corona pandemic. For the evaluation, the arithmetic mean was calculated from the individual values determined by the panel members. The 90% confidence intervals prescribed by ISO 16000-28 were ± 2.0 pi for perceived intensity and ± 1.0 for hedonics. The container was filled for approx. 30 secs after sampling. This time is sufficient for a 15 l sample container and a flow rate of 0.9 l/s.

3. Results

3.1 Simplified measurement of perceived intensity

Both measurements i.e. the determination of the mean value of the perceived intensity using a comparative scale and the 'greater than or less than/equal to' query were performed in parallel to check the concept of the simplified measurement. The simplified method is suitable if both measurements lead to the same evaluation in terms of indoor use suitability.

Different product groups – elastic, textile and wood-based floor coverings - were investigated at the air quality laboratory of the HTW Berlin. Furthermore a lacquer with various volatile organic components added artificially was investigated by several laboratories as part of a round robin test conducted by the BAM.

Figure 5

Determination of perceived intensity as per ISO 16000-28 and percentage of evaluation > 7 pi (Brandt 2022c)

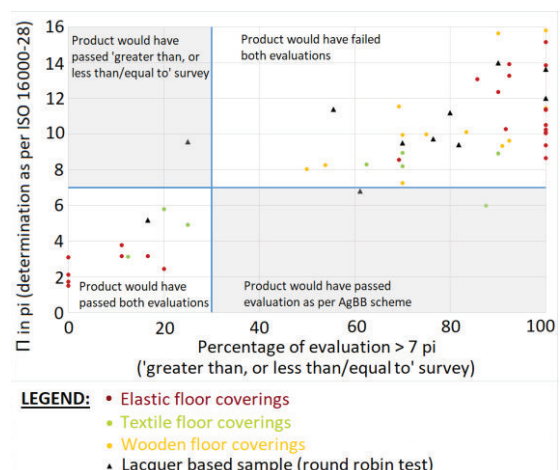


Figure 5 shows the evaluation results. In the diagram, the x-axis shows the results of the 'greater than or less than/equal to' query and the y-axis the mean values of the perceived intensities. The diagram is divided into 4 areas. If the points are in the white areas, the product has either passed or failed both tests. The grey areas indicate that a product has passed only one of the two evaluations. The dots indicate the results of the measurements at HTW Berlin and the triangles indicate the results of the labs taking part in the round robin test.

The results indicate that the 'greater than or less than/equal to' query leads to the same evaluation as the determination of perceived intensity in most measurements. Looking at the results of the air quality laboratory, of HTW Berlin, only one measurement dot from the evaluation of a textile floor covering can be found in the grey area. Its result i.e. 6 pi for perceived

intensity is within the 90% confidence interval of ± 2 pi around 7 pi. The results of the round robin test show that two measurements are within the grey areas. This means that the comparison of the two measurement methods does not lead to the same evaluation. One of those triangles falls close to the 7 pi line and thus within the measurement uncertainty of the method using the comparative scale.

3.2 Sample presentation with the adapter

Figure 6 shows the results of the analytical measurements. It gives the standardised values of VOC concentrations related to the values in the emission test chamber. The substances are sorted by their retention time from low to high. The concentrations of substances in the adapter's container are nearly the same as in the emission test chamber air. The recovery rates for the substances in the container filled via the funnel are somewhat lower.

Figure 6

Concentrations of different VOCs in the emission test chamber and in Tedlar containers

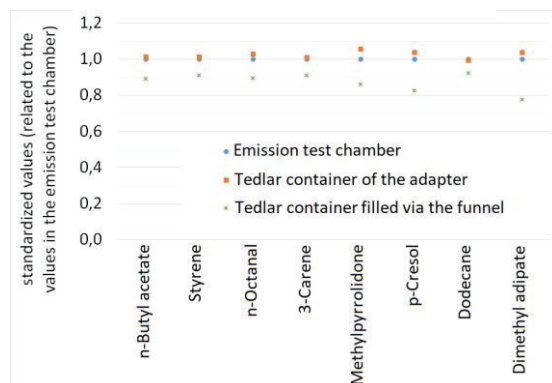
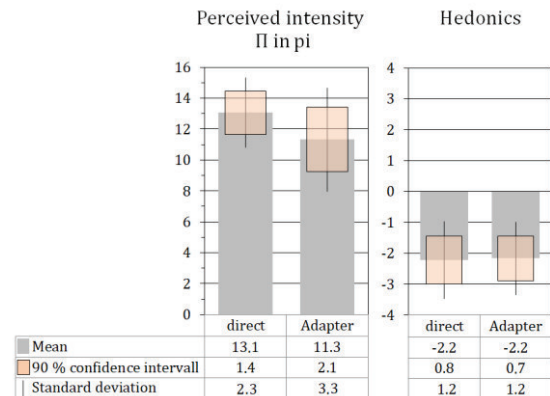


Figure 7 shows the results of perceived intensity and hedonics for direct evaluation and evaluation using an adapter. The calculated mean value of the perceived intensity is 11.3 pi for the adapter i.e. lower than 13.1 pi obtained in direct evaluation. The difference of 1.8 pi shows that the results, compared with each other, are within the measurement uncertainty of the method. Despite the low number of panel members (9), the required 90% confidence interval has been met by direct evaluation and just missed by the method using an adapter. The number of panel members and the standard deviation influence the confidence interval. Having the same number of panel members, the standard deviation is significantly greater in the adapter method since the values recorded by the individual panel members are very different: they are between 7 and 15 pi. Hedonics is rated the same at -2.2 in direct evaluation and in the test using the adapter. The 90% confidence interval of the hedonics is also almost the same for both tests: 0.7 and 0.8.

Figure 7

Perceived intensity and hedonics – directly determined and using an adapter



4. Discussion

4.1 Simplified measurement of perceived intensity

The results indicate that the simplified measurement of perceived intensity leads to the same evaluation as the determination of perceived intensity in most measurements. Different results are obtained in 3 out of 50 measurements (6%). In principle the method is therefore considered suitable. Products rated with intensities greater than 10 pi or less than 4 pi also receive clear evaluations of greater than 80% and less than 20%, respectively, in the 'greater than or less than/equal to' query.

It is important to know that the uncertainty of the measurement of perceived intensity applying ISO 16000-28 is ± 2 pi. That means that measurements with a result between greater than 7 and less than 9 pi could also lead to a value less than 7 pi and thus these measurements could also have passed evaluation as per the AgBB scheme. Alternatively, measurements with a result between greater than 5 and less than 7 pi could lead to a value greater than 7 and thus they would have failed evaluation as per the AgBB scheme. This must be considered when a decision is made on the suitability of the simplified method. Different evaluations in the range between 5 and < 7 or > 7 and 9 pi do not per se mean that the simplified method is not suitable.

The approach with the simplified method is completely new. Other studies in this context are not known. In future studies different laboratories should participate and further product groups should be investigated. It is also important to find out if panel members have to be trained on the acetone scale and how many are needed for reliable measurements. Special attention should be given to products with a perceived intensity in the range between 5 and 7 pi.

4.2 Sample presentation with the adapter

The results of the analytical measurements show, as expected, that the sample air has a very similar composition in the adapter's container as in the emission test chamber. Recovery rates for the substances slightly above and below 100% are within the uncertainty of the GC/MS method. The concentrations of the substances in the container placed over the funnel are somewhat lower for all substances. It is generally accepted that the concentrations in sample containers are lower. The substances show a recovery of 80% or more which is still an acceptable result. It has to be considered that it is also the second container to be filled and losses become more likely. A second container does not have to be filled for the odour measurements, as the panel members evaluate directly at the funnel. The container is necessary for analytical measurements only. The adapter is a suitable device in terms of analytics. The measurements will also be carried out using Nalophan sample containers.

The results of the olfactory measurements, one of which was presented here as an example, show overall that the intensities determined using the adapter are often reported as lower and the standard deviations are higher. Further investigations have shown that an air backflow via the funnel into the sample adapter's container may be the cause. As soon as a panel member stops pressing the button for the blower, air flows back because the emptied sample container exerts a suction effect. The sample air is thus provided in different compositions for the individual panel member. The adapter is currently being optimised so that a non-return valve can be installed between the funnel and the sample container. The measurements will be repeated after the modification and a larger number of panel members will be employed.

Overall, it can be assumed that all sampling systems without mechanical backflow prevention can lead to sample air dilution. The smaller the sample containers are, and the more frequently the fan is operated by the testers to empty the bag, the more noticeable this becomes in the olfactory measurements.

The adapter should be used on test chambers from approx. 250 l in size, as the exhaust air volume at these chambers is still sufficiently large to fill a bag within an acceptable time. With a 15 l bag, an air exchange rate of 0.5 h⁻¹ is achieved and after being completely emptied by a panel member, a bag can be entirely refilled in approx. 8 minutes.

The advantage of the adapter over the commonly used sampling systems is that the air in the bags does not remain for a longer period and thus only small changes can be assumed. The odour evaluation can be operated in laboratories where odour assessment is

feasible near the emission test chamber. When planning the measurement, the time taken to fill the bags must be considered. For each sample a fresh adapter must be used.

5. Conclusion

5.1 Simplified measurement of perceived intensity

The 'greater than or less than/equal to' query is basically suitable as a simplified test. In the next course of the project, products with intensities in the range of 7 +/- 2 pi will be investigated since their simplified evaluation seems to be difficult for the panel members. The number of panel members required for the test will also be determined and the need for panel member training will be investigated.

5.2 Sample presentation with the adapter

An adapter consisting of a sample container (Tedlar or Nalophan) and the necessary accessories was developed to allow alternating operation between the collecting process and sample air provision. It might be helpful to develop the odour measurement method further (ISO 16000-28). Furthermore, using the adapter gives results more comparable to direct evaluation. Overall, this will further increase the acceptance of ISO 16000-28. As a result, the dissemination of odour measurements for indoor building products can result in a higher benefit of health and energy-efficient building operation.

6. Acknowledgements

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