Investigation into emissions from internal doors relevant to indoor air in order to assess the behavior of building products with respect to hygiene, health and environmental protection

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Abstract As part of a research project door leaves and door frames as specified in DIN EN 14351-2 have for the first time been comprehensively investigated by the test chamber method with regard to emissions relevant to indoor air. Tests were conducted in both the 1 m³ test chamber and a walk-in 24 m³ test chamber. Evaluation of results with respect to indoor-air hygiene is based on the German AgBB (Committee for Health-Related Evaluation of Building Products) scheme and on the French regulations for labeling building products. To summarize, it may be stated in conclusion that although the products tested do represent a source of emissions in the indoor environment the level of such emissions is however comparatively low.

Untersuchung der raumluftrelevanten Emissionen von Innentüren zur Bewertung des Verhaltens von Bauprodukten in Bezug auf Hygiene, Gesundheit und Umweltschutz

Zusammenfassung Im Rahmen eines Forschungsprojekts wurden erstmals Türblätter und Türzargen nach DIN EN 14351-2 mit der Prüfkammermethode umfassend auf raumluftrelevante Emissionen untersucht. Die Untersuchungen erfolgten sowohl in 1-m³-Prüfkammern wie auch in einer begehbaren 24-m³-Prüfkammer. Die raumlufthygienische Bewertung der Ergebnisse basiert auf dem deutschen AgBB-Schema und der französischen Verordnung zur Kennzeichnung von Bauprodukten. Zusammenfassend kann festgestellt werden, dass die untersuchten Produkte zwar eine Quelle für Emissionen im Innenraum darstellen, die Höhe der Emissionen aber vergleichsweise gering ist.

1 Introduction

For many years now the emissions from products in the indoor environment have been a focus of interest. Discussions have covered the very volatile organic compounds (VVOCs), volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs), which may be the source of a wide variety of impacts on human health. The necessary requirements for regulation were first implemented on the European level by the Construction Products Directive (CPD) [1] and from 2013 by the Construction Products Regulation (CPR) [2]. In the "Essential requirements – ER 3" (CPD) or "Basic requirements for construction works – BRCW 3" (CPR) relating to hygiene, health and environmental protection, general requirements are laid down as regards the emission behavior of building products. Accordingly, the health of individuals dwelling in a building must not be endangered by the release of toxic gases [1; 2].

In Germany the German Institute for Civil Engineering (DIBt, Deutsches Institut für Bautechnik) has already been issuing general building regulations approvals for building products since 2004 [3]. In addition, on the basis of ECA Report No. 18 [4] the Committee for Health-Related Evaluation of Building Products (AgBB) introduced the AgBB scheme in 2000. The current version may be found on the web site of the German Environmental Protection Agency (Umweltbundesamt) [5]. Using this scheme building products can be evaluated on the basis of emission criteria (VOCs/SVOCs), thereby also helping to implement requirements relating to hygiene, health and environmental protection (ER 3 or BRCW 3). In France it has since 2010 been mandatory for building products to be classified into four different emission classes on the basis of the Grenelle Act [6; 7] and so labeled. In 2012 Belgium filed formal notification of emission requirements for building products [8]; these are similar to the German AgBB scheme and are due to come into force in 2014.

Since 2006, under Mandate 366 [9] of the European Commission, technical committee CEN TC 351 "Assessment of release of dangerous substances from building products" has been preparing horizontal test standards for building product emissions investigations [10]. These test standards serve to provide specifics for the Construction Products Regulation and will in future be applied throughout Europe in the CE marking of emission properties. The upcoming product standard DIN EN 14351-2 [11] for internal doors (internal pedestrian doorsets) will also include a corresponding section.

This article will present the results of a joint research project of the Fraunhofer-Wilhelm-Klauditz Institute (WKI) and the ift Rosenheim in which systematic emissions data have for the first time been secured for the product "internal doors". The results should help make it possible to classify internal doors with regard to existing and possible future evaluative criteria. Here a check was also to be made to see whether specific product variants could be classified as *wt* (without testing) or *wft* (without further testing) and thus enable considerable reductions in the testing effort required for the corresponding products. In this regard the current situation is such that in Germany internal doors do not have to be approved under aspects relating to emissions (VOCs/SVOCs). In France, on the other hand, there is already mandatory labeling for internal doors.

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2 Material and methods

2.1 Door leaves and door frames tested

The subject of testing was internal doors in accordance with DIN EN 14351-2 [11]. As regards market share these were

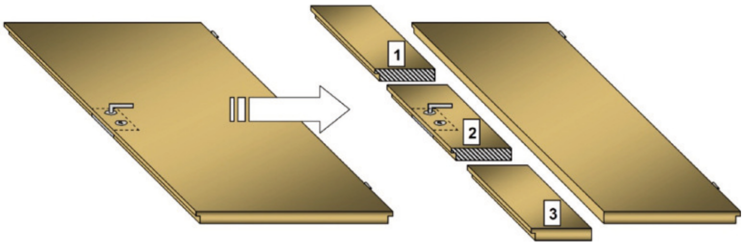

Figure 1. Piece cut from a door leaf in three sections for investigation in the 1 m³ emission test chamber.

Figure 2. View into the open 24 m³ emission test chamber with installation of a complete internal door consisting of door leaf and door frame.

predominantly flush doors, in other words, door leaves and door frames made of wood and wood-based composites in accordance with DIN 68706-1 [12] or DIN 68706-2 [13]. The principal differentiating characteristic of the materials under investigation is the face layer used in each case or the surface coating applied to it. The product group under consideration may be subdivided into the following variants:

- Ready-for-use surfaces (decor papers, foils, laminates).
- Direct coating (white or colored paint on wood-based panel surface).
- Veneered/painted surfaces.

2.2 History of samples before emission testing

Sampling complete door leaves and door frames was carried out at the manufacturer in their ready-for-use state (earliest possible time at which the product can be put on the market) immediately following the end of the manufacturing process. In order to conserve this state the samples were packed airtight in special aluminum foil and then, protected against contamination, sent to the WKI where emission testing took place. Before the actual emission testing commenced, the period of time which elapsed in practice between manufacturing and the earliest impact on the indoor air was noted and taken into consideration. This was effected by an air-conditioned, 'ageing storage facility' which made it possible to secure reproducibility of storage: here the test samples were stored uncovered in a climatised room (23 °C, 50% rel. humidity) for seven days before test chamber investigations. This is because a detailed assessment of the product history as part of the project had indicated that a period of seven days was clearly the shortest time in which internal doors fresh off the production line could come into contact with the indoor air of the inhabited indoor environment. In practice however there is generally a considerably longer period of time elapsing between production of the internal doors and their use.

2.3 Emission testing

A series of standardized tests exist for determining the emissions from building products and these are also used in AgBB measurements and in product declarations in compliance with French regulations [14 to 17]. These standards also form the basis for the horizontal test method currently in preparation by CEN TC 351 in WG 2 [10]. In the present project these standards were used for the following investigations:

- Short-term studies with micro-chambers [18] and emissions test chambers as screening methods for the preliminary selection of products, which were subjected to 28-day emission testing. These preliminary investigations of approx. 70 variants of different surface coatings will not be dealt with further in this paper.

Table 1. Loading and ventilation conditions in different emission test chambers and in the reference room.

Parameter	Test chamber 1	Test chamber 2	Reference room
Volume in m³	1	24	30
Air exchange in h^{-1}	0.5	0.5	0.5
Area door leaf in m²	1.09	1.21	1.6
Area door frame in m²	1.09	1.02	1.06*)
Loading door leaf in m²/m³	1.09		0.05
Loading door frame in m²/m³	1.09		0.04*)
Loading door leaf + door frame in m²/m³		0.09	0.09*)
Area specific air flow rate door leaf in m³/(m² h)	0.46		9.38
Area specific air flow rate door frame in m³/(m² h)	0.46		14.15
Area specific air flow rate door leaf + door frame in m³/(m² h)		5.38	5.64*)
Sampling point	3d, 7d, 14d, 28d	3d, 7d, 14d, 28d	

*) For the reference room the surface area of a door frame is not specified until now. Within the context of the present project a visible surface area of 1.06 m² has been taken as the basis for the door frame in the reference room.

- 28-day emission testing of 22 door leaves and 6 door frames in a 1 m^3 emissions test chamber.
- 28-day emission testing of a complete door leaf and case assembly in a 24 m^3 emissions test chamber.

The great majority of tests were conducted in 1 m^3 emissions test chambers. This meant that test pieces had to be cut to size. The pieces thus prepared were cut in such a way that the largest possible portions were obtained which also covered the full structure of the door leaf along its longitudinal edge (**Figure 1**).

For the indoor-air hygiene evaluation of the air concentrations measured in the 1 m^3 test chamber, these figures were converted up for a reference room of 30 m^3 volume and then assessed with the aid of the AgBB scheme and the French limit values for product labeling.

The following sections each contain a brief description of the investigative methods used. A full description of the methods will be found in [19].

2.3.1 Emission testing in a 1 m³ emissions test chamber

Emission tests in accordance with [16] extending over a period of 28 days were conducted in 1 m^3 emissions test chambers with glass walls (WKI-built). Defined sections were cut out from the door leaves and door frames immediately before the start of testing. The raw edges created by this cutting were sealed off with low-emission adhesive tape. The door leaves were tested with a door handle set screwed on. Door frames were tested without their rear side being sealed off. Loading conditions and times of air sampling are shown in **Table 1**.

2.3.2 Emission testing in a 24 m³ emissions test chamber

Testing of a complete internal door consisting of a door leaf with door frame (directly coated with white paint) was carried out in a walk-in 24 m^3 emissions test chamber (Weiss Umwelttechnik, Reiskirchen) with stainless steel walls. As per Section 2.3.1 the door leaf and door frame were also at the same time investigated individually in a 1 m^3 test chamber for the purposes of comparison. The internal door was positioned in the middle of the 24 m^3 test chamber with the aid of an aluminum frame (item Industrietechnik, Solingen). The surfaces of the door leaf and door frame which are visible with a normal installation were exposed without any covering to the test chamber atmosphere. The rear of the internal door was sealed off with a special low-emission foil while the item frame covered the back of the door frame (see **Figure 2**). Loading conditions and sampling times of the investigation are shown in Table 1.

2.4 Analysis

2.4.1 Determination of VOCs/SVOCs in accordance with DIN ISO 16000-6 [15]

VOCs/SVOCs were measured using Tenax TA® sampling tubes which were evaluated by thermo-desorption and gas chromatography/mass spectrometry (TD/GC/MS) within the retention ranges C_6-C_{16} (VOCs) and C_{16}-C_{22} (SVOCs). LCI substances (LCI stands for “lowest concentration of interest“) were quantified with the aid of original reference substances, non-LCI substances by means of the toluene response. The TVOC value was determined by adding together the individual substance concentrations so obtained (AgBB assessment) as well as by evaluating all individual substances with a toluene standard (French assessment).

2.4.2 Determination of formaldehyde and acetaldehyde in accordance with DIN ISO 16000-3 [14]

DNPH cartridges (2,4-dinitrophenylhydrazine, Supelco) were used for measuring formaldehyde and acetaldehyde. Quantitative determination was carried out by high-performance liquid chromatography (HPLC) and an ultraviolet detector.

2.5 Conversion to reference room concentrations

The exposure scenario (room size, loading conditions, air exchange rate) is of crucial importance in the health assessment of emissions from building products. The AgBB scheme [5] specifies a model room with an air volume of 30 m^3 and an air exchange rate of 0.5 h^{-1}. The French regulation for building product labeling also use this model room, which will also be included as a normative reference room in the future harmonized European standard for building product emissions measurement [10]. Here it is specified that the internal door has a surface area of 1.6 m^2. The surface area of a door frame is not specified until now. Within the context of the present project a visible surface area of 1.06 m^2 has been taken as the basis for the door frame in the reference room. The resulting loading conditions are shown in Table 1. On the basis of the measured concentrations (1 m^3 test chamber) and the boundary conditions of the investigation it was possible to determine, by Eq. (1), area-specific emission rates which were then, by Eq. (2), used to calculate room air concentrations for the 30 m^3 reference room.

$$SER_A = C \cdot ACH/L \qquad (1)$$

$$C = SER_A \cdot L/ACH \qquad (2)$$

where

SER_A: area-specific emission rate in µg/(m^2 h)
C: concentration in µg/m^3
ACH: air exchange per hour in 1/h
L: loading factor in m^2/m^3

The room air concentrations in the reference room thus obtained were evaluated in accordance with the AgBB scheme and the French emissions regulations. According to the upcoming product standard [11] the product “internal door“ consists of door leaf and door frame. Since it cannot here be automatically assumed that door leaves and door frames have passed along an identical manufacturing process and sales channel, in the present project the individual products were assessed separately. As regards testing in the 24 m^3 test chamber the boundary conditions of the investigation were selected such that the specific ventilation rate was approximately equal to that in the reference room (30 m^3) (see Table 1). For this reason the concentrations measured in the 24 m^3 emissions test chamber did not require further conversion.

4 Results and discussion

Figures 3 (door leaves, TVOC), **4** (door leaves, formaldehyde), **5** (door frames, TVOC) and **6** (door frames, formaldehyde) show for the reference room the calculated room air concentrations (µg/m^3) after 3, 7, 14 and 28 days for the individual parameters. Over the 28 day period most of the test pieces investigated showed an in part marked fall in TVOC concentrations. Their qualitative composition was basically

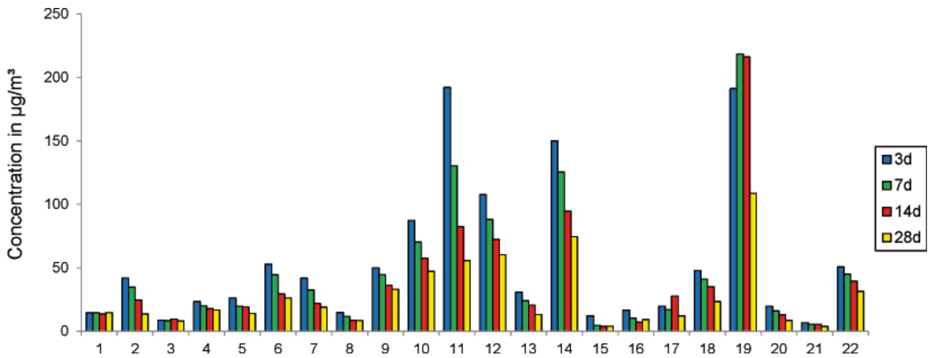

Figure 3. Door leaves, calculated TVOC concentrations (AgBB assessment) after 3, 7, 14 and 28 days in the reference room (30 m³); 1 to 5: ready-for-use surfaces; 6 to 14: direct coating; 15 to 22: veneered/painted surfaces.

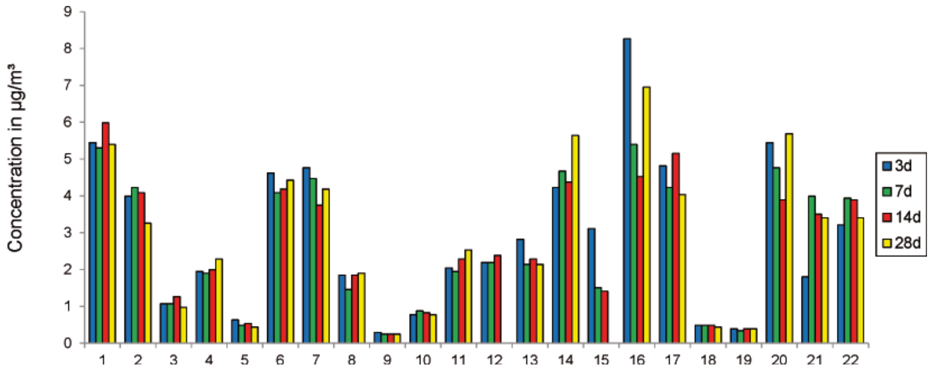

Figure 4. Door leaves, calculated formaldehyde concentrations after 3, 7, 14 and 28 days in the reference room (30 m³); 1 to 5: ready-for-use surfaces; 6 to 14: direct coating; 15 to 22: veneered/painted surfaces.

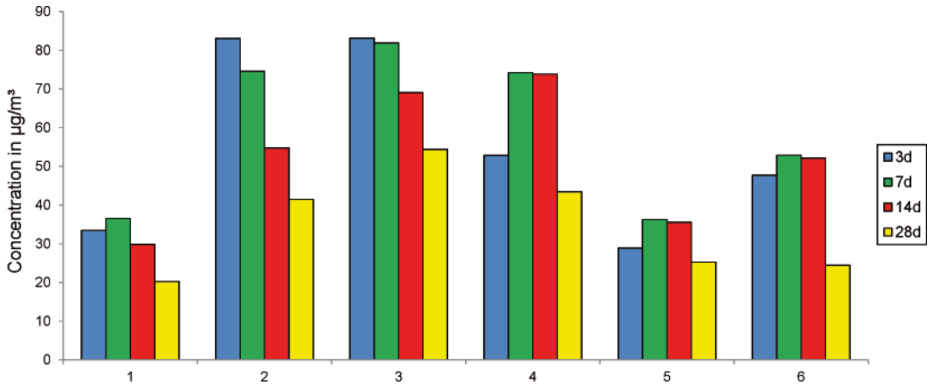

Figure 5. Door frames, calculated TVOC concentrations (AgBB assessment) after 3, 7, 14 and 28 days in the reference room (30 m³); 1: ready-for-use surfaces; 2 to 3: direct coating; 4 to 6: veneered/painted surfaces.

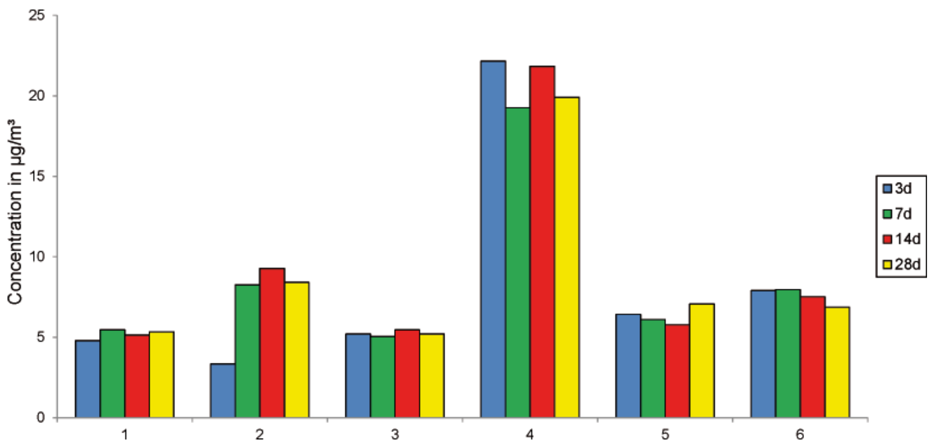

Figure 6. Door frames, calculated formaldehyde concentrations after 3, 7, 14 and 28 days in the reference room (30 m³); 1: ready-for-use surfaces; 2 to 3: direct coating; 4 to 6: veneered/painted surfaces.

influenced by the type of surface coating (ready-for-use surface, direct coating or veneered/painted surface). The highest emissions were found with the direct coatings and the veneered/painted surfaces while ready-for-use surfaces had comparatively lower emissions. The principle individual substances are listed in **Table 2** with the lowest and greatest calculated concentrations after 28 days. When the concentration of formaldehyde emissions is plotted over time however, no significant decay can be observed. The level of formaldehyde emissions was primarily dependent on the adhesives used in each case and not on the type of surface coating. **Figure 7** presents a comparison of the results of the investigation in the 24 m³ test chamber (measured) as well as the 1 m³ test chamber (calculated for 30 m³) for the TVOC and Formaldehyde parameters. It can be seen from the diagram that there is very close agreement between the measured and the calculated concentrations. This example confirms that the results of the investigation in the 1 m³ test chamber can be converted up to the reference room. The effort involved in testing is considerably reduced by the possibility of testing sections of an internal door or door frame.

4.1 Assessment in accordance with the AgBB scheme

The AgBB assessment is based on the 2010 LCI values list [5]. The air samples which were taken in addition 7 and 14 days after loading the chamber supplied useful information about how the measured emissions decayed over time. The individual parameters of the AgBB scheme will now be considered.

Carcinogenic substances parameter after 3 and 28 days: In none of the tested samples were any carcinogenic substances detected in the test chamber atmosphere after 3 or 28 days with a detection limit of 0.001 mg/m³. The corresponding limit values of the AgBB scheme are 0.010 mg/m³ (3-day value) and 0.001 mg/m³ (28-day value).

TVOC parameter after 3 and 28 days: The TVOC limit values of the AgBB scheme are 10 mg/m³ (3-day value) and 1.0 mg/m³ (28-day value). The 3-day value calculated for the reference room was for all investigated

Table 2. Limit value requirements of French emission labeling for emission classes A+, A, B, C, LCI values (German AgBB scheme) and calculated reference room air concentrations (min/max) for selected individual substances after 28 days; dimension µg/m³.

Emission classes	C	B	A	A+	LCI value (list from 2010)	Reference room 28 day
Formaldehyde	> 120	< 120	< 60	< 10	VVOC, no LCI	< 1 to 20
Acetaldehyde	> 400	< 400	< 300	< 200	VVOC, no LCI	< 1
Toluene	> 600	< 600	< 450	< 300	1,900	< 1
Tetrachloroethene	> 500	< 500	< 350	< 250	70	< 1
Xylene	> 400	< 400	< 300	< 200	2,200	< 1 to 20
1,2,4-Trimethylbenzene	> 2,000	< 2,000	< 1,500	< 1,000	1,000	< 1 to 5
1,4-Dichlorbenzene	> 120	< 120	< 90	< 60	VOC without LCI	< 1
Ethylbenzene	> 1,500	< 1,500	< 1,000	< 750	4,400	< 1
2-Butoxyethanol	> 2,000	< 2,000	< 1,500	< 1,000	980	< 1
Styrene	> 500	< 500	< 350	< 250	860	< 1
TVOC (toluene equivalent)	> 2,000	< 2,000	< 1,500	< 1,000		1 to 78
Methyl isobutyl ketone					830	< 1 to 10
1,2-Propylene carbonate					250	< 1 to 6
Acetic acid					500	< 1 to 25
n-Butyl acetate					4,800	< 1 to 52
2,4,7,9 Tetramethyl-5-decyne-4,7-diol					VOC without LCI	< 1 to 24
Dipropylene glycol methyl ether					3,100	< 1 to 16
2-Hydroxy-2-methyl-1-phenyl-propan-1-one					VOC without LCI	< 1 to 24
Ethylene glycol monobutyl ether					980	< 1 to 16
1-Butoxy-2-propanol					VOC without LCI	< 1 to 14
Ethyl acetate					VVOC, no LCI	< 1 to 5
1-Methoxy-2-propyl acetate					2,700	< 1 to 13
Hexanal					890	< 1 to 6

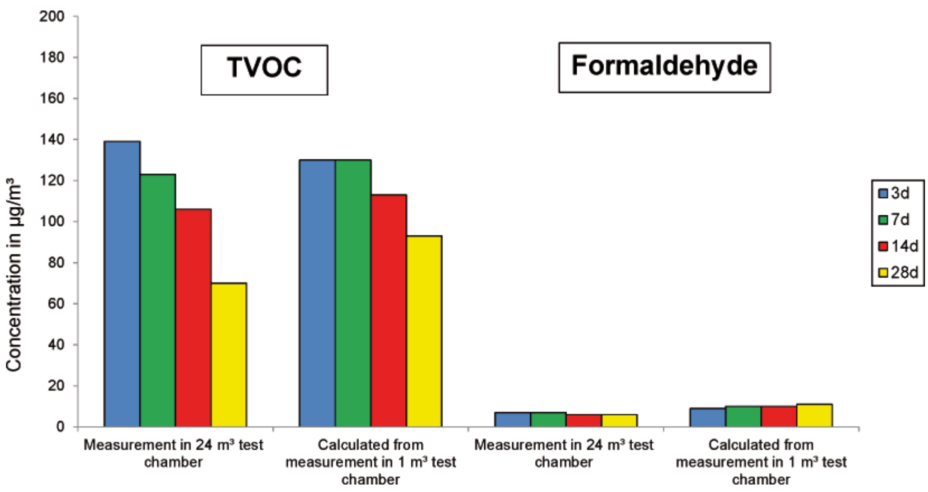

Figure 7. TVOC (AgBB assessment) and formaldehyde concentrations of a complete internal door (door leaf and door frame, direct coating) after 3, 7, 14 and 28 days in the reference room (30 m³); 24 m³ vs. 1 m³ emissions test chamber.

VOCs with LCI (R value) parameter after 28 days: With the aid of the LCI value, around 175 individual VOCs (for selected compounds see Table 2) for which toxicological information is available are evaluated in the AgBB scheme.

According to the AgBB scheme, the (dimensionless) value for parameter R for VOC with LCI should not exceed 1 for the 28-day value. For the evaluation of each compound i the ratio R_i is established as defined in Eq. (3):

$$R_i = C_i/LCI_i \qquad (3)$$

products lower than the limit value of 10 mg/m³ by at least a factor of 50. In the case of the 28-day value, the limit value was not reached by any sample by at least a factor of 10. When the white-painted internal doors were tested in the 24 m³ test chamber a TVOC value of 0.14 mg/m³ was measured after 3 days and 0.07 mg/m³ after 28 days. This meant that the TVOC limit value for the 3-day value was not reached by a factor of 70 and the TVOC limit value for the 28-day value not reached by a factor of 15.

where

C_i is the chamber concentration of compound i.

LCI_i is the lowest concentration of interest of compound i

For $R_i < 1$, it is assumed that there will be no effects. If several compounds with a concentration > 5 mg/m³ are detected, additivity of effects is assumed and it is required that R, the sum of all R_i, shall not exceed the value 1.

R = sum of all R_i = sum of all ratios $(C_i/LCI_i) < 1$.

In the present project the value calculated for R for all investigated door leaves and door frames was at least 16 times lower than the limit value. Investigation in the 24 m³ chamber produced an R value of 0.03.

VOCs without LCI parameter after 28 days: In the AgBB scheme the limit value for VOC individual substances without LCI value is 0.1 mg/m³ after 28 days. For most products no VOCs without LCI were detectable. Only in the case of three door leaves with a painted surface were VOCs without LCI detected: 2,4,7,9-tetramethyl-5-decyne-4,7-diol (0.024 mg/m³), the photoinitiator 2-hydroxy-2-methyl-1-phenylpropane-1-one (0.024 mg/m³) and the substance 1-butoxy-2-propanol (0.014 mg/m³) (see Table 2). The limit value for VOCs without LCI was thus taken up by no more than a quarter. In the case of investigation in the 24 m³ chamber no VOCs without LCI could be detected.

SVOCs parameter after 28 days: In the AgBB scheme the limit value for SVOCs after 28 days is 0.1 mg/m³. In the case of testing in the 1m³ test chamber, for the boundary conditions of the reference room no SVOCs were detected above 0.001 mg/m³ for all investigated door leaves and door frames. As regards testing in the 24 m³ test chamber no SVOCs were detected either.

Formaldehyde parameter: The AgBB scheme does not include measurement of formaldehyde. However, according to the DIBt (German Institute for Civil Engineering) with general building regulations approvals such products as can, due to the materials used, emit formaldehyde must also be tested for the corresponding emissions. The result was that for all investigated door leaves and door frames the national requirement [20] regarding permissible formaldehyde emissions (E1 classification) is satisfied and in part levels are considerably lower than the limit.

4.2 Assessment using the French emission classes

In the French assessment system [6; 7], building products are classified into four different emission classes on the basis of the results of test chamber measurements (28-day value): A+, A, B and C. Only 10 individual substances and the TVOC value are taken into consideration here (see Table 2). What decides how a product is classed is the parameter with the worst classification. The TVOC limit value for the strictest emission requirement (A+) is < 1000 µg/m³. In contrast to the AgBB scheme the TVOC value in the French product declaration is not measured by the original response but as the ttoluene equivalent. In the case of the samples measured as part of the present project the TVOC value determined by original response (Figures 3 and 5) was on average 1.8 times higher than that determined with the toluene equivalent. The range of this factor extends from 1.1 to 3.0. All investigated materials lay markedly below the TVOC limit value of the A+ class. As regards the individual substances (with the exception of formaldehyde) all investigated products satisfied the requirements for an A+ classification. The individual substances listed in the requirements (Table 2) play virtually no role at all in emissions from internal doors and other than formaldehyde were detected individually in very low concentrations of a few µg/m³ at most. As regards VOC/TVOC it is for this reason immaterial in classifying the products whether the door leaves and door frames are assessed separately or as a combined product. The critical parameter as regards an A+ classification concerns the substance formaldehyde. Meeting the A+ requirements requires compliance with a limit value of 10 µg/m³ formaldehyde. This A+ class limit value requirement for formaldehyde was satisfied by all door leaves investigated (Figure 4). With the door frames (Figure 6) the limit values of the A+ requirement were complied with in five out of the six products. With one type of door frame the limit requirement was just exceeded with approx. 20 µg/m³. Since only a very small number of door frames was investigated, the extent to which the results are representative of door frames is not at the moment definitively clear. With product labeling by the French emission classes it may therefore be significant in individual cases whether door leaves and the associated door frames are labeled as a single product or as separate products.

5 Summary

The results indicate that door leaves and door frames can in principle represent an emission source for VOCs and formaldehyde in the indoor environment. All of the door leaves and door frames investigated meet national requirements with regard to the permissible emission of formaldehyde. Should a general building regulations approval for internal doors be required in Germany on the basis of AgBB measurements, all of the investigated variants of door leaves and door frames would without exception very comfortably satisfy these requirements (even as combinations of door leaf and door frame). The same will be true when the upcoming Belgian limit values are applied. There is therefore no reason to introduce mandatory measurement for the product group under investigation. In the case of labeling in accordance with the French emission classes the products (individually or as combinations of door leaf and door frame) can be assigned to Emission Class A. In individual cases documented evidence for classification in Emission Class A+ can be supplied by an emission test. For the scenario whereby Europe-harmonized emission classes for building products are to be introduced in the future, it is conceivable that internal doors will be classed as products *wft* (without further testing) or *wt* (without testing) or be assigned without the requirement for an individual certificate to one of the emission classes then to be specified.

The investigative method used for emission measurements of internal doors (door leaves, door frames) as presented here has proved its worth and may be regarded as fit for practice. Should it nevertheless become necessary, in terms of what has been written here, for emission measurements to be taken, the test method described here could be used as a basis for the product standard DIN EN 14351-2 [11]. It is equally possible for it to be used within the context of a voluntary product labeling system. With regard to their market share, internal doors in accordance with DIN EN 14351-2 [11] correspond predominantly with flush doors made of wood or wood-based products in accordance with DIN 68706-1 [12] or DIN 68706-2 [13]. The variants of decisive importance for this product group have been investigated on a broad basis as part of the project. Statements regarding the emission behavior of other types and designs of door would require further investigations to be carried out.

Acknowledgements

IGF project 16210 N/2 of the research association Internationaler Verein für Technische Holzfragen e. V. – iVTH, Bienroder Weg 54 E, 38108 Braunschweig has been financed via the German Federation of Industrial Research Associations (AiF) as part of a program for promoting industrial community research and development (IGF) of the Federal Ministry of Economics and Technology on the basis of a resolution of the German Bundestag. In addition to public-sector financing, the project has also been supported in advisory capacity by the following project partners: Verband der Deutschen Holzwerkstoffindustrie e.V., Grauthoff Türengruppe GmbH, Jeld-Wen Deutschland GmbH & Co. KG, Neuform – Türenwerk Hans Glock GmbH & Co. KG, Schwering Türenwerk GmbH & Co. KG, Türelemente Borne Handelsgesellschaft mbH, Weiss Umwelttechnik GmbH.

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[9] Mandate/366EN: Horizontal complement to the mandates to CEN/CENELEC, concerning the execution of standardization work for the development of horizontal standardized assessment methods for harmonized approaches relating to dangerous substances under the construction products directive (CPD) – Emission to indoor air, soil, surface water and ground water, European Commission, Brussels, 16th March 2005.

[10] CEN/TC 351/WG2: Construction products – Assessment of emissions of regulated dangerous substances from construction products – Determination of emissions into indoor air.

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