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Indoor air quality after installation of building products in energy-efficient buildings

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Indoor air quality after installation of building products in energy-efficient buildings

by

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Abstract

Central Europeans spend most of their time inside buildings. Therefore the quality of the indoor air is important for human health and well-being.

Unpleasant odour perceptions up to odour nuisance, but also health complaints such as irritating eyes, nose and throat, headache, fatigue or concentration difficulties are the most common impairments reported by occupants of indoor spaces.

In order to preserve a good air quality, materials and articles used indoors should have low-emissions, i.e. they should give off as few harmful and odorous substances as possible. Interior materials (building products and equipment and materials for facilities in indoor spaces) play an important role because their selection is often not within the user's discretion and because many of them cover large surface areas in the room.

The results of this project should identify ways to avoid indoor air problems, including odour nuisance, by selecting suitable building products.

Within this project the indoor air quality with regard to volatile organic compounds (VOC) and odours in various energy-efficient buildings, real buildings before and after renovation, and building products and their combinations have been investigated. Various methods for odour assessment in room air samples have been examined and compared. Furthermore wall and floor assemblies have been installed in special testing rooms to measure their emissions.

The results show that the combination of unobtrusive materials in terms of odour and VOC emissions, with proper application, can lead to a good indoor air quality.

Kurzbeschreibung

Einen Großteil seiner Zeit verbringt der Mitteleuropäer innerhalb von Gebäuden. Die Qualität der Luft in Innenräumen ist daher wichtig für die menschliche Gesundheit und das Wohlbefinden.

Unangenehme Geruchsempfindungen bis hin zur Geruchsbelästigung, aber auch gesundheitsbezogene Beschwerden wie die Reizung von Augen, Nase und Rachen, Kopfschmerzen, Müdigkeit oder Konzentrationsschwierigkeiten gehören zu den häufigsten Beeinträchtigungen, die Personen beim Aufenthalt in Innenräumen nennen.

Damit die Raumluft von vornherein wenig belastet wird, sollten Materialien und Gegenstände, die im Innenraum genutzt werden, emissionsarm sein, also möglichst wenige Schad- und Geruchsstoffe ausdünsten. Innenraummaterialien (Bauprodukte und Materialien zur Ausstattung und Einrichtung von Innenräumen) spielen hier eine wesentliche Rolle, weil ihre Auswahl häufig nicht im Ermessen der Raumnutzer liegt und weil viele von ihnen großflächig in den Raum eingebracht werden.

Die Ergebnisse des Vorhabens sollen mögliche Wege aufzeigen, wie man durch geeignete Auswahl von Bauprodukten spätere Innenraumprobleme inklusive geruchlicher Belästigungen vermeiden kann.

Im Rahmen dieses Forschungsprojekts wurde die Innenraumluftqualität im Hinblick auf flüchtigen organischen Verbindungen (VOC) und Gerüche in einigen energieeffizienten Gebäuden, realen Gebäuden vor und nach der Sanierung und Bauprodukte und deren Kombinationen untersucht. Es wurden verschiedene Geruchs-Bewertungsmethoden von Raumluftproben betrachtet und miteinander verglichen. Weiterhin wurden Boden- und Wandaufbauten in speziell eingerichteten Prüfräumen eingebracht und deren Emissionen gemessen.

Die Ergebnisse der Untersuchungen zeigen, dass die Kombination von Geruch- und Immissionsunauffälligen Produkten bei sachgerechter Anwendung auch zu guten Raumluftbedingungen führt.

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List of abbreviations

AgBB	Committee for Health Evaluation of Building Products
AirProbe	Sample provision device for odour samples
AQ	Air quality
BMUB	Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
CLIMPAQ	Chamber of laboratory investigations of materials, population and air quality
CP	Construction phase
D3, D4, D5	Hexamethyl cyclotrisiloxane, octamethyl cyclotetrasiloxane, decamethyl cyclopenta-siloxane
DNPH	2,4-dinitro-phenylhydrazine
EPS	Expanded polystyrene
GC/MS	Gas chromatography with coupled mass spectrometry
GV I	Guide value I
HPLC/UV	High performance liquid chromatography
LCI	Lowest concentration of interest
MBO	Standard Building Code
n.a.	non analysed
n.d.	non detectable
n.r.	not registered
n.m.	non measurable
TE	Toluene equivalent
TVOC	Sum of all volatile organic compounds
UBA	German Environment Agency
VOC	Volatile organic compounds

Summary

Introduction and aim of the research project

The health-related evaluation of emissions from building products has gained more and more importance over the last years. This is due not only to the fact that people spend 80-90 % of their time inside buildings but also to the increased air-tightness of the building envelope as a result of the energy-efficient construction. Thus, the emissions from building products can influence the occupant's health today more than in the past.

Since 2005 Germany has implemented health-related requirements for emissions within the approval of building products. Flooring materials, adhesives, floor coatings and underlays need technical approval before being used in indoor spaces. However, even if products fulfil the emission requirements of the Committee for Health-related evaluation of Building Products (AgBB), health complaints due to odour nuisance or irritation can be registered. These can lead to a situation where room occupants demand the removal of the building materials. Therefore the exposure (Immission) situation after installation of products has to be checked beside the emissions measurements in the test chambers. Possible odour nuisance has to be equally recorded and evaluated.

The original aim of the study was to investigate the indoor air quality of energy-efficient retrofitted buildings using the example of the German Environment Agency's (Umweltbundesamt, UBA) office building in Bismarckplatz in Berlin. The building was due to be extensively renovated between 2011 and 2014 and subsequently include single work units from other UBA office buildings. The building had to meet high environmental standards and sustainably renovated. This implied a targeted selection of low-emission products during the planning stages.

The objective of this project was to identify ways to avoid indoor air problems including odour nuisance by selecting suitable building products. The project intended to close knowledge gaps about the emission behaviour of volatile organic compounds (VOC) and odours in retrofitted rooms (also for a combination of building products). Energy-efficient construction and good indoor air quality were to be brought together through a reasonable selection of building materials. The results of the research project would help answer the question of whether the evaluation of odours has to be considered to a greater degree than in the past.

Due to the postponement of the remediation actions in the Bismarckplatz office building, the specification of the project changed in agreement with UBA and the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB). The new UBA building "Haus 2019" and one floor in an office building to be renovated were then included in the new specification of the project. Both buildings are located in Berlin. In addition, further olfactory analyses of various wall and floor assemblies installed in test rooms of the eco-INSTITUT in Cologne were conducted.

Assignment of tasks

The original aim of the study was to investigate the indoor air quality of energy-efficient retrofitted buildings using the example of the UBA Bismarckplatz office building in Berlin. For this purpose the following analyses were conducted:

1. Systematic analysis of the indoor air quality concerning odours in 20 empty offices of UBA Bismarckplatz prior to the remediation works starting. The panellists evaluated the perceived intensity and hedonics of the indoor air. (chapter 4)

   The odour tests were conducted in 10 rooms using the following three methods (a to c). By means of the results, a decision was made on which of the two methods should be used to execute the following measurements, or if further analyses using the three methods were needed:

a) Air sampling in special containers and evaluation by the trained panel in the laboratory
b) Air sampling in special containers and evaluation by the trained panel on site (UBA Bismarckplatz)
c) Direct odour testing on site.

2. During the second experimental phase the analyses under (1) were repeated. Odour tests were performed during the placement of various flooring assemblies, after installation of insulating materials (with and without wall covering) and placement of acoustic ceiling or after various sealing measures. The workflow for these measurements was coordinated together with UBA. The analyses were conducted room by room depending on the progress of the remediation works. 20 rooms were analysed.

3. During the third phase the analyses were repeated after the end of the remediation works including painting the rooms and placement of doors and windows. The first measurements were conducted 4 weeks after finishing single rooms. A second measurement was conducted after 3-4 months and the last measurement after 6-8 months. 20 rooms were analysed.

UBA performed measurements of the concentrations of VOC and aldehydes in selected rooms.

Additional analyses such as evaluation of single products or combinations of materials in emission test chambers and real rooms were planned. The evaluation of odours during the project, before installation of materials in the building was a reasonable addition. For this purpose the following analyses were conducted:

I. Measurement of combinations of building materials in emission test chambers

To reduce the analyses under (2) it was helpful to simulate single remediation phases in the emission test chambers. In this way the sampling was simplified and various assemblies could be tested beforehand. The best products were then selected.

II. Analyses of combinations of selected materials in real rooms before the products were installed in the building

The combination of products in real rooms is as good as unexplored so far, but it provided the opportunity to check the behaviour of these compositions regarding odour emissions under real conditions. In addition, analytical measurements were performed by UBA.

Due to the postponement of the remediation works, only the analyses under (1) and the additional measurements under (I) and (II) have been conducted. The investigations under (1) were used for the comparison of various methods for odour assessment.

Various measurements, in addition to those under (I) and (II), were conducted in cooperation with the eco-INSTITUT in Cologne. 4 wall and 4 floor assemblies were installed in Cologne and the emission of volatile organic compounds and odours were assessed. All single products and some combinations were additionally tested in the emission chambers.

Due to the postponement of the remediation actions in the Bismarckplatz office building, the specification of the project was changed in agreement with UBA and BMUB. The new building "UBA Haus 2019" and one floor in an office building to be renovated were included in the new specification of the project. Both buildings are located in Berlin.

Results

Comparison of methods

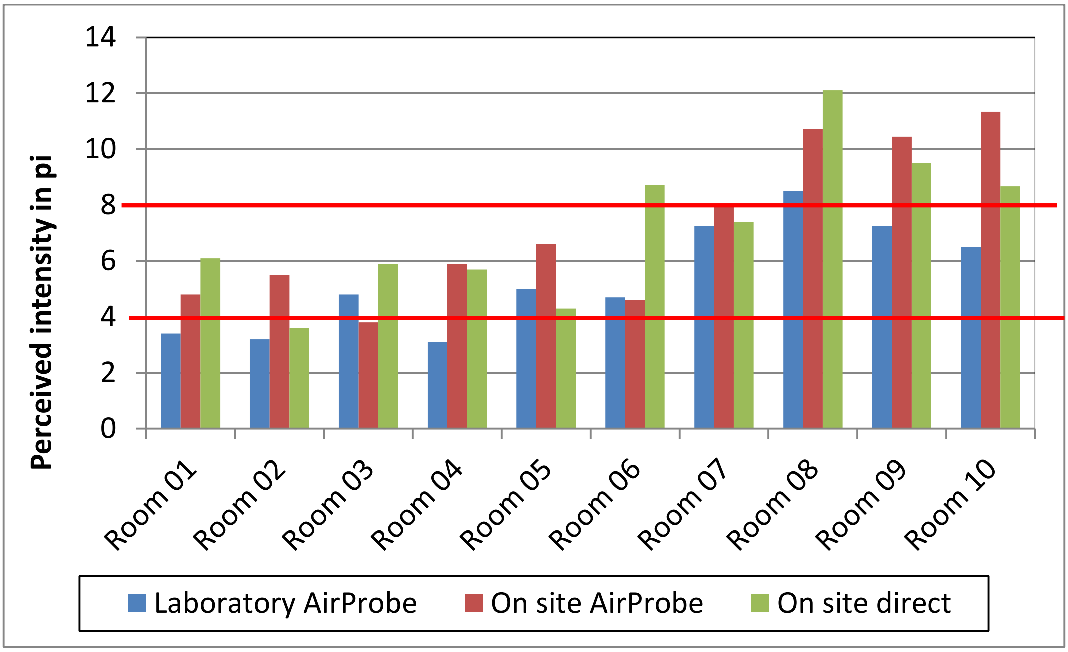
The first work package deals with analyses for assessing the as-is state of the air quality in selected rooms at UBA Bismarckplatz before starting the remediations actions. Various assessment methods of the indoor air were used and compared to identify the most suitable method for evaluating odours and to verify the comparability of the results from the different methods used.

The evaluation of odours in the office rooms was conducted according to the following methods:

a) Air sampling in special containers and evaluation by the trained panel in the laboratory
b) Air sampling in special containers and evaluation by the trained panel on site (UBA Bismarckplatz)
c) Direct odour testing on site.

The following diagram compares the perceived intensity for the three evaluation methods described above in the analysed rooms.

Figure 1 Perceived intensity: comparison of methods



Generally, it can be concluded that the results of the three assessment methods lie within the accuracy requirements of +/- 2 pi. This means that the mean value for the three different methods is calculated and that the deviations around this mean value are not allowed to exceed the accuracy requirements of +/- 2 pi. The three methods provide similar results. This finding was important in deciding the subsequent approach in this project and selecting the evaluation method to be used during the various phases of the remediation works. The laboratory results from the AirProbe provide the lowest perceived intensities. The other two methods show very good consistencies but also some differences in the assessment. By comparing the results of the rooms, it can be said that the offices 01 to 07 have a medium air quality and the rooms 08 to 10 exhibit a slightly poorer indoor air quality.

Method selection

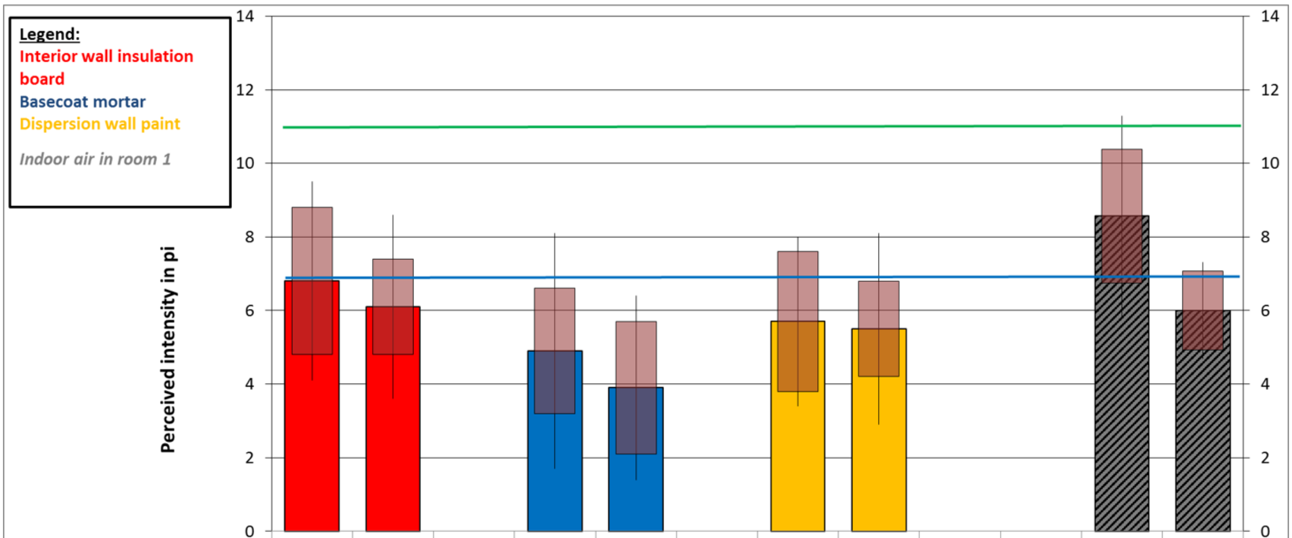
On the basis of these analyses and in cooperation with UBA, the two methods on site (b and c) were selected for the following investigations in UBA Bismarckplatz. The LaborAirProbe should always be selected when an on-site evaluation due to remediation works is not possible.

Measurements in test rooms

Due to the postponement of the renovation works, the investigation of combinations of building materials was conducted in the next phase. Various wall and floor assemblies in real test rooms of the eco-INSTITUT in Cologne were installed and the emissions tested. In addition, the single building products installed in the rooms were tested in the emission chambers.

Diagram 2 shows the perceived intensity of the in-place products and of the indoor air in the test room 1 at UBA Bismarckplatz. The results of the assessments for all single products are below the criteria for the Blue Angel on day28 (< 7 pi). The perceived intensity of the room air (black/grey) is also situated in this range (6 pi).

Figure 2 Perceived intensities of the products and the indoor air in test room 1 (Bismarckplatz)



	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28
Intensity mean value	6.8	6.1	4.9	3.9	5.7	5.5	8.6	6.0
Half confidence interval	2.0	1.3	1.7	1.8	1.9	1.3	1.8	1.1
Temperature in °C	23.5	23.5	23.5	23.5	23.5	23.5	24.7	19.8
Relative humidity in %	50.0	50.0	50.0	50.0	50.0	50.0	77.5	63.0
Confidence interval min.	4.8	4.8	3.2	2.1	3.8	4.2	6.7	4.9
Standard deviation max.	9.5	8.6	8.1	6.4	8.0	8.1	11.3	7.3
Standard deviation min	4.1	3.6	1.7	1.4	3.4	2.9	5.8	4.7
Confidence interval max.	8.8	7.4	6.6	5.7	7.6	6.8	10.4	7.1

The evaluation of the single building products in the emission test chambers provided similar results to the assessment of the room air.

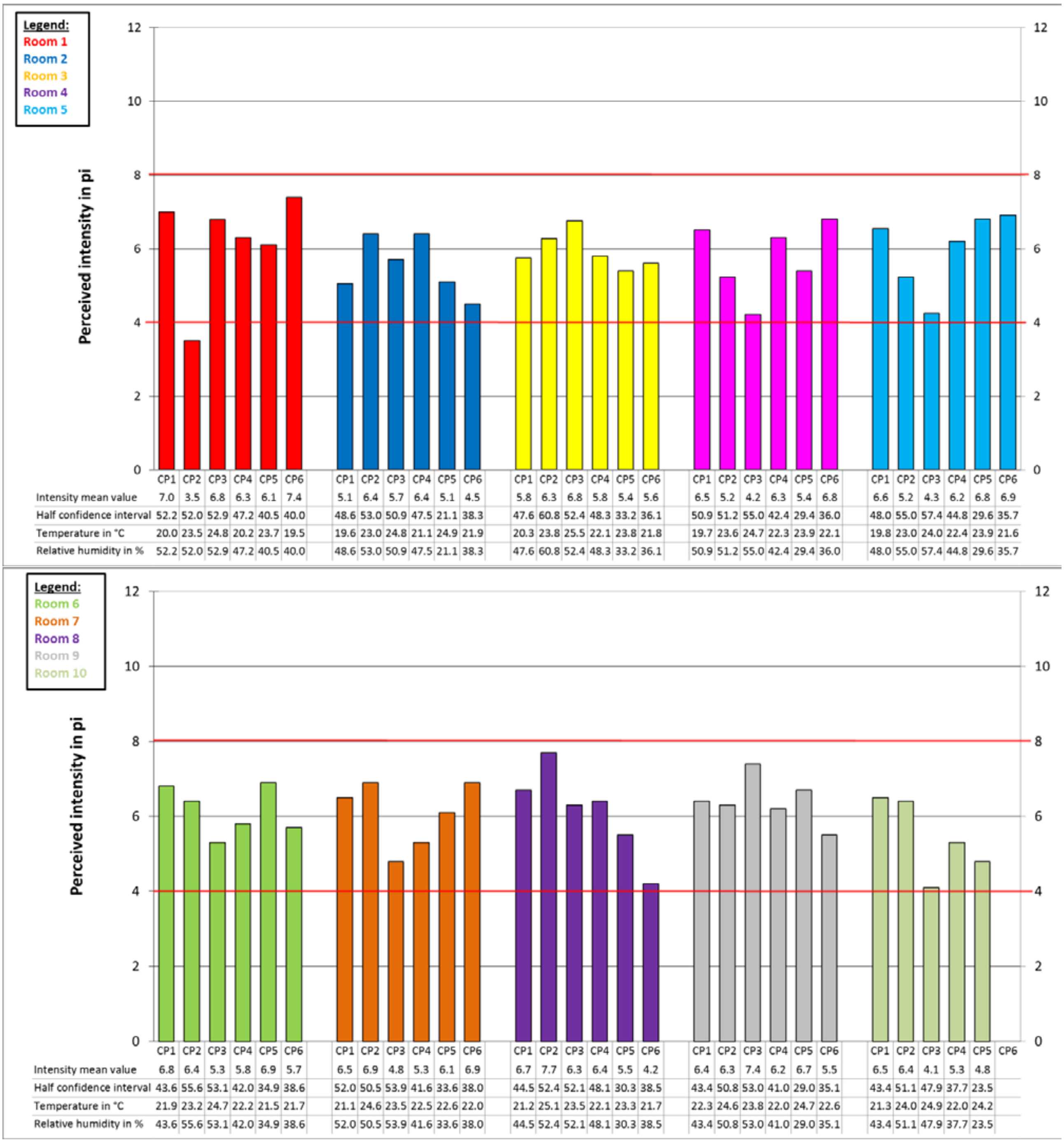
The single products showed very low chemical emissions. Higher concentrations were measured during the remediation works for the indoor air; these decayed over the investigation period and reached similar values as the as-is state of the rooms on the last measurement day.

Research object "UBA Haus 2019"

Between 2011 and 2013 a zero-energy building with 31 offices and 3 meeting rooms was built in Berlin Marienfelde. The title "Haus 2019" was chosen since this construction as of now fulfils the energy requirements for public buildings, which starts in 2019. Olfactory and analytical measurements of the indoor air were conducted during the construction works and after occupancy by the users.

Diagram 3 shows the intensity of the analysed rooms during the various stages of the construction.

Figure 3 Perceived intensity of the indoor air (UBA Haus 2019)



Generally, all perceived intensities in the offices are situated in a medium quality range. During the construction works (before using the rooms, CP 1-3) the intensities of the rooms 2 (blue), 3 (yellow) and 9 (grey) slightly increase, in the remaining rooms the intensities decrease.

With continuous use of the rooms (CP 4-6), intensities in the offices 2 (blue), 3 (yellow), 8 (purple) and 9 (grey) remain in the same range or slightly decrease. For the other rooms the mostly low intensities increase after completion of the construction of the building (CP 3) and occupancy by the users (CP 4-6). This means that by using the building further odours are being introduced in the building fabric, which influences the indoor air quality.

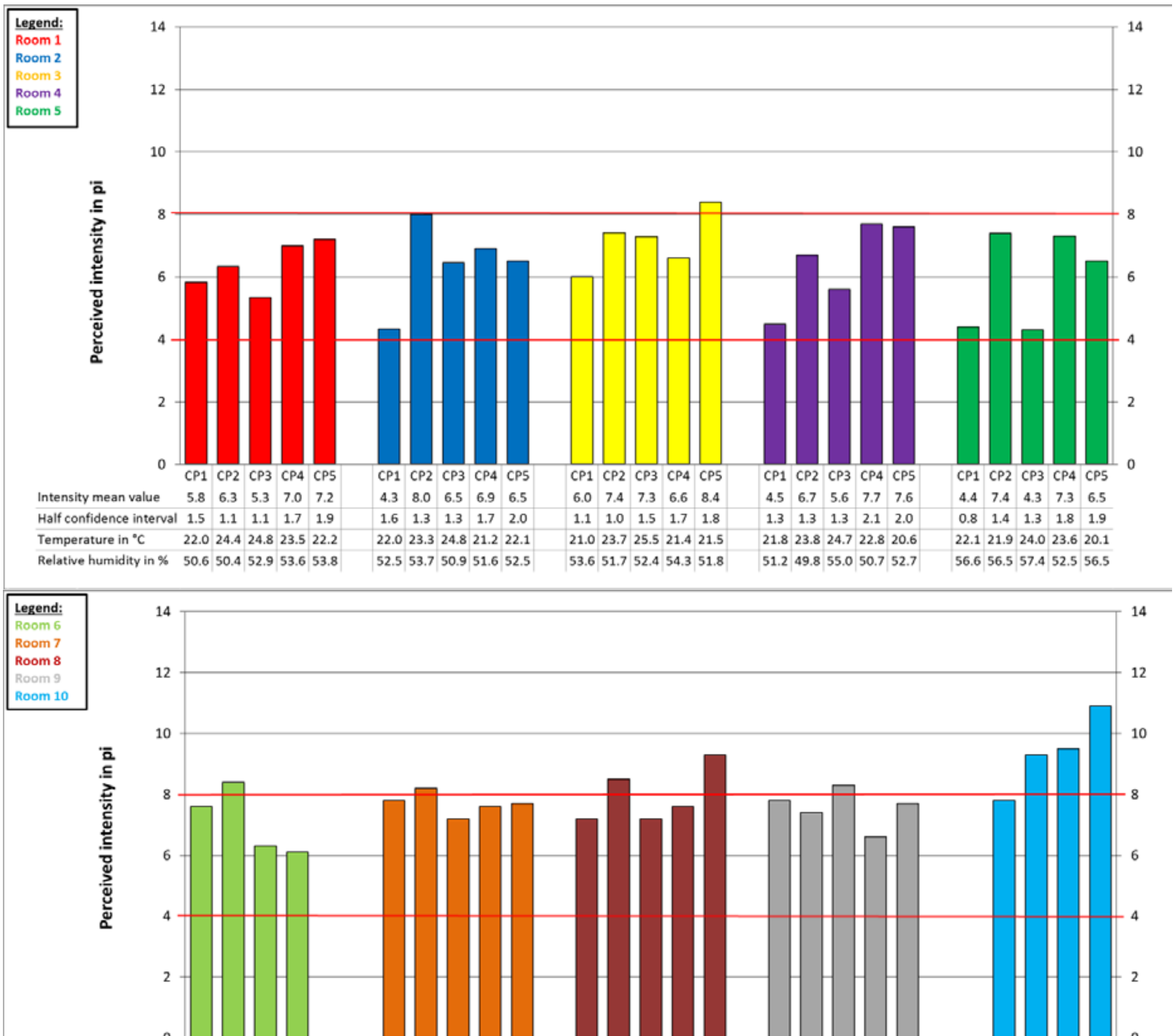
Regarding chemical emissions into indoor air, higher concentrations were measured during the construction works; these decayed over the investigation period and reached good values for a newly built building on the last measurement day.

Research object "Office renovation"

In this chapter remediation works to a floor in a large office building in Berlin have been accompanied. This floor has no ventilation system, so only manual ventilation by opening the windows is available.

Diagram 4 shows the perceived intensity of all analysed rooms during the measurement phases (CP 1-5).

Figure 4 Intensity of the room air (office renovation)



Room 1:

	CP1	CP2	CP3	CP4	CP5
Intensity mean value	5.8	6.3	5.3	7.0	7.2
Half confidence interval	1.5	1.1	1.1	1.7	1.9
Temperature in °C	22.0	24.4	24.8	23.5	22.2
Relative humidity in %	50.6	50.4	52.9	53.6	53.8

Room 2:

	CP1	CP2	CP3	CP4	CP5
Intensity mean value	4.3	8.0	6.5	6.9	6.5
Half confidence interval	1.6	1.3	1.3	1.7	2.0
Temperature in °C	22.0	23.3	24.8	21.2	22.1
Relative humidity in %	52.5	53.7	50.9	51.6	52.5

Room 3:

	CP1	CP2	CP3	CP4	CP5
Intensity mean value	6.0	7.4	7.3	6.6	8.4
Half confidence interval	1.1	1.0	1.5	1.7	1.8
Temperature in °C	21.0	23.7	25.5	21.4	21.5
Relative humidity in %	53.6	51.7	52.4	54.3	51.8

Room 4:

	CP1	CP2	CP3	CP4	CP5
Intensity mean value	4.5	6.7	5.6	7.7	7.6
Half confidence interval	1.3	1.3	1.3	2.1	2.0
Temperature in °C	21.8	23.8	24.7	22.8	20.6
Relative humidity in %	51.2	49.8	55.0	50.7	52.7

Room 5:

	CP1	CP2	CP3	CP4	CP5
Intensity mean value	4.4	7.4	4.3	7.3	6.5
Half confidence interval	0.8	1.4	1.3	1.8	1.9
Temperature in °C	22.1	21.9	24.0	23.6	20.1
Relative humidity in %	56.6	56.5	57.4	52.5	56.5

Room 6:

	CP1	CP2	CP3	CP4	CP5
Intensity mean value	7.6	8.4	6.3	6.1	
Half confidence interval	1.8	1.9	1.5	1.8	
Temperature in °C	21.7	20.7	24.7	21.5	
Relative humidity in %	57.0	60.1	53.1	56.1	

Room 7:

	CP1	CP2	CP3	CP4	CP5
Intensity mean value	7.8	8.2	7.2	7.6	7.7
Half confidence interval	1.6	1.7	1.8	1.9	1.4
Temperature in °C	22.3	21.2	23.5	23.7	22.4
Relative humidity in %	58.4	54.3	53.9	57.0	46.2

Room 8:

	CP1	CP2	CP3	CP4	CP5
Intensity mean value	7.2	8.5	7.2	7.6	9.3
Half confidence interval	1.8	1.4	1.6	1.7	2.0
Temperature in °C	22.0	21.6	23.5	23.0	21.3
Relative humidity in %	58.0	54.7	52.1	57.0	53.3

Room 9:

	CP1	CP2	CP3	CP4	CP5
Intensity mean value	7.8	7.4	8.3	6.6	7.7
Half confidence interval	1.3	1.4	1.6	1.1	1.8
Temperature in °C	21.9	21.6	23.8	23.1	20.5
Relative humidity in %	56.4	53.9	53.0	46.1	49.3

Room 10:

	CP1	CP2	CP3	CP4	CP5
Intensity mean value		7.8	9.3	9.5	10.9
Half confidence interval		1.2	1.6	2.0	1.7
Temperature in °C		24.6	24.9	24.5	22.9
Relative humidity in %		55.7	47.9	42.9	47.9

The standard deviations and the confidence intervals are not shown in this picture but can be found in the data table. The requirements for these parameters are fulfilled. Generally the intensity in almost all rooms slightly increases after the second construction phase (CP 2) when the flooring material is installed. In CP 3 (one month after CP 2) the intensities decrease to some extent. One exception can be observed in room 10 where linoleum is used; here the intensity reaches the highest value during the measurement phases. Apart from this, there is insignificant change to the intensities during the measurement phases and these are located, with some exceptions, in a marginal mid-range for the room air quality (between 6 and 8 pi).

Regarding chemical emissions into indoor air, higher concentrations were measured during the remediation works. Thus, the indoor air guide values for some compounds are exceeded. The concentrations of the volatile organic compounds decayed over the investigation period and reached good values on the last measurement day.

Discussion/Outlook

In this research project the indoor air quality in energy-efficient buildings has been investigated with regard to odours and volatile organic compounds.

The original aim of the study was to investigate the indoor air quality of energy-efficient retrofitted buildings using the example of the UBA Bismarckplatz office building in Berlin. Due to the postponement of the remediation works for the Bismarckplatz office building, the project specification was changed in agreement with UBA and BMUB. The new UBA building "Haus 2019" and one floor in an office building to be renovated were included in the new project specification. Both buildings are located in Berlin. In addition, further olfactory analyses of various wall and floor assemblies installed in test rooms of the eco-INSTITUT in Cologne were conducted. For the evaluation of the indoor air quality in the test rooms of UBA Bismarckplatz and eco-INSTITUT Cologne, direct and air sampling methods (AirProbe) were used. Both assessment methods provided comparable results.

Around 60 single products and combinations of materials have been tested in emission chambers. These products were also placed in the new or refurbished buildings or evaluated in real test rooms. Many of the single products examined achieved very good olfactory evaluations and, consequently, most of them fulfilled the proposed Blue Angel and AgBB criteria for odour assessment. Furthermore, the product evaluations from this project provide excellent information for an olfactory database which can be used in future projects. In this way various products can be compared and materials can be selected according to their odorous properties before placing them in buildings.

The results show the influence of combinations of various single products on the indoor air quality. The evaluation of the perceived intensities for the single products can be found again in the results for the combinations. The corresponding emission measurements show a similar behaviour. The comparison of the room air and product testing reveals the fact that odour emissions from building products can be found in the room air.

By measurements in real test rooms one has to consider that the temperature and humidity of the room air cannot always be adjusted as in the laboratory. The laboratory tests take place under constant and defined ventilation; therefore different test conditions are possible. Further measurements of combinations of materials have to be conducted to achieve a larger database and to be able to draw appropriate conclusions.

The measurements of the VOC and aldehyde concentrations show good results in all tested objects on day 28. The selection of products has a big influence on the emissions. During the construction works, higher concentrations of chemicals were measured in the indoor air of the investigated rooms. These values declined over the investigation period. Due to a low air exchange rate in "unused" rooms the VOC and aldehyde concentrations show a slower decay over the measurement phases. In this case it has to be ensured that the hygienically recommended minimum air exchange rate of 0.5 1/h is achieved.

The building materials used in the buildings show low or very low emissions.

The results show that the use of unobtrusive materials in terms of odour and VOC emissions can lead to a good indoor air quality.

Zusammenfassung

Einleitung und Zielsetzung des Forschungsvorhabens

Die gesundheitliche Bewertung der Emissionen aus Bauprodukten hat in den letzten Jahren immer mehr an Bedeutung gewonnen. Zum einen deshalb, weil wir uns 80-90 % des Tages in geschlossenen Räumen aufhalten, zum anderen, weil durch die energieeffiziente Bauweise die Luftdichtheit der Gebäudehülle deutlich zugenommen hat und sich von Bauprodukten ausgehende Emissionen mehr als früher gesundheitlich negativ bemerkbar machen können.

In Deutschland werden seit 2005 Gesundheitsanforderungen an die Emissionen in die Zulassung von Bauprodukten integriert und diese wurden für Bodenbeläge, Klebstoffe, Beschichtungen und Verlegeunterlagen bereits erfolgreich eingeführt. Aber selbst wenn die Produkte die Anforderungen der vom Ausschuss zur gesundheitlichen Bewertung von Bauprodukten (AgBB) festgelegten Prüfkriterien für die Emission erfüllen, kann es zu gesundheitlichen Beschwerden, unter anderem wegen Geruchsproblemen oder Reizerscheinungen kommen. Diese gehen soweit, dass die Raumnutzer die Entfernung der Baumaterialien fordern. Neben der Emissionssituation in der Prüfkammer muss daher mehr als bisher auch die Immissionssituation nach Einbau der Produkte im Innenraum geprüft werden. Ebenso gilt es, mögliche Geruchsbelästigungen zu erfassen und zu bewerten.

Ziel des ursprünglichen Forschungsvorhabens ist es, die Innenraumluftqualität nach Einbau von Bauprodukten in energetisch sanierten Gebäuden am Beispiel des Dienstgebäudes Bismarckplatz des Umweltbundesamtes (UBA) in Berlin zu untersuchen. Das Gebäude sollte zwischen 2011 und 2014 umfassend saniert werden und danach einzelne Arbeitseinheiten aus verschiedenen UBA-Liegenschaften aufnehmen. Das Gebäude wird in Analogie des Hauptgebäudes in Dessau hohen ökologischen Ansprüchen genügen und soll nachhaltig saniert werden. Dazu zählt auch, dass bereits bei der Planung eine gezielte Produktauswahl auch im Hinblick auf mögliche Emissionen erfolgt.

Die Ergebnisse des Vorhabens sollen mögliche Wege aufzeigen, wie man durch geeignete Auswahl von Bauprodukten spätere Innenraumprobleme inklusive geruchlicher Belästigungen vermeiden kann. Das Projekt soll helfen, Wissenslücken über das Emissionsverhalten in sanierten Räumen (Kombination von Bauprodukten) sowohl für die flüchtigen organischen Verbindungen (VOC) als auch für die Geruchsproblematik zu schließen. Energieeffiziente Bauweise und gute Raumluftqualität sollen hier über eine sinnvolle Baumaterialauswahl zusammengeführt werden. Die Untersuchungsergebnisse sollen helfen, die Frage zu beantworten, ob und in welcher Form Geruchsbewertungen stärker als bisher berücksichtigt werden sollten.

Aufgrund der Verschiebung des Beginns der Sanierungsarbeiten am Dienstgebäude Bismarckplatz wurde, in Abstimmung mit dem Umweltbundesamt (UBA) und dem Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (BMUB), eine Änderung der Leistungsbeschreibung und eine Neuverteilung der restlichen Finanzierungsmittel beantragt und vorgenommen. In der neuen Leistungsbeschreibung wurden als Untersuchungsobjekte der Neubau des UBA „Haus 2019“ sowie eine zu sanierende Etage in einem Bürogebäude ausgesucht. Beide Objekte befinden sich in Berlin. In Ergänzung dazu wurden weitere olfaktorische Untersuchungen von verschiedenen Wand- sowie Fussbodenaufbauten in Prüfräumen am eco-INSTITUT in Köln durchgeführt.

Aufgabenstellung

Ziel des ursprünglichen Projektes ist es, die Innenraumluftqualität nach Einbau von Bauprodukten und deren Kombinationen in energetisch sanierten Gebäuden am Beispiel des UBA Dienstgebäudes Bismarckplatz zu untersuchen. Dazu sollten folgende Untersuchungen durchgeführt werden:

1. Systematische Untersuchung der Raumluftqualität im Hinblick auf Gerüche in Büroräumen des UBA-Dienstgebäudes Bismarckplatz in leerem Zustand vor Beginn der Sanierungsarbeiten für 20

Räume. Die Probanden bewerten immer die empfundene Intensität und die Hedonik der Raumluft. (Kapitel 4)

Die Geruchsprüfung erfolgt für 10 Räume mit den folgenden drei Methoden (a bis c) nach der Auswertung der Ergebnisse der ersten 10 Räume wird entschieden mit welchen beiden Methoden die folgenden Messungen durchgeführt werden oder ob weitere Messungen mit allen drei Methoden nötig sind:

a) Probenahme mittels Probenbehältern und Bewertung durch geschulte Prüfer am Untersuchungsinstitut
b) Probenahme mittels Probenbehälter und Bewertung durch geschulte Prüfer vor Ort am Bismarckplatz
c) Probenahme und Bewertung durch geschulte Prüfer vor Ort am Bismarckplatz (direkte Geruchsprüfung).

2. In der zweiten Versuchsphase erfolgt die Wiederholung der Versuche aus (1) während der Sanierungsphase. Es können Prüfungen der Gerüche während des Aufbaus verschiedener Fußbodenaufbau¬konstruktionen, Prüfung der Gerüche nach Einbau von Dämmmaterialien (ohne und mit Wandverkleidung) und nach Einbau von Akustikdecken mit Dämmmaterial und Prüfung der Gerüche nach verschiedenen Abdichtungsmaßnahmen durchgeführt werden. Der Ablauf der hier gewünschten Untersuchungen wird eng mit dem Auftraggeber abgestimmt. Diese Versuche werden raumweise je nach Sanierungsfortschritt zugeordnet. Die Gesamtzahl der zu untersuchenden Räume bleibt gleich denen in der ersten Runde (20).

3. Wiederholung der Versuche nach Beendigung aller Sanierungsarbeiten inklusive malermäßiger Überarbeitung der Räume und Einbau von Türen und Fenstern. Messbeginn ist frühestens 4 Wochen nach Fertigstellung einzelner Räume. Eine zweite Messung soll nach 3-4 Monaten, eine dritte Messung nach 6-8 Monaten erfolgen. Die Gesamtzahl der untersuchten Räume bleibt wie in den Messungen zuvor gleich bei 20.

Im Rahmen der Eigenforschung führt das Umweltbundesamt Messungen der VOC- und Aldehyd-Konzentrationen in ausgewählten Räumen durch.

Zusätzliche Untersuchungen wie Einzelbewertungen oder Kombinationen in Kammern bzw. in realen Räumen werden bereits mit angedacht. Eine Bewertung des Geruchs während der Projektlaufzeit und vor dem Einbau im Objekt durchzuführen ist eine sinnvolle Ergänzung. Die Ergänzungen könnten wie folgt aussehen:

I. Kombinationsversuche von Bauprodukten in Emissionskammer:

Um die Untersuchungen der Messreihe 2 zu entlasten, ist es hilfreich die einzelnen Sanierungsfortschritte in Emissionskammern nachzustellen. So könnte die Beprobung vereinfacht und verschiedene Komplettaufbauten im Vorfeld geprüft werden. Es könnten dann die besten Produkte integriert werden.

II. Kombinationsversuche in realen Räumen der ausgewählten Produkte vor dem Einbau im Objekt:

Die Kombination von Bauprodukten in realen Räumen ist noch so gut wie unerforscht bieten aber Möglichkeiten Geruchsverhalten verschiedener Kombinationen unter realen Bedingungen zu prüfen.

Ergänzend werden auch hier analytische Messungen durch UBA vorgenommen.

Aus den ursprünglich verabredeten Untersuchungen konnten wegen der Bauverzögerung nur die Punkte 1 und dann die Zusatzuntersuchungen I und II durchgeführt werden. Die Messungen unter Punkt 1 dienen für einen Methodenvergleich im Rahmen der Geruchsbewertung.

In Ergänzung dazu gibt es weitere Untersuchungen in Zusammenarbeit mit dem eco-INSTITUT in Köln zu den unter I und II aufgeführten Versuchen. Es werden 4 komplette Wandaufbauten und 4 komplette Fußbodenaufbauten in Köln aufgebaut und analytisch und geruchlich untersucht und zusätzlich werden alle Produkte und einige Kombinationen daraus in Emissionskammern analytisch und geruchlich betrachtet.

Aufgrund der Verschiebung des Beginns der Sanierungsarbeiten am Dienstgebäude Bismarckplatz wurde, in Abstimmung mit dem UBA und dem BMUB, eine Änderung der Leistungsbeschreibung vorgenommen. In der neuen Leistungsbeschreibung wurden als Untersuchungsobjekte der Neubau des UBA „Haus 2019“ sowie eine zu sanierende Etage in einem Bürogebäude ausgesucht. Beide Objekte befinden sich in Berlin.

Ergebnisse

Methodenvergleich

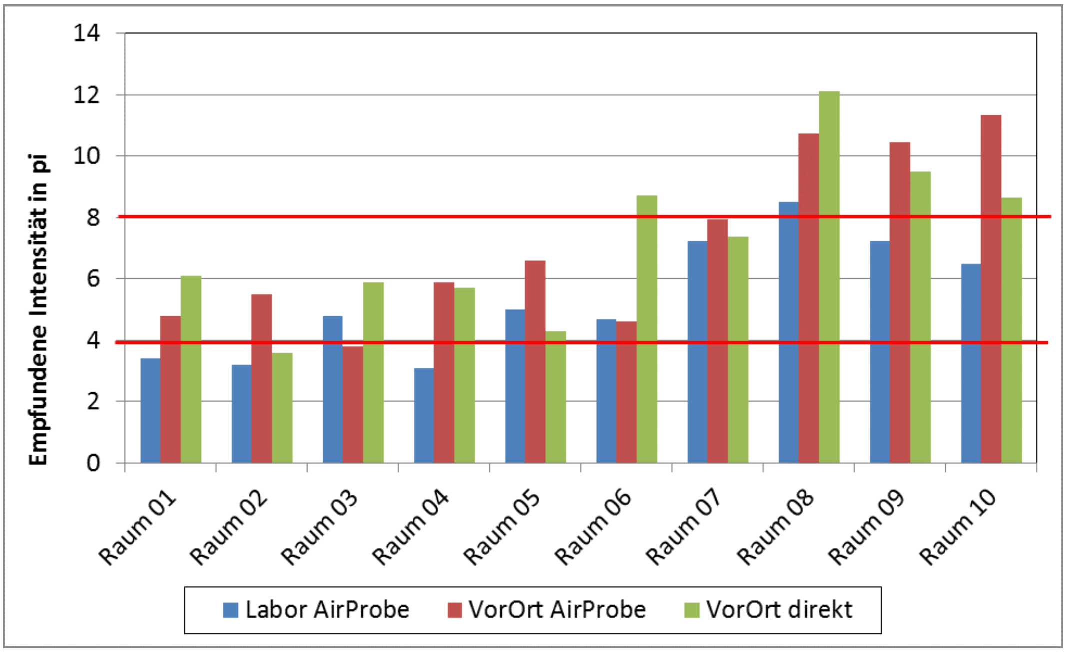
Das erste Arbeitspaket befasst sich mit Untersuchungen zur Ermittlung des IST-Zustands der Raumluftqualität des Gebäudes Bismarckplatz vor Sanierungsbeginn. Dabei werden verschiedene Verfahrensarten der Raumluftbewertung angewendet und untereinander verglichen, um die für die örtlichen Gegebenheiten günstigste Verfahrensart zu ermitteln sowie eine Vergleichbarkeit der Ergebnisse nachzuweisen.

Demnach erflogen die Geruchsbewertungen für die einzelnen Räume nach folgenden Bewertungsmethoden (a bis c):

a) Labor AirProbe: Probenahme der Raumluft (mittels AirProbe) und anschließende Geruchsprüfung im Labor
b) VorOrt direkt: direkte Geruchsprüfung durch Begehung vor Ort (mittels Vergleichsmaßstab)
c) VorOrt AirProbe: Probenahme der Raumluft (mittels AirProbe) und anschließende Geruchsprüfung Ort am Bismarckplatz

Die nachfolgende Abbildung 9 zeigt einen Vergleich der empfundenen Intensitäten für die drei Bewertungsmethoden der untersuchten Räume.

Abbildung 1: Methodenvergleich Intensität (Abbildung 9 im Bericht)



Grundsätzlich lässt sich feststellen, dass die Ergebnisse aller drei Bewertungsmethoden im Rahmen der Genauigkeit schwanken (Abweichung +/-2 pi). Für die drei verschiedenen Methoden heißt das, dass der Mittelwert der drei Einzelwerte bestimmt wird und die Schwankungen um diesen Mittelwert nicht größer als die geforderte Genauigkeit von +/-2 pi sein sollte. Sie liefern somit vergleichbare Werte. Diese Erkenntnis ist wichtig für das weitere Vorgehen im Projekt, und wichtig für die Entscheidung der weiter zu verwendenden Methoden, je nach Sanierungsstand. Die Bewertungen im Labor mit Hilfe des AirProbe liefern häufig die geringsten Intensitäten. Die Bewertungen mit Hilfe der beiden anderen untersuchten Methoden liefern zum Teil sehr gute Übereinstimmungen aber auch Unterschiede in den Bewertungen. Wenn man die Räume untereinander vergleicht fällt auf, dass Raum 01-Raum 07 im mittleren Raumluftqualitätsbereich liegen. Die Räume 08 bis 10 weisen etwas schlechte Raumluftqualitäten auf.

Methodenauswahl

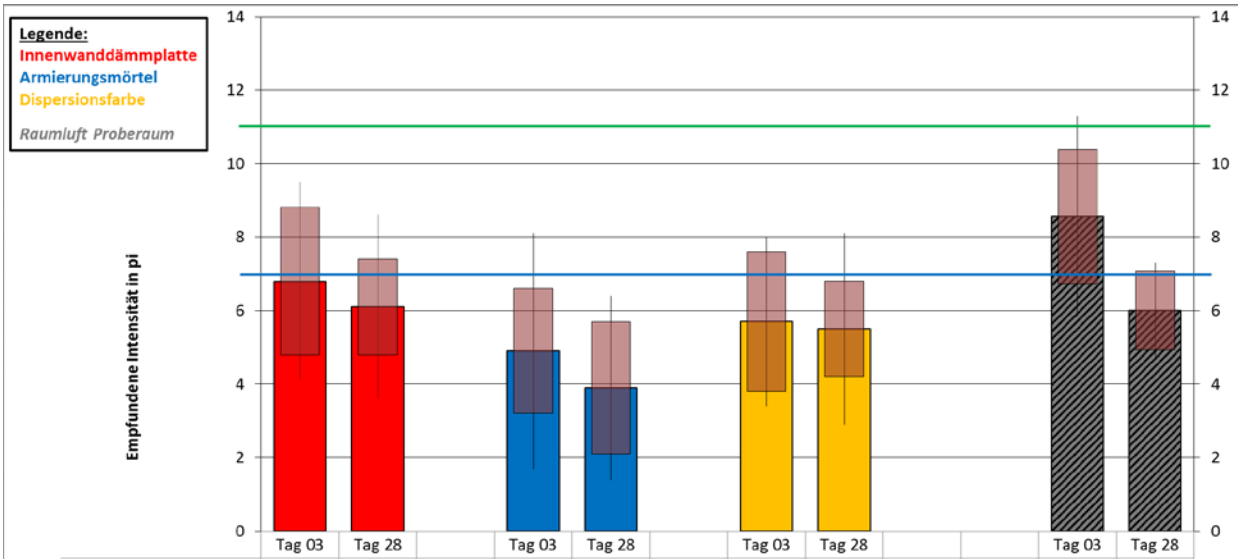
Auf Grundlage der durchgeführten Untersuchungen wurde zusammen mit dem Auftraggebern entschieden, dass für das Objekt am Bismarckplatz zunächst die beiden Methoden vor Ort (b und c) weiter verfolgt werden. Die Methode im Labor ist aber immer dann vorzuziehen, wenn beispielsweise bei der Sanierung keine Bewertung vor Ort möglich ist.

Untersuchungen in Versuchsräumen

Aufgrund der sich zu diesem Zeitpunkt bereits andeutenden Bauverzögerungen werden als nächster Arbeitsschritt Kombinationsversuche in realen Räumen des Bismarckplatz untersucht. Ergänzend werden verschiedenen Wand- bzw. Bodenaufbauten in reale Versuchsräume beim eco-INSTITUT in Köln eingebracht und olfaktorisch untersucht. Zusätzlich dazu werden die eingesetzten Einzelprodukte in Emissionkammern im Luftqualitätslabor bewertet.

Die nachfolgende Abbildung 27 zeigt exemplarisch die Intensitäten der eingesetzten Produkte sowie der Raumluftuntersuchung von Versuchsraum 1 im UBA Bismarckplatz. Alle Bewertungen der Einzelprodukte liegen am Tag28 unter dem Kriterium des Blauen Engels (<7 pi). Die Intensität der Raumluft (sw/grau) liegt am Tag28 ebenfalls in diesem Wertebereich (6 pi).

Abbildung 2: Intensität Produkte Versuchsraum 1 (Bismarckplatz) (Abbildung 27 in Bericht)



	Tag 03	Tag 28	Tag 03	Tag 28	Tag 03	Tag 28	Tag 03	Tag 28
Mittelwert Intensität	6,8	6,1	4,9	3,9	5,7	5,5	8,6	6,0
Halbes Konfidenzintervall	2,0	1,3	1,7	1,8	1,9	1,3	1,8	1,1
Temperatur in °C	23,5	23,5	23,5	23,5	23,5	23,5	24,7	19,8
rel. Feuchte in %	50,0	50,0	50,0	50,0	50,0	50,0	77,5	63,0
Konfidenzintervall Min.	4,8	4,8	3,2	2,1	3,8	4,2	6,7	4,9
Standardabweichung Max.	9,5	8,6	8,1	6,4	8,0	8,1	11,3	7,3
Standardabweichung Min.	4,1	3,6	1,7	1,4	3,4	2,9	5,8	4,7
Konfidenzintervall Max.	8,8	7,4	6,6	5,7	7,6	6,8	10,4	7,1

Die Bewertungen der Einzelprodukte in den Emissionskammern liefern ähnliche Ergebnisse wie die Bewertungen der Versuchsraumluft.

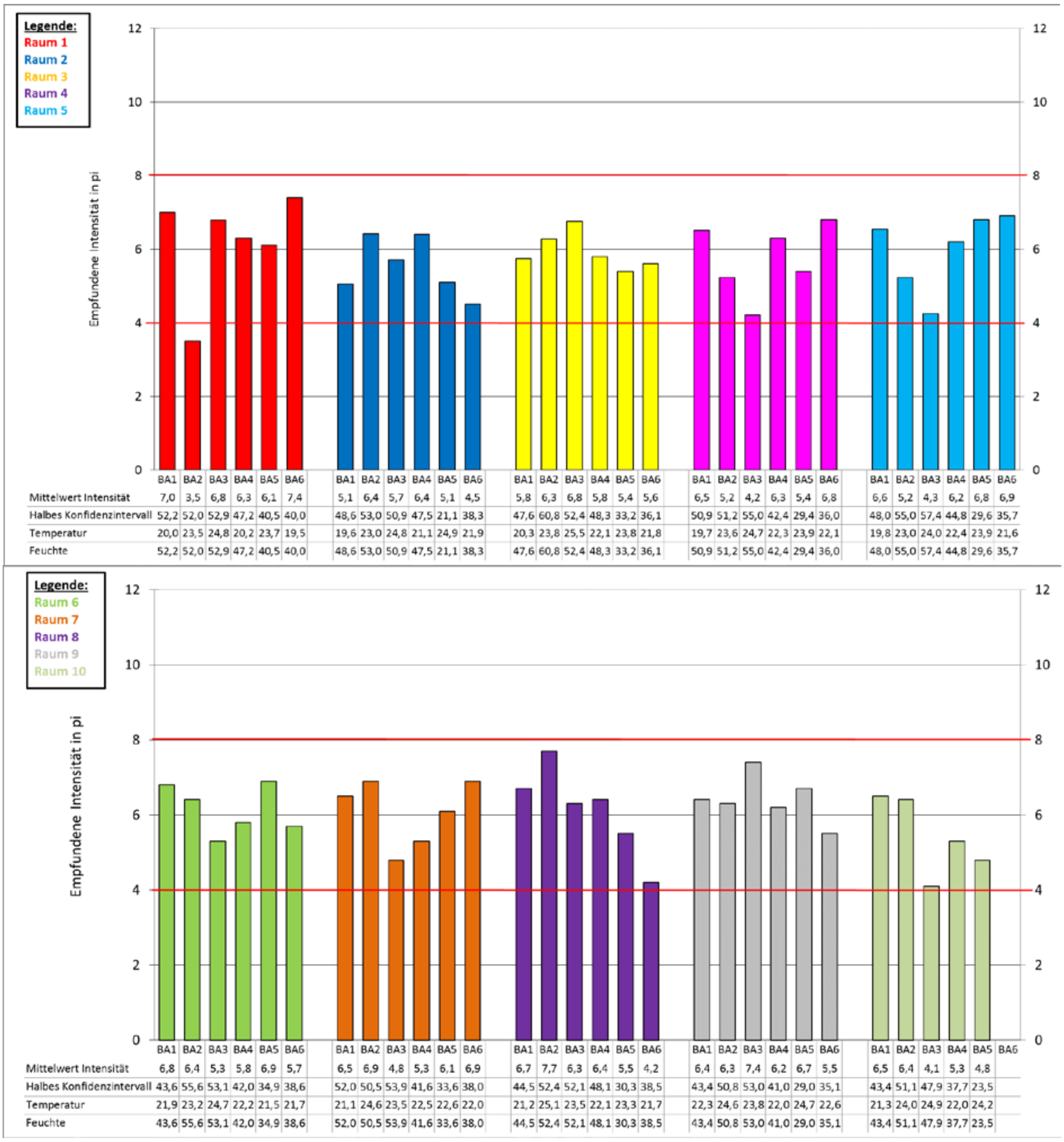
Die getesteten Bauprodukte zeigen niedrige bis sehr niedrige Emissionen in den Prüfkammern. Bei der Bewertung der Raumluftqualität werden während der Baumaßnahmen höhere VOC- und Aldehyd-Konzentrationen gemessen. Diese nehmen aber mit der Zeit ab und erreichen am letzten Untersuchungstag ähnliche Werte wie im Ist-Zustand der Räume.

Untersuchungsobjekt UBA Haus 2019

In Berlin-Marienfelde entstand in den Jahren 2011 bis 2013 ein Nullenergiehaus mit 31 Büroarbeitsplätzen und drei Besprechungsräumen. Seinen Arbeitstitel „Haus 2019" erhielt das Gebäude, da es schon jetzt die Vorgabe der europäischen Gebäuderichtlinie erfüllen soll, dass Gebäude der öffentlichen Hand ab dem Jahr 2019 eine übers Jahr gerechnet ausgeglichene Energiebilanz vorweisen sollen. Während der Bauarbeiten im Innenbereich sowie nach Bezug der Räumlichkeiten werden in bestimmten Abständen olfaktorische und analytische Raumluftbewertungen durchgeführt.

Abbildung 64 zeigt die empfundenen Intensitäten der untersuchten Räume an den verschiedenen Untersuchungstagen (Bauabschnitten).

Abbildung 3: Intensität Raumluft (UBA Haus 2019) (Abbildung 64 im Bericht)



Raum 1	BA1	BA2	BA3	BA4	BA5	BA6
Mittelwert Intensität	7,0	3,5	6,8	6,3	6,1	7,4
Halbes Konfidenzintervall	52,2	52,0	52,9	47,2	40,5	40,0
Temperatur	20,0	23,5	24,8	20,2	23,7	19,5
Feuchte	52,2	52,0	52,9	47,2	40,5	40,0

Raum 2	BA1	BA2	BA3	BA4	BA5	BA6
Mittelwert Intensität	5,1	6,4	5,7	6,4	5,1	4,5
Halbes Konfidenzintervall	48,6	53,0	50,9	47,5	21,1	38,3
Temperatur	19,6	23,0	24,8	21,1	24,9	21,9
Feuchte	48,6	53,0	50,9	47,5	21,1	38,3

Raum 3	BA1	BA2	BA3	BA4	BA5	BA6
Mittelwert Intensität	5,8	6,3	6,8	5,8	5,4	5,6
Halbes Konfidenzintervall	47,6	60,8	52,4	48,3	33,2	36,1
Temperatur	20,3	23,8	25,5	22,1	23,8	21,8
Feuchte	47,6	60,8	52,4	48,3	33,2	36,1

Raum 4	BA1	BA2	BA3	BA4	BA5	BA6
Mittelwert Intensität	6,5	5,2	4,2	6,3	5,4	6,8
Halbes Konfidenzintervall	50,9	51,2	55,0	42,4	29,4	36,0
Temperatur	19,7	23,6	24,7	22,3	23,9	22,1
Feuchte	50,9	51,2	55,0	42,4	29,4	36,0

Raum 5	BA1	BA2	BA3	BA4	BA5	BA6
Mittelwert Intensität	6,6	5,2	4,3	6,2	6,8	6,9
Halbes Konfidenzintervall	48,0	55,0	57,4	44,8	29,6	35,7
Temperatur	19,8	23,0	24,0	22,4	23,9	21,6
Feuchte	48,0	55,0	57,4	44,8	29,6	35,7

Raum 6	BA1	BA2	BA3	BA4	BA5	BA6
Mittelwert Intensität	6,8	6,4	5,3	5,8	6,9	5,7
Halbes Konfidenzintervall	43,6	55,6	53,1	42,0	34,9	38,6
Temperatur	21,9	23,2	24,7	22,2	21,5	21,7
Feuchte	43,6	55,6	53,1	42,0	34,9	38,6

Raum 7	BA1	BA2	BA3	BA4	BA5	BA6
Mittelwert Intensität	6,5	6,9	4,8	5,3	6,1	6,9
Halbes Konfidenzintervall	52,0	50,5	53,9	41,6	33,6	38,0
Temperatur	21,1	24,6	23,5	22,5	22,6	22,0
Feuchte	52,0	50,5	53,9	41,6	33,6	38,0

Raum 8	BA1	BA2	BA3	BA4	BA5	BA6
Mittelwert Intensität	6,7	7,7	6,3	6,4	5,5	4,2
Halbes Konfidenzintervall	44,5	52,4	52,1	48,1	30,3	38,5
Temperatur	21,2	25,1	23,5	22,1	23,3	21,7
Feuchte	44,5	52,4	52,1	48,1	30,3	38,5

Raum 9	BA1	BA2	BA3	BA4	BA5	BA6
Mittelwert Intensität	6,4	6,3	7,4	6,2	6,7	5,5
Halbes Konfidenzintervall	43,4	50,8	53,0	41,0	29,0	35,1
Temperatur	22,3	24,6	23,8	22,0	24,7	22,6
Feuchte	43,4	50,8	53,0	41,0	29,0	35,1

Raum 10	BA1	BA2	BA3	BA4	BA5	BA6
Mittelwert Intensität	6,5	6,4	4,1	5,3	4,8	
Halbes Konfidenzintervall	43,4	51,1	47,9	37,7	23,5	
Temperatur	21,3	24,0	24,9	22,0	24,2	
Feuchte	43,4	51,1	47,9	37,7	23,5	

Hauptsächlich werden alle empfundenen Intensitäten der Räume im mittleren Qualitätsbereich eingestuft. Im Laufe der Baumaßnahmen also vor Nutzung der Räumlichkeiten (BA1-3) sind die Raumluftintensitäten bei den Räumen 2 (blau), 3 (gelb) und 9 (grau) leicht gestiegen, bei den übrigen Räumen aber gesunken.

Mit fortlaufender Nutzung der Räumlichkeiten (BA4-6) bleiben die Intensitäten bei den Räumen 2 (blau), 3 (gelb), 8 (lila) sowie 9(grau) in etwa im gleichen Bereich bzw. sinken leicht. Bei den anderen Räumen steigen die teilweise bereits niedrigen Intensitäten nach Beendigung der Baumaßnahmen (BA3) im Laufe der Nutzung (BA4-6) wieder an. Daraus lässt sich schließen, dass mit der Nutzung der Räumlichkeiten weitere Gerüche eingebracht werden, welche unabhängig von den Baumaßnahmen (siehe Tabelle 16 z.B. Kaffee) einen Einfluss auf die Geruchsqualität der Räume haben.

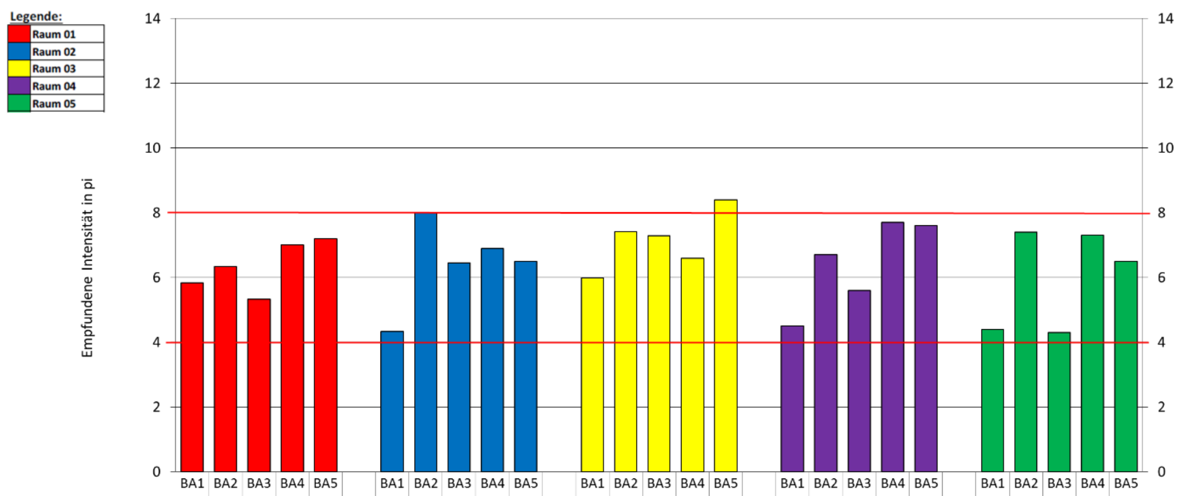
Die Bewertung der Raumluftqualität zeigt höhere VOC- und Aldehyd-Konzentrationen während der Baumaßnahmen. Diese nehmen aber mit der Zeit ab. Am letzten Untersuchungstag wird eine gute Innenraumluftqualität für ein neues Gebäude erreicht.

Untersuchungsobjekt Bürosanierung

Des Weiteren wird die Sanierung neuer Büroräume in einer Etage eines großen Bürogebäudes in Berlin begleitet. Die Büroetage verfügt über keine Lüftungsanlage, weshalb nur ein manuelles Lüften über Öffnen der Fenster möglich ist.

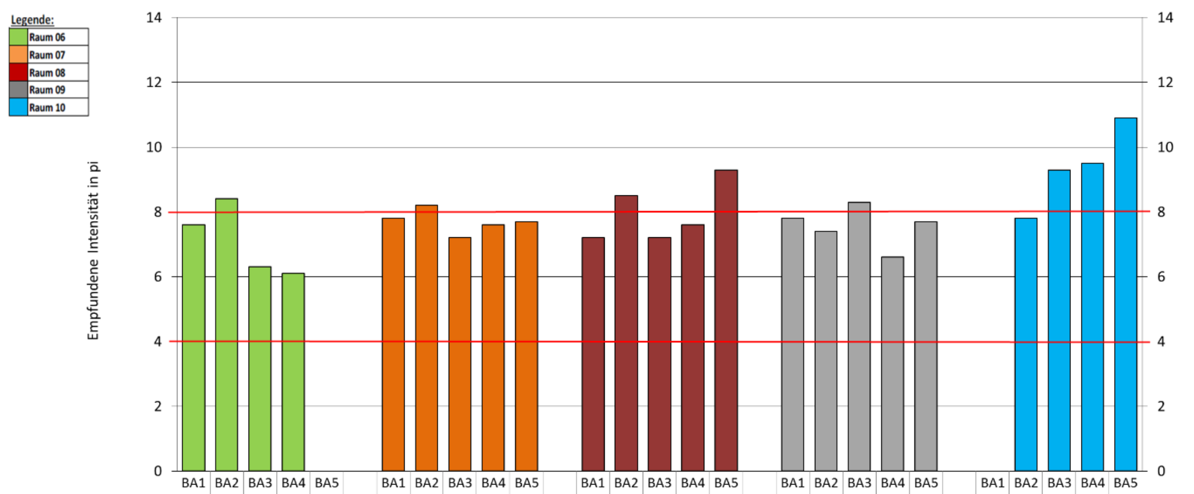
Abbildung 82 zeigt die empfundenen Intensitäten aller untersuchten Räume an den einzelnen Untersuchungstagen (BA1-BA5).

Abbildung 4: Intensität Raumluft (Bürosanierung) (Abbildung 82 im Bericht)



	BA1	BA2	BA3	BA4	BA5	BA1	BA2	BA3	BA4	BA5	BA1	BA2	BA3	BA4	BA5
Mittelwert Intensität	5,8	6,3	5,3	7,0	7,2	4,3	8,0	6,5	6,9	6,5	6,0	7,4	7,3	6,6	8,4
Halbes Konfidenzintervall	1,5	1,1	1,1	1,7	1,9	1,6	1,3	1,3	1,7	2,0	1,1	1,0	1,5	1,7	1,8
Temperatur in °C	22,0	24,4	24,8	23,5	22,2	22,0	23,3	24,8	21,2	22,1	21,0	23,7	25,5	21,4	21,5
rel. Feuchte in %	50,6	50,4	52,9	53,6	53,8	52,5	53,7	50,9	51,6	52,5	53,6	51,7	52,4	54,3	51,8

	BA1	BA2	BA3	BA4	BA5	BA1	BA2	BA3	BA4	BA5
Mittelwert Intensität	4,5	6,7	5,6	7,7	7,6	4,4	7,4	4,3	7,3	6,5
Halbes Konfidenzintervall	1,3	1,3	1,3	2,1	2,0	0,8	1,4	1,3	1,8	1,9
Temperatur in °C	21,8	23,8	24,7	22,8	20,6	22,1	21,9	24,0	23,6	20,1
rel. Feuchte in %	51,2	49,8	55,0	50,7	52,7	56,6	56,5	57,4	52,5	56,5



	BA1	BA2	BA3	BA4	BA5	BA1	BA2	BA3	BA4	BA5	BA1	BA2	BA3	BA4	BA5
Mittelwert Intensität	7,6	8,4	6,3	6,1		7,8	8,2	7,2	7,6	7,7	7,2	8,5	7,2	7,6	9,3
Halbes Konfidenzintervall	1,8	1,9	1,5	1,8		1,6	1,7	1,8	1,9	1,4	1,8	1,4	1,6	1,7	2,0
Temperatur in °C	21,7	20,7	24,7	21,5		22,3	21,2	23,5	23,7	22,4	22,0	21,6	23,5	23,0	21,3
rel. Feuchte in %	57,0	60,1	53,1	56,1		58,4	54,3	53,9	57,0	46,2	58,0	54,7	52,1	57,0	53,3

	BA1	BA2	BA3	BA4	BA5	BA1	BA2	BA3	BA4	BA5
Mittelwert Intensität	7,8	7,4	8,3	6,6	7,7		7,8	9,3	9,5	10,9
Halbes Konfidenzintervall	1,3	1,4	1,6	1,1	1,8		1,2	1,6	2,0	1,7
Temperatur in °C	21,9	21,6	23,8	23,1	20,5		24,6	24,9	24,5	22,9
rel. Feuchte in %	56,4	53,9	53,0	46,1	49,3		55,7	47,9	42,9	47,9

Der Übersicht halber sind die Standardabweichungen und Konfidenzintervalle hier nicht graphisch dargestellt. Das halbe Konfidenzintervalle ist in der Datentabelle aufgeführt und wurde bei allen Untersuchungen eingehalten. Grundsätzlich steigt bei fast allen Räumen die Intensität nach dem 2.Bauabschnitt (BA2) etwas an, was auf das Einbringen des Bodenbelags hinweist. Bei BA3, also etwa ein Monat nach BA2, fallen die Intensitäten wieder etwas geringer aus. Ausnahme ist hier Raum 10, welcher mit Linoleum ausgestattet ist und im Vergleich zu den anderen Räumen die höchsten Intensitäten im Laufe des Untersuchungszeitraums aufweist. Ansonsten ändern sich die Intensitäten im Laufe des Untersuchungszeitraums nur noch geringfügig und liegen mit einigen Ausnahmen knapp im mittleren Raumluftqualitätsbereich (zwischen 6 und 8 pi).

Die Bewertung der Raumluftqualität zeigt höhere VOC- und Aldehyd-Konzentrationen während der Baumaßnahmen. Es werden teilweise auch Innenraumrichtwerte für einige chemische Substanzen überschritten. Die Konzentrationen der flüchtigen organischen Verbindungen nehmen aber mit der Zeit ab. Die Bewertung der Raumluft am letzten Untersuchungstag erreicht gute Ergebnisse.

Diskussion/Ausblick

Im Rahmen dieses Forschungsprojekts wurde die Innenraumluftqualität im Hinblick auf flüchtigen organischen Verbindungen VOC- und Gerüche in einigen energieeffizienten Gebäuden untersucht.

Ziel des ursprünglichen Forschungsvorhabens war es, die Innenraumluftqualität nach Einbau von Bauprodukten in energetisch sanierten Gebäuden am Beispiel des Dienstgebäudes Bismarckplatz des Umweltbundesamtes in Berlin zu untersuchen. Aufgrund der Verschiebung des Beginns der Sanierungsarbeiten am Dienstgebäude Bismarckplatz wurde eine Änderung der Leistungsbeschreibung vorgenommen. In der neuen Leistungsbeschreibung sind als Untersuchungsobjekte der Neubau des UBA „Haus 2019“ sowie eine zu sanierende Etage in einem Bürogebäude ausgesucht worden. Beide Objekte befinden sich in Berlin. In Ergänzung dazu wurden weitere olfaktorische Untersuchungen von verschiedenen Wand- sowie Fussbodenaufbauten in Prüfräumen am eco-INSTITUT in Köln durchgeführt. Bei den Raumluftuntersuchungen in den Versuchsräumen in den Objekten Bismarckplatz und am eco-INSTITUT in Köln wurde sowohl die direkte als auch indirekte Bewertungsmethode (AirProbe) angewandt. Beide Bewertungsmethoden zeigen hier vergleichbare Ergebnisse.

Im Rahmen dieses Projekts werden etwa 60 Einzelprodukte bzw. Kombinationen von Produkten olfaktorisch und analytisch im Luftqualitätslabor untersucht. Zusätzlich werden diese Produkte in Neubauten oder Sanierungen oder nachgestellten Sanierungen verwendet und in „realen Räumen“ bewertet. Viele der untersuchten Einzelprodukte erzielten sehr gute olfaktorische Bewertungen und die Mehrzahl der Produkte erfüllt somit die vorgeschlagenen Kriterien des Blauen Engels bzw. des AgBB-Schemas für die Geruchsbewertung. Des Weiteren liefern, die in diesem Projekt durchgeführten Produktbewertungen, eine sehr gute Datengrundlage für eine olfaktorische Produktdatenbank, welche in zukünftigen Projekten hilfreich sein kann. Damit lassen sich verschiedene Produkte miteinander vergleichen und die Auswahl von Bauprodukten hinsichtlich ihrer möglichen Geruchsbeeinträchtigung im Vorfeld von Baumaßnahmen erleichtern.

Darüber hinaus zeigen die Ergebnisse dieses Projekts den Einfluss von Kombinationen verschiedener Einzelprodukte auf die empfundene Luftqualität auf. Die Bewertung der empfundenen Geruchsintensitäten von Einzelprodukten kann in der Bewertung der Produktkombinationen wiedergefunden werden. Die dazugehörigen Emissionsmessungen zeigen ein ähnliches Verhalten. Der Vergleich von Raumluft- und Produktuntersuchungen in Kammern zeigt, dass Gerüche aus Bauprodukten in der Raumluft wiederzufinden sind bzw. beide Untersuchungen die gleichen Ergebnisse liefern.

Bei Messungen in realen Räumen muss berücksichtigt werden, dass es nicht immer möglich ist die Raumlufttemperatur und relative Feuchte wie im Labor einzustellen. Die Untersuchungen im Labor finden unter ständiger definierter Belüftung statt. Es kann also zu unterschiedlichen Versuchsbedingungen kommen. Daher sollten weitere Messungen gerade auch mit Kombinationen von Produkten durchgeführt werden, um die Datenbasis zu erhöhen und genauere Aussagen treffen zu können.

Die Messung der VOC- und Aldehyd-Konzentrationen zeigen am 28. Untersuchungstag (bei allen Untersuchungen) in den Gebäuden oder Prüfräumen gute Ergebnisse. Die Auswahl der eingesetzten Produkte hat einen großen Einfluss auf die Ergebnisse. Während der Baumaßnahmen werden auch höhere Schadstoff-Konzentrationen in der Raumluft der beprobten Räume gemessen. Diese nehmen aber generell über den Untersuchungszeitraum ab. In ‚unbenutzten' Räume ist, aufgrund des niedrigen Luftwechsels, eine langsamere Abnahme der VOC- und Aldehyd-Konzentrationen zu verzeichnen. Hierzu muss im Rahmen eines Neubaus oder einer Sanierung dafür gesorgt werden, dass der empfohlene hygienische Mindestluftwechsel von 0,5 1/h erreicht wird.

Die eingesetzten Baumaterialien zeigen niedrige bis sehr niedrige Emissionen.

Die Ergebnisse zeigen, dass geruchlich unauffällige und emissionsarme Bauprodukte zu geruchlich unauffälligen und emissionsarmen Räumen führen können.

1 Introduction and aim of the research project

The health-related evaluation of emissions from building products has gained more and more importance over the last years. This is due not only to the fact that people spend 80-90 % of their time inside buildings but also to the increased air-tightness of the building envelope as a result of the energy-efficient construction. Thus, the emissions from building products can influence the occupant's health today more than in the past.

Since 2005 Germany has implemented health-related requirements for emissions within the approval of building products. Flooring materials, adhesives, floor coatings and underlays need technical approval before being used in indoor spaces. However, even if products fulfil the emission requirements of the Committee for Health-related evaluation of Building Products (AgBB), health complaints due to odour nuisance or irritation can be registered. These can lead to a situation where room occupants demand the removal of the building materials. Therefore the exposure (Immission) situation after installation of products has to be checked beside the emissions measurements in the test chambers. Possible odour nuisance has to be equally recorded and evaluated.

The original aim of the study was to investigate the indoor air quality of energy-efficient retrofitted buildings using the example of the German Environment Agency's (Umweltbundesamt, UBA) office building in Bismarckplatz in Berlin. The building was due to be extensively renovated between 2011 and 2014 and subsequently include single work units from other UBA office buildings. The building had to meet high environmental standards and sustainably renovated. This implied a targeted selection of low-emission products during the planning stages.

The objective of this project was to identify ways to avoid indoor air problems including odour nuisance by selecting suitable building products. The project intended to close knowledge gaps about the emission behaviour of volatile organic compounds (VOC) and odours in retrofitted rooms (also for a combination of building products). Energy-efficient construction and good indoor air quality were to be brought together through a reasonable selection of building materials. The results of the research project would help answer the question of whether the evaluation of odours has to be considered to a greater degree than in the past.

Due to the postponement of the remediation actions in the Bismarckplatz office building, the specification of the project changed in agreement with UBA and the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB). The new UBA building "Haus 2019" and one floor in an office building to be renovated were then included in the new specification of the project. Both buildings are located in Berlin. In addition, further olfactory analyses of various wall and floor assemblies installed in test rooms of the eco-INSTITUT in Cologne were conducted.

2 Assignment of tasks

The original aim of the study was to investigate the indoor air quality of energy-efficient retrofitted buildings using the example of the UBA Bismarckplatz office building in Berlin. For this purpose the following analyses were conducted:

1. Systematic analysis of the indoor air quality concerning odours in 20 empty offices of UBA Bismarckplatz prior to the remediation works starting. The panellists evaluated the perceived intensity and hedonics of the indoor air. (Chapter 4)

   The odour tests were conducted in 10 rooms using the following three methods (a to c). By means of the results, a decision was made on which of the two methods should be used to execute the following measurements, or if further analyses using the three methods were needed:

a) Air sampling in special containers and evaluation by the trained panel in the laboratory
b) Air sampling in special containers and evaluation by the trained panel on site (UBA Bismarckplatz)
c) Direct odour testing on site.

2. During the second experimental phase the analyses under (1) were repeated. Odour tests were performed during the placement of various flooring assemblies, after installation of insulating materials (with and without wall covering) and placement of acoustic ceiling or after various sealing measures. The workflow for these measurements was coordinated together with UBA. The analyses were conducted room by room depending on the progress of the remediation works. 20 rooms were analysed.

3. During the third phase the analyses were repeated after the end of the remediation works including painting the rooms and placement of doors and windows. The first measurements were conducted 4 weeks after finishing single rooms. A second measurement was conducted after 3-4 months and the last measurement after 6-8 months. 20 rooms were analysed.

UBA performed measurements of the concentrations of VOC and aldehydes in selected rooms.

Additional analyses such as evaluation of single products or combinations of materials in emission test chambers and real rooms were planned. The evaluation of odours during the project, before installation of materials in the building was a reasonable addition. For this purpose the following analyses were conducted:

I. Measurement of combinations of building materials in emission test chambers

To reduce the analyses under (2) it was helpful to simulate single remediation phases in the emission test chambers. In this way the sampling was simplified and various assemblies could be tested beforehand. The best products were then selected.

II. Analyses of combinations of selected materials in real rooms before the products were installed in the building:

The combination of products in real rooms is as good as unexplored so far, but it provided the opportunity to check the behaviour of these compositions regarding odour emissions under real conditions.

In addition, analytical measurements were performed by UBA.

Due to the postponement of the remediation works, only the analyses under (1) and the additional measurements under (I) and (II) have been conducted. The investigations under (1) were used for the comparison of various methods for odour assessment.

Various measurements, in addition to those under (I) and (II), were conducted in cooperation with the eco-INSTITUTE in Cologne. 4 wall and 4 floor assemblies were installed in Cologne and the emission of volatile organic compounds and odours were assessed. All single products and some combinations were additionally tested in the emission chambers (Chapter 5.2).

4. Due to the postponement of the remedial actions in the Bismarckplatz office building, the specification of the project was changed in agreement with UBA and BMUB. The new building “UBA Haus 2019” (Chapter 6) and one floor in an office building to be renovated were included in the new specification of the project (Chapter 7). Both buildings are situated in Berlin.

3 Fundamentals

VOC emissions are often associated with odour perceptions, sensory testing has therefore been included in the AgBB scheme as an important parameter. The first standards for odour assessment from building products and in rooms (ISO 16000-28 and 30 and VDI 4302 Part 1) have been published. (ISO 16000-28 2012, ISO 16000-30 2015, VDI 4302 Part 1 2015)

Replacing the human nose in the determination of perceived air quality has not been successful despite improving analysis capabilities and the development of "artificial noses". Odours arise from a number of chemical substances but not all substances generate the perception of smell in humans. Many thousands of different substances can be detected in the room air, but even a quantitative determination of each single substance would not enable the combined smell effect to be described.

Various methods for assessing perceived air quality have been established, some of them were investigated in previous projects (Müller 2007; p. 9 and Müller 2011; p. 11). This new project looks into the perceived intensity using a comparative scale and hedonics. The relevant procedures and accompanied issues are described below.

3.1 Sensory-based tests

3.1.1 Intensity

Odour intensity describes the strength of smell perception that has been triggered by an odour stimulus. The determination of the intensity is suitable both for the assessment of room air and odour emissions from indoor materials. Two procedural approaches are available for the determination of odour intensity:

1. Use of a comparative scale and assessment by a smaller panel of trained panellists (at least 8 people; 12 to 15 people are recommended)
2. Use of category scales and evaluation by a larger panel of untrained panellists (at least 15 people; 20 to 25 people are recommended) or a smaller group of trained panellists (at least 8 people, 12 to 15 people are recommended).

The results of the assessment (figures) of the two procedural approaches are not identical. (VDI 4302 Part1 2015)

For the investigations carried out in this research project, method 1 (use of a comparative scale) has been used.

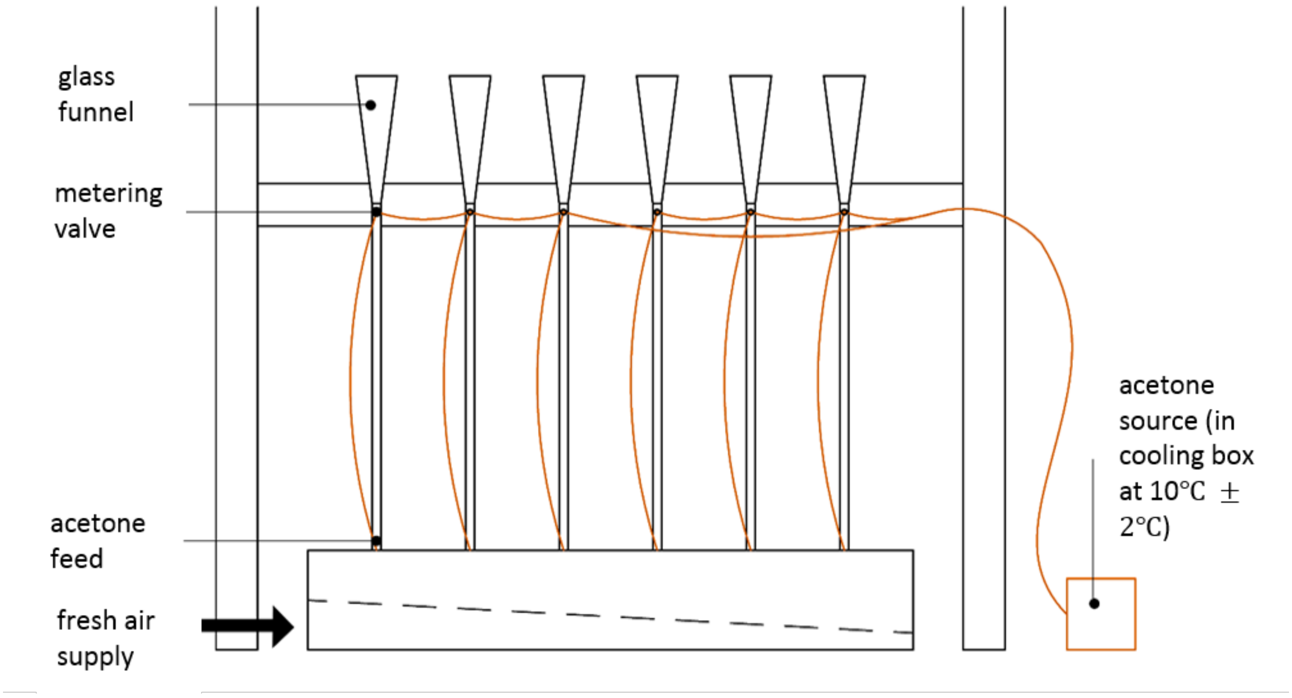
When the comparative scale is used, the sample air is compared with reference stimuli. This enables a standardisation of intensity assessment and leads to a reduction in the variance of the measured values by the standardisation of the assessment criterion. The unit of perceived intensity π is pi. The setting of the comparative scale was done using acetone as the reference substance. The comparative scale is supposed to cover the entire spectrum of samples to be tested and consists of at least five pi steps. It is recommended that six different fixed pi steps in the range between 0 pi and 15 pi are provided. The concentration of the pi steps must remain constant over the entire test period. A maximum deviation of ± 0.5 pi is permissible up to 10 pi, and a maximum deviation of ± 1 pi is permissible from 11 pi. The comparative scale for the intensity is defined by the following points:

- 0 pi corresponds by definition to an acetone concentration of 20 mg/m^3.
- 15 pi correspond to an acetone concentration of 320 mg/m^3. The number of steps beyond 15 pi can be extended upwards if required.
- The acetone concentrations for 1 pi to n pi follow a linear gradation, i.e. an increase of 1 pi corresponds to an increase of 20 mg/m^3 of acetone.

During the entire test, the panellists stay in odour-neutral rooms. At the beginning of the test all panellists stay in an accommodation area for at least ten minutes. The test manager can use this time to explain the purpose of the odour test. (VDI 4302 Part 1 2015)

Figure 1 below shows the scheme of the comparative scale.

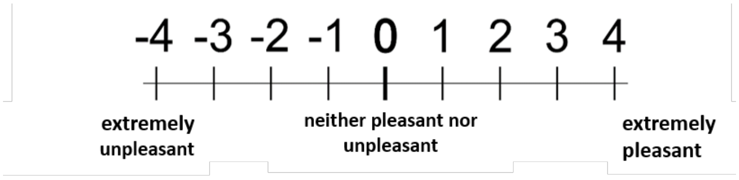
Figure 1: Scheme of comparative scale



3.1.2 Hedonics

Hedonics describes whether an odour impression is perceived as pleasant or unpleasant. The hedonic note of an odour represents the average assessment of a panel. The graduated scale shown in Figure 2 has been used to assess the hedonic smell effect. To avoid different interpretations, the terminal points and middle of the bipolar scale are marked accordingly. The assessment is carried out using a 9-step scale from "extremely unpleasant" (- 4) to "extremely pleasant" (+4). Consecutive numbers are assigned to the categories. (VDI 4302 Part 1 2015)

Figure 2: Hedonic scale



3.1.3 Assessment accuracy

The accuracy of the odour tests can be expressed by the 90% confidence interval of the mean value according to VDI 4302 Part 1. The arithmetic mean of the panel is calculated from the determined individual values of the panellists and the 90% confidence interval of the mean value is calculated.

The width of the confidence interval is determined by the number of panellists, the estimated standard deviation of the panel's assessments and the probability of error. When the number of panellists increases, the confidence interval becomes narrower, that is the average assessment of the sensory odour features becomes more accurate.

The accuracy of the intensity measurement using a comparative scale is considered to be sufficient if the half width of the 90% confidence interval of the mean value does not exceed 2 pi. The accuracy of the hedonic assessment is considered to be sufficient if the half width of the 90% confidence interval of the mean value does not exceed 1. (VDI 4302 Part 1 2015)

3.1.4 Test description – odour assessment of indoor air

Sensory assessment of indoor air can be carried out using two methods:

- direct odour test on site
- sampling room air and odour test in the laboratory.

In the case of a direct odour test on site, the panellists are asked to go to the test site. The odour test is carried out according to ISO 16000-30 single panellists who visit the room and perform an assessment immediately after reaching the measurement site by inhaling the air. When the room air has been sampled, the room air samples are collected in sample containers at the measurement site using a suitable device. The sample containers are then transported to an odour laboratory where panellists carry out the actual odour test some time later. The requirements for test location, accommodation area, etc. are defined by ISO 16000-30 and must be adhered to and recorded during the measurements. (ISO 16000-30 2015)

The "AirProbe" sampling and sample provision system developed within a thesis (Müller 2002) was used for room air sampling. Its purpose is to fill and empty sample containers made from Tedlar© (see Figures 3 and 4). The problem with fans is that they can change the air sample due to their own emissions or emissions from lubricants. Adsorption or desorption processes can occur within the fans or on the walls of the connecting pipes, which may influence the air sample composition. Therefore, no fans have been installed in the sample air pathway in the AirProbe system, and the supply and discharge pipes have been kept short. Air transport is produced by two fans integrated into the housing. One fan produces a vacuum, the other one generates pressure, and accordingly, the first one fills and the second one empties the sample container without getting into direct contact with the air. The sampling container is attached to a short stainless steel tube in the housing and the sample air is transferred to the sample container. When samples are needed, air is transported in the opposite direction to the outside. The following figures show the AirProbe system's principle sketch (Figure 3) and the opened AirProbe with the Tedlar© sample container installed (Figure 4).

Figure 3: AirProbe principle sketch (Müller 2002)

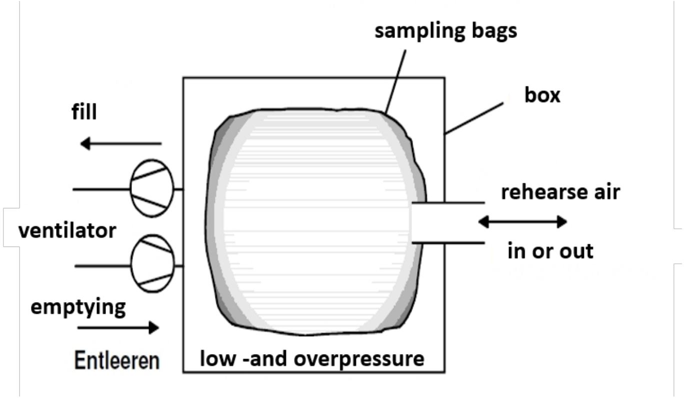


Figure 4: AirProbe and sample container

The sample containers used have a dimension of 100x100x30 mm and a corresponding volume of about 300 litres. Previous studies have shown that this volume is sufficient to carry out a test run by 12 panellists. In order not to influence the sample air, the containers are heated at approx. 80 °C before and after use for several hours. A constant air flow rate of 0.9 l/s (± 0.1 l/s) is provided for air sample provision.

Interpretation of the results

Annex F of VDI 4302 Part 1 lists quality values for the various assessment methods. Table 1 shows the value ranges for perceived intensity and Table 2 the value ranges for hedonics. (VDI 4302 Part 1 2015)

Table 1: Table F2: Room air quality and associated value ranges for perceived intensity using a comparative scale of indoor air for accommodation areas (as per MBO) (VDI 4302 Part 1 2015)

Perceived intensity using a comparative scale	Room air quality
< 4 pi	high
≥ (4…8) pi	medium
> 8 pi	low

Table 2: Table F4: Room air classes and associated value ranges for medium hedonics of indoor air for accommodation areas (as per MBO) (VDI 4302 Part 1 2015)

Hedonics	Room air quality
≥ 0	high
-1 to < 0	medium
< -1	low

The results of the sensory indoor air measurements described in later chapters will show the quality ranges for perceived intensity and hedonics proposed in Tables 1 and 2 in red lines.

3.1.5 Test description – indoor material odour assessment

The sensory tests were carried out in the air quality laboratory (AQ laboratory) of HTW Berlin. The laboratory consists of a test cubicle where the panellists perform their assessments, plus a cabin where the panellists can stay between assessments for their sense of smell to recover. Both cabins are supplied by a special low-odour air conditioning system. A slight pressure in the cabins prevents ambient air from entering the cabins. The materials used for components in contact with air are glass and stainless steel. Both odour emission and adsorption of substances in these materials is low. Odour-laden air from the emission chambers is conveyed through stainless steel pipes to the assessment cabins and led to a glass funnel where the panellists perform their odour assessment. The sample to be assessed is not visible to the panellists.

Indoor materials to be tested for odour assessment are placed in a glass and stainless steel emission chamber (CLIMPAQ) for 28 days and a constant flow rate of low-odour air is allowed to flow around them. The term CLIMPAQ is an acronym of "Chamber for Laboratory Investigations of Materials, Pollution and Air Quality". The chambers meet the DIN EN ISO 16000-9 requirements and are optimised for the tests being carried out. (ISO 16000-9 2008)

The following Figure 5 shows the AQ laboratory: the chamber with the comparative scale is on the left and the CLIMPAQ emission chambers are on the right. Figure 6 shows an emission chamber (CLIMPAQ) loaded with a textile floor covering.

Figure 5: AQ laboratory of HTW Berlin

Figure 6: CLIMPAQ

Glass plates measuring 20 cm x 65 cm have been used as carriers for viscous materials (plasters, adhesives, paints). Solid materials (plate materials or insulating materials) can be placed directly into the chambers. The edges are covered by an odour-neutral aluminium adhesive tape to ensure that only the material surface is exposed to the air flow.

Loading was selected according to ISO 16000-28 depending on the material to be tested and in such a way that the area-specific air flow rate q was 0.4 $m^3/(h\ m^2)$ for wall materials, q = 1.2 $m^3/(h\ m^2)$ for floor materials and q = 44 $m^3/(h\ m^2)$ for sealing materials. Therefore, air flow rate was adjusted to the air-flow-exposed surface of the respective materials. When the air flow rate was between 0.6 l/s and 1.0 l/s, assessment could be performed directly at the CLIMPAQ. (VDI 4302 Part 1 2015) Otherwise, an air sample was provided from a sample container (Teldar©) using AirProbe.

Olfactory assessments by trained panellists took place on day 3, day 7, day 14 and day 28 after placing the materials into the chamber. VOC and aldehyde emissions were determined on day 3 (7) and day 28.

In a previous research project a large number of building products underwent olfactory tests (Müller 2011). On the basis of their results, test values for the perceived intensity and hedonics were derived and suggested for the Blue Angel and the AgBB scheme. They are 7 pi and a hedonics of -1 for the Blue Angel (Figure 7) and 11 pi and a hedonics of -2 for the AgBB scheme (Figure 8).

Figure 7: Suggestion for sensory-based test values for Blue Angel (Müller 2011; p. 112)

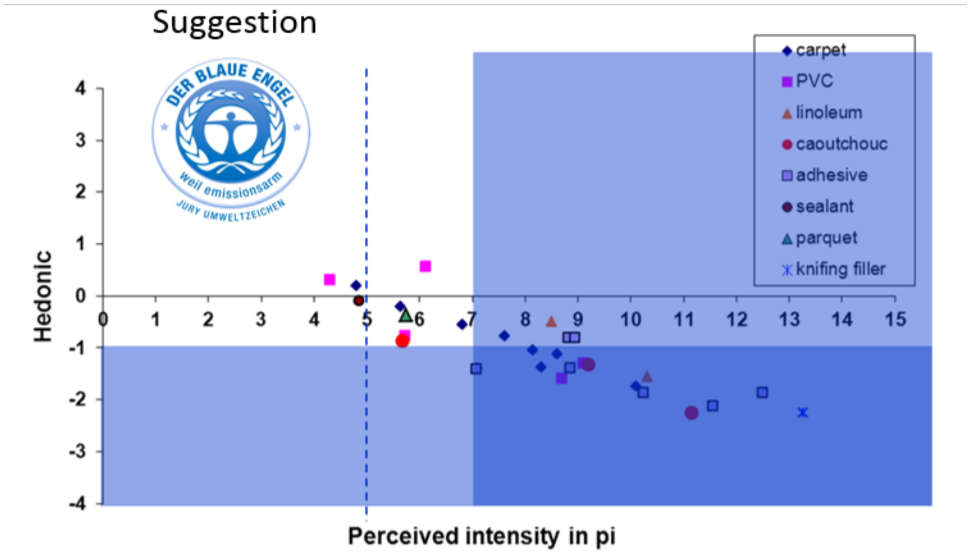
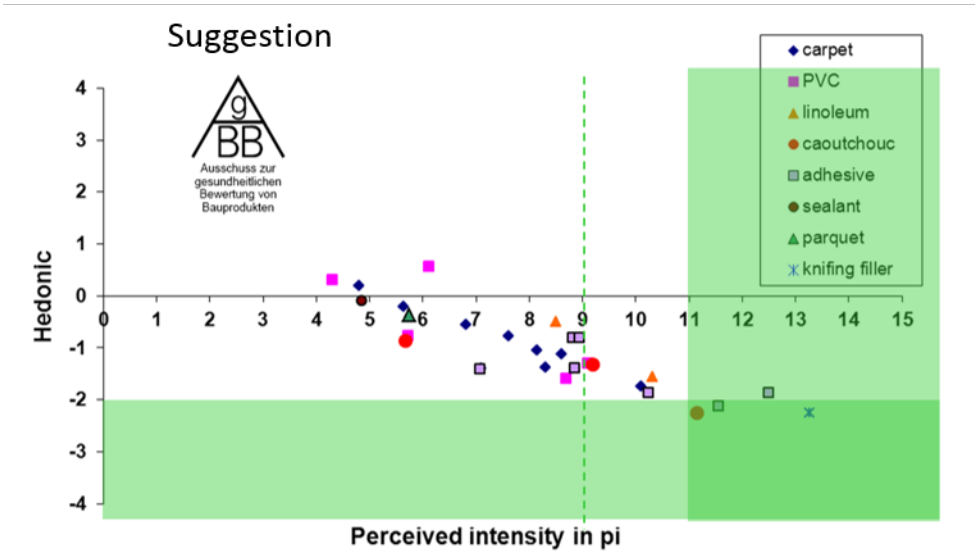


Figure 8: Suggestion for sensory-based test values for the AgBB scheme (Müller 2011; p. 113)



The values described here are also presented as blue (Blue Angel) and green (AgBB scheme) lines in the figures for the tested building materials to give a clear overview.

3.1.6 Influence of temperature and humidity

The thermal state (temperature and humidity or specific enthalpy) of inhaled air influences the perception of odours and the analysis of air samples. Conversion to other air temperatures and humidities is not yet known. Therefore, odour should always be assessed within the thermal comfort range. A temperature of 21 °C to 22 °C is recommended and a temperature range of 20 °C to 25 °C must be observed.

Relative humidity must be 50% ± 10%. It is recommended to keep the specific enthalpy of humid air within the range of 43 kJ/kg ± 5 kJ/kg. (VDI 4302 Part 1 2015)

When considering the dependence of odorant perception on the thermal state of the air, the assessment methods must be taken into account since the assessment parameters will be affected differently. A number of studies have shown the influence of temperature and humidity on odour assessment. Acceptance decreases with increasing enthalpy of the air regardless of whether the increase in enthalpy is due to an increase in temperature or humidity. (VDI 4302 Part 1 2015)

This is evident from the results of Fanger's investigations (Fang 1997 and Fang 1998) that were confirmed by Böttcher (Böttcher 2003). Intensity assessed using the category scale decreases with increasing specific enthalpy, which means the smell is perceived as less intense at high temperatures and humidities than in dry, cold air. This was found by Kerka and Humphreys (Kerka 1956). The strength of the influence by the specific enthalpy varies depending on the odorant.

In the case of intensity assessment using a comparative scale, odour intensity decreases in accordance with increasing relative humidity. However, unlike the assessment based on a category scale, there is no direct dependency on specific enthalpy, so if relative humidity is constant, a variation in the temperature does not significantly interfere with intensity assessment although specific enthalpy increases. This result was found by Böttcher (Böttcher 2003) in his investigations.

3.2 Analytical investigations

The analytical investigations in Chapters 5.1, 6 and 7 were carried out by UBA within the framework of their in-house research. The analysis in Chapter 5.2 was carried out by the eco-INSTITUT Cologne.

3.2.1 Analytics for the measurement of volatile organic compounds

Chapters 5.1, 6 and 7: VOC sampling from the room or emission test chamber air is always carried out actively as a double sample according to DIN ISO 16000-6 combined with enrichment on Tenax® TA tubes and a subsequent GC/MS analysis. Active sampling is performed by an AMA pump. These pumps contain a mass flow rate controller that keeps flow rate constant and also integrates volume measurement. The sample volume is generally 2 to 4 litres and the flow rate is 120 ml/min. The Tenax tubes are spiked with 2 µl of an internal standard solution before sampling. As a result, each sample contains about 90 ng of cyclooctane and about 100 ng of cyclododecane. (ISO 16000-6 2011)

Most VOCs can be measured using this method. The method has a determination limit of approx. 1 µg/m^3. The room air values for the total VOC content (= TVOC value) are determined by the summation of the individually quantified values. In addition, in some studies, the TVOC value is determined from the sum of all peak areas in the chromatogram in the range from hexane to hexadecane. The TVOC value is calculated as a toluene equivalent (TE) from the corrected peak area sum.

Chapter 5.2: The analysis is performed according to DIN ISO 16000-6. The determination limit is 1 µg/m^3.

3.2.2 Analysis using DNPH to measure aldehydes and ketones

Chapters 5.1, 6 and 7: The determination of volatile aldehydes, including formaldehyde, is carried out according to DIN ISO 16000-3. They are enriched on DNPH cartridges and analysed by HPLC/UV after elution with acetonitrile. The determination limit of the indicated aldehydes is substance-specific and lies between 1 and 3 µg/m³. Sampling is carried out actively or passively (to reduce the load on the user for the building "UBA Haus 2019" investigation object). (ISO 16000-3 2013)

The following compounds can be quantified using this method: formaldehyde, acetaldehyde, acetone, furfural, propanal, 2-butanone, butanal, benzaldehyde, cyclohexanone, pentanal, methylglyoxal, hexanal, benzophenone, heptanal, octanal, nonanal, decanal, undecanal, butenal, pentenal, hexenal, heptenal, octenal, nonenal, decenal.

Chapter 5.2: The analysis is performed according to DIN ISO 16000-3. The determination limit for formaldehyde and acetaldehyde is 3 µg/m³.

3.3 Air exchange rate measurement

Sufficient air exchange is of fundamental importance for indoor air quality. For the health and comfort of the user, as well as protection against damage e.g. due to excessive humidity, appropriate ventilation of all buildings is required. However, today's furnishing of residential and office buildings with hermetically sealed windows can result in insufficient air exchange, so in addition to the desired energy saving and noise reduction, this leads to a rise in concentration of substances emitted in indoor spaces. Therefore, manual ventilation by the users or the use of a mechanical ventilation system is required, especially during the heating period. Excessive air exchange, however, can lead to discomfort and increased energy consumption during the heating period. In order to be able to draw conclusions about the air exchange conditions in indoor spaces, the air exchange rate n must be determined. If the air exchange rates are known, compliance with hygienic and building physics ventilation objectives can be checked. The air exchange rate n, in h-1, is the quotient of the supplied air volume flow rate V˙L in m³/h to the zone volume VR in m³. It specifies how often the room volume is exchanged with supplied air in an hour. The hygienic minimum air exchange rate is about 0.5 h-1. This is a minimum requirement for ensuring fresh air below which odour problems, dust and microorganism load plus excessive radon concentrations may occur. (VDI 4300 Part 7 2001)

The air exchange rate is determined using an indicator gas (CO_2) and a gas analyser with a dosage unit made by the Lumasense company according to the concentration decay method. At first, the CO_2 concentration of the room to be tested is measured for a period of time. Then the so-called dosage starts and the device pumps a specified CO_2 concentration into the room. A fan ensures optimum distribution in the room. When the defined concentration reaches a constant in the room, the dosage ends and the measuring process starts. The device then measures the CO_2 concentration in the room continuously.

The measured values obtained provide a drop in concentration from which the air exchange rate can be calculated according to the following formula: (VDI 4300 Part 7 2001)

$$n = \frac{1}{t_2 - t_1} * ln\frac{C_{t1}}{C_{t2}}$$

where:

n	air exchange rate in [1/h]
C(t1)	indicator gas concentration at time t_1 [ppm]
C(t2)	indicator gas concentration at time t_2 [ppm]
t	time of sampling the indicator gas in [h]

4 Comparison of different methods for sensory-based indoor air assessment

The first work package (as described in Chapter 2) covers the systematic investigation of room air quality with regard to odours and volatile organic compounds in the office rooms of UBA's Bismarckplatz office building. The investigation period was approximately 6-7 months after the start of the project. About 20 rooms were assessed in an empty state before the start of refurbishment work. Within the scope of odour investigations, the panellists always assessed the perceived intensity and the hedonics of the room air.

The aim of the investigations was to determine the as-is state of room air quality in the building before the start of the renovation. Various room air assessment methods were used and compared in order to determine the most favourable method for local conditions and to prove the comparability of the results.

Two methods can be used for odour assessment of indoor air according to DIN ISO 16000-30 (see Chapter 3):

- direct odour test on site
- sampling room air and subsequent odour test in the laboratory.

A direct on site odour test can be accompanied by less technical effort than the sampling method. If there are difficulties in the assessment, the test can simply be repeated. The direct on site odour test is followed by a context-dependent assessment.

DIN ISO 16000-28 describes the requirements for sampling room air using sample containers. Nevertheless, there is a risk that high temperatures due to direct sun radiation, insufficient pre-treatment of the sample containers or too long storage times may change the sample during transport and storage. (ISO 16000-28 2012)

Room air sampling and subsequent odour tests in the laboratory are preferred if

- there is a risk that the assessment will be adversely affected by unsettling ambient conditions (e.g. noise, glaring light),
- the odour of the indoor air can be influenced by the panellists themselves (e.g. in the case of a small room volume),
- a visual recognition of possible sources is undesirable for the assessment,
- no room is available for the panellists' sense of smell to regenerate,
- transportation of the panellists to the test site requires much logistic effort,
- the comparative scale influences the odour of the indoor air (e.g. air flow from the comparative scale's place of installation to the room to be tested). (ISO 16000-30 2015)

In addition to the two procedures described, a third evaluation method can be used given UBA's agreement. This comprises sampling and subsequent on site assessment in the Bismarckplatz building. This assessment method minimises long sample storage times and the influence of visual effects on the assessment. Moreover, a near-time repetition of the measurement is possible.

Consequently, odour assessments for the individual rooms were carried out according to the following assessment methods (a to c):

a) **AirProbe laboratory:** Room air sampling (using AirProbe) and subsequent odour test in the laboratory.
This method includes sampling room air contained in special sample containers using AirProbe. The containers are then transported to the air quality laboratory and evaluated promptly by the panellists.

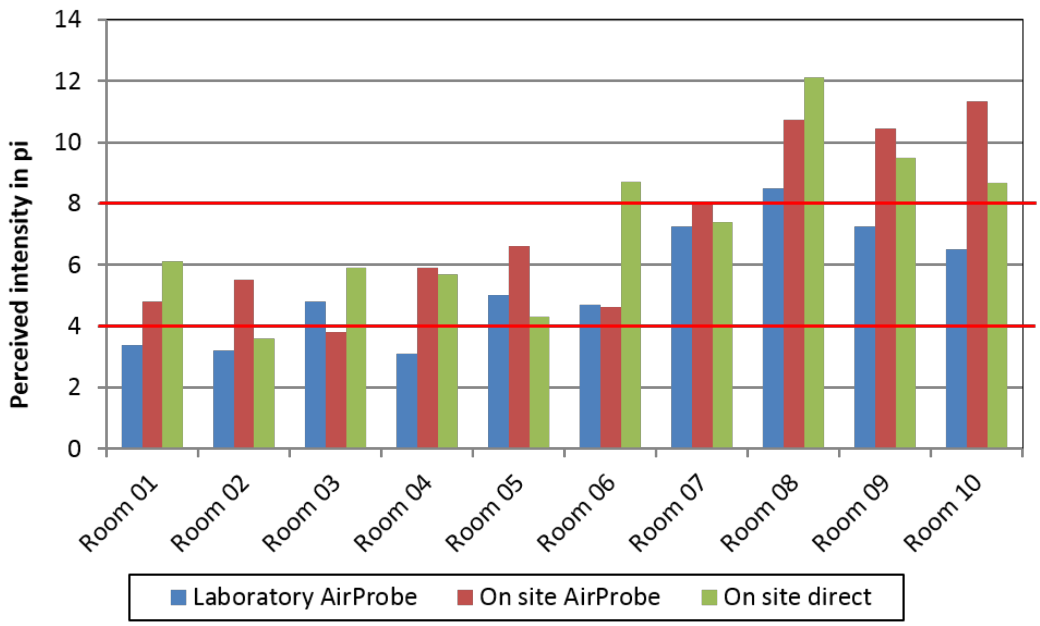
b) **On site direct:** Direct odour test on site (using a comparative scale)
In this method, a comparative scale is established in a room close to the test rooms. The panellists go directly into the room to be assessed and perceive the smell there. Then they compare and assess it using the comparative scale in the neighbouring room. Since the comparative scale for this method is in a room without exhaust air, the acetone concentration in the room is measured during the measurements. Too high a background concentration may influence the assessment of the samples. The measured room air concentration did not exceed the value of 15 mg acetone/m^3. Also, odour assessments in the room after the measurement did not give high odour intensities (< 2 pi). Furthermore, the room was ventilated by opening the window several times during pauses in the measurements.

c) **On site AirProbe:** Room air sampling (using AirProbe) and subsequent odour test at Bismarck-platz
Room air samples are taken in this variant using AirProbe, similar to method a. But they are then presented and assessed on site using the comparative scale.

After assessing the results of the first 10 rooms, a deliberation was made to see whether using all three measurement methods was necessary or which of the methods should be used for the next set of measurements as described in Chapter 2.

Figure 9 below shows a comparison of perceived intensities for the three assessment methods of the tested rooms.

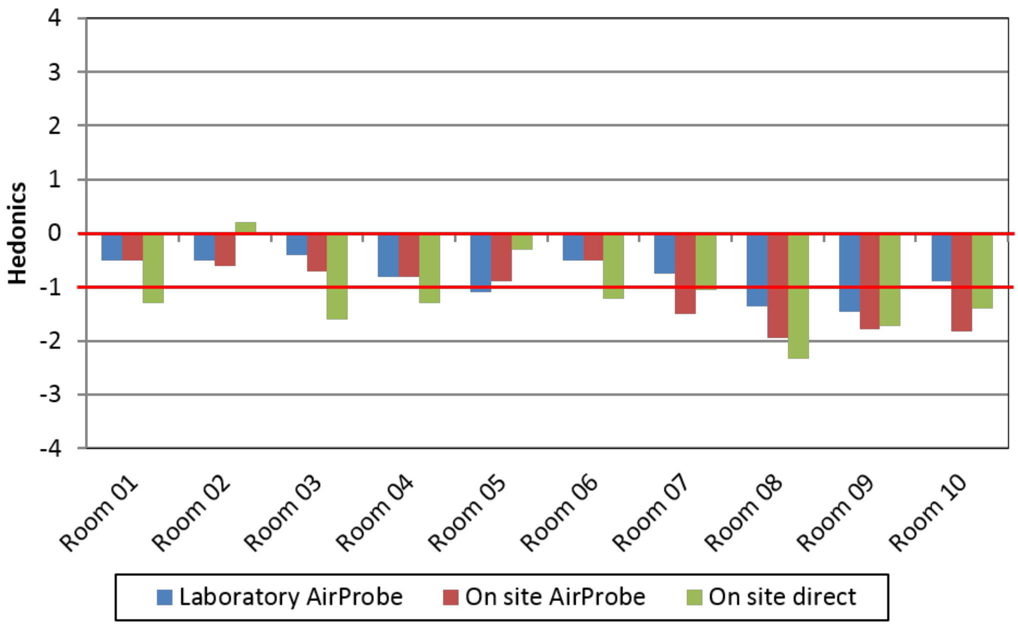
Figure 9: Methods comparison for intensity



It can be said that the results of all three assessment methods fluctuate within the accuracy (deviation +/-2 pi). This implies that the mean value of the three individual values for the three different methods is determined and the fluctuations around this mean value should be no greater than the required accuracy of +/-2 pi. They thus provide comparable values. This finding is important for the procedure to be pursued in the project and for the decision as to which methods should be used depending on the status of renovation. The results in the laboratory using the AirProbe often provide the lowest intensities. The assessments using the other two test methods provide, in part, very good matches but also show differences in the assessments. If one compares the rooms, it is noticeable that rooms 01 to 07 are in the medium room air quality range while rooms 08 to 10 exhibit poor room air quality (according to Table 1, Chapter 3.1).

Hedonics evaluations (see Figure 10) also show a good agreement of all assessment methods. A comparison of the rooms shows that rooms 01 to 06 are in the medium range and rooms 07 to 10 in the poor quality range (according to Table 2, Chapter 3.1).

Figure 10: Methods comparison for hedonics



The measured VOC and aldehyde concentrations in the empty rooms before the start of the renovation, showed very low values close to the limit of determination. Due to the large number of substances, these values are not listed in the report. These results are common for rooms that have been empty and unfurnished for several years.

Methods selection:

On the basis of the investigations carried out it was decided, together with UBA, that the two on site methods (b and c) should be pursued for the Bismarckplatz office (see Chapter 5.1). However, the method in the laboratory is always preferable when, for example, no on-site assessment is possible.

5 Investigations in test rooms

Because of construction delays already apparent at this point, the next step was to examine combinations in real rooms at Bismarckplatz (see Chapters 2 and 5.1). In addition, tests in Cologne were coordinated with the eco-INSTITUT (see Chapter 5.2).

Buildings are constructed to be air-tight for reasons of energy saving and efficiency. Natural ventilation by air exchange through walls and windows in air-tight buildings do not provide sufficient air exchange for the well-being of room users and to remove humidity. Indoor odours are therefore an increasing source of complaints from room users. Odour sources are mostly inside but they can also enter from the building surroundings. Odour sources include building products, materials for interior design, indoor equipment including their emission and decomposition products, technical equipment, building damage, animals and the room users themselves. In closed rooms, persistent odours whose occurrence cannot be controlled by the room users are usually perceived as a nuisance. Exposure to such odours can both impair well-being and reduce performance. (ISO 16000-30 2015)

Emissions from construction products can have a significant impact on the quality of indoor air. Since different odour sources can occur in real (i.e. used) rooms, so-called test rooms have proved to be useful for investigating the odour impacts of construction products and combined assemblies. Here, other odour sources (for example, use of the rooms) are minimised or excluded, this is why only the influences from construction products under real conditions are included in the odour assessment of the room air. In addition to the assessments of the room air, assessments of the products in emission chambers (CLIMPAQ) (see Chapter 3.I) were carried out in the air quality laboratory in order to be able to draw conclusions about their impact in real rooms.

The aim of these investigations was to find potential odour problems caused by construction products or their combination before renovation and minimise them by the correct selection of products.

5.1 Bismarckplatz test rooms

5.1.1 Test description

In the German Environment Agency's Bismarckplatz office building there are five very similar, vacant offices that were used as test rooms within the scope of the investigation. These rooms were checked for their comparability before the tests (as-is condition) and classified in the same intensity and hedonics range. (cf. Annex, Section 5.1.1)

Four of the five rooms were equipped with different test assemblies. Emphasis was placed on variants of the interior wall insulation. Test room 5 remained unchanged (empty) and was regarded as a reference value. Odour and chemical assessments (the latter by UBA themselves) of the rooms were performed at various intervals before, during and after installation of the assemblies. In addition, some of the building materials used in the rooms were assessed in the emission chambers in the air quality laboratory in order to be able to draw conclusions about the impacts of real rooms.

In the run-up to the investigations, air exchange measurements were carried out in two of the five test rooms in order to verify the comparability of the rooms with regard to air exchange.

Table 3 below shows the composition of the set-ups in the individual test rooms.

Table 3: Bismarckplatz test rooms

Material layer	Test room 1	Test room 2	Test room 3	Test room 4	Test room 5
1	Interior wall insulation board (mineral wool)	Interior wall insulation board (mineral wool)	Interior wall insulation board (mineral wool)	Clay insulation board	Unchanged (used as a reference value)
2	Reinforcing mortar	Gypsum plasterboard + putty	Basecoat mortar	Flush-mounted loam and loam finishing plaster	
3	Dispersion wall paint	Dispersion wall paint	Flush-mounted loam and loam finishing plaster	Clay paint	

The materials were installed in three successive construction phases. A sensory-based and an analytical assessment of the test room air was carried out after each construction phase.

Table 4 shows an overview of the room air assessments carried out at the Bismarckplatz object.

Table 4: Overview of indoor air measurement at Bismarckplatz

Measurement phase	Description of state
AS-IS	As-is state before reconstruction measures
Day -14	After construction phase 1
Day -7	After construction phase 2
Day 1	1 day after completion (after construction phase 3)
Day 3	3 days after completion
Day 7	7 days after completion
Day 14	14 days after completion
Day 28	28 days after completion

5.1.2 Air exchange rate measurement

Test rooms 1 and 4 were selected as examples for determining the air exchange rate of the test rooms. Windows and doors remained closed for the period of measurement. The concentration decay method was used as the measuring method (see Chapter 3.3). In this method an indicator gas (CO_2) is introduced into the room to be tested and the drop in concentration is measured as a function of time. The following figures (Figure 11 and Figure 12) show the measured drop in concentration in the test rooms 1 and 4. The calculation of the air-flow rate n is carried out according to VDI-4300 Part 7 (VDI 4300 Part 7 2001) and is also shown in the diagram.

Figure 11: CO_2 concentration drop in test room 1

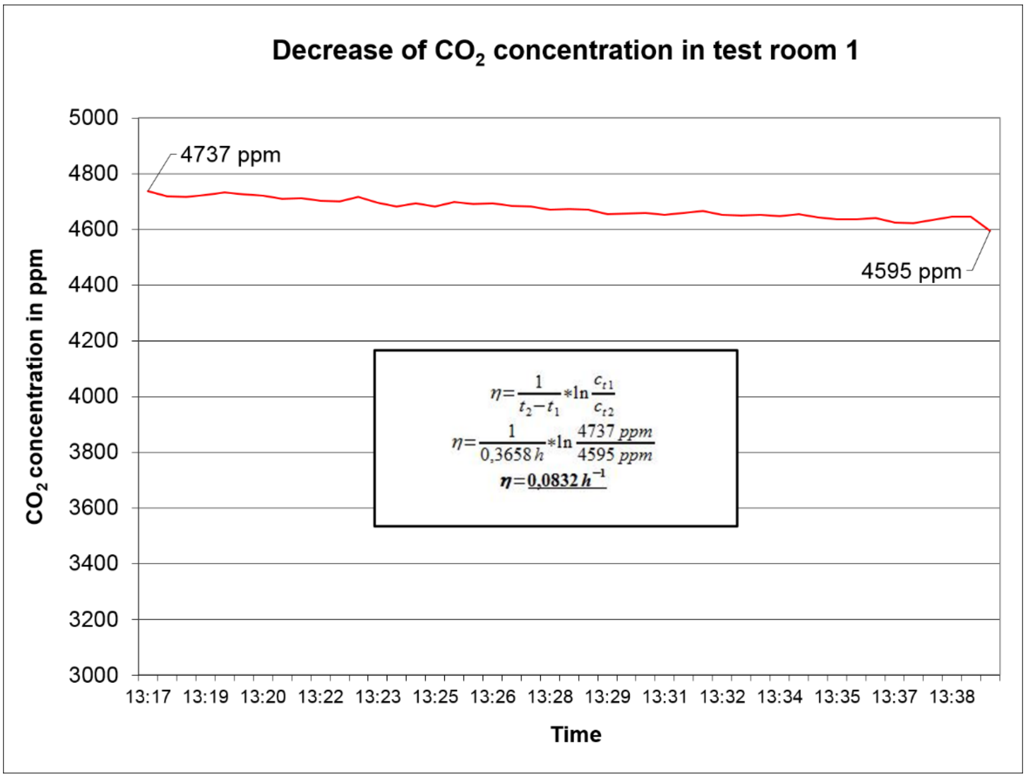
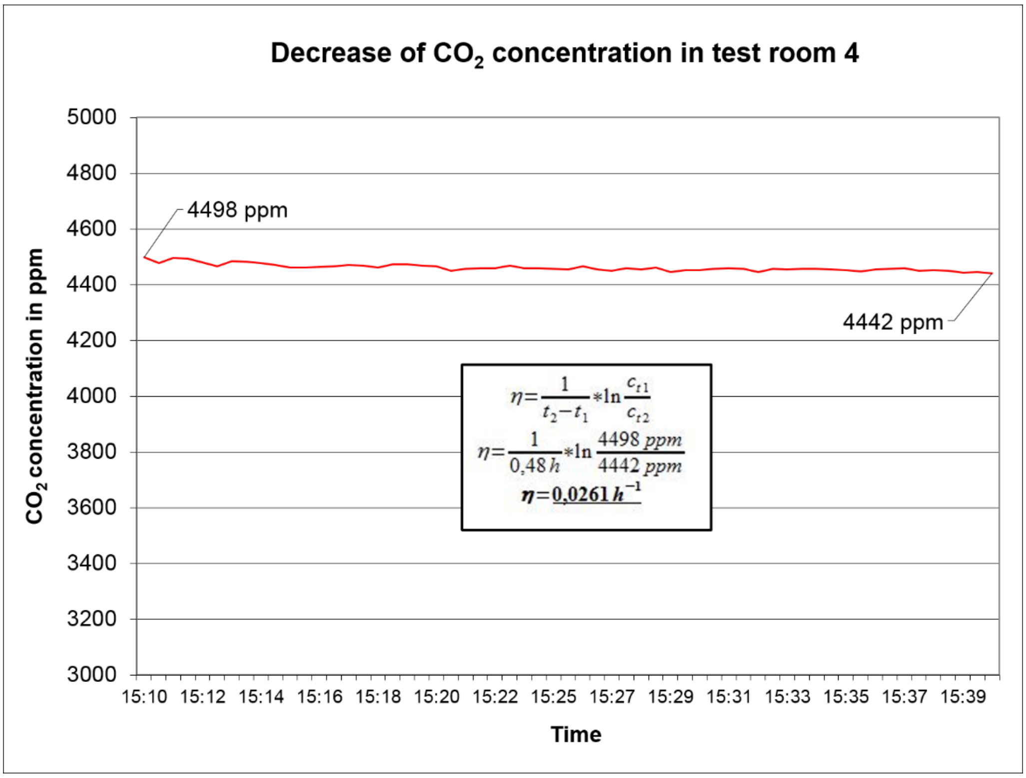


Figure 12: CO_2 concentration drop in test room 4



It stood out that in both rooms the concentration of the indicator gas decreased only very slowly over time. In test room 1, the measurement began with a CO_2 concentration of 4737 ppm and dropped to

4595 ppm. According to VDI 4300-7, this corresponds to an air exchange rate of 0.083 h-1. In test room 4, the initial concentration was approximately 4498 ppm and dropped to 4442 ppm in about half an hour. This corresponds to an air exchange rate of 0.026 h-1. (VDI 4302 Part 1 2015)

This means that almost no air exchange took place in the test rooms, which is characteristic of very dense spaces.

5.1.3 Indoor air measurements

The room air investigations in the test rooms were carried out one day after the respective reconstruction activities have been completed. On the day before the analysis, the test rooms were ventilated for 10 minutes by opening the windows. Temperature and relative humidity of the room air were recorded during sampling. These values were listed in the intensities diagrams as well as in the measurement protocols in Annex Section 5.1.3.

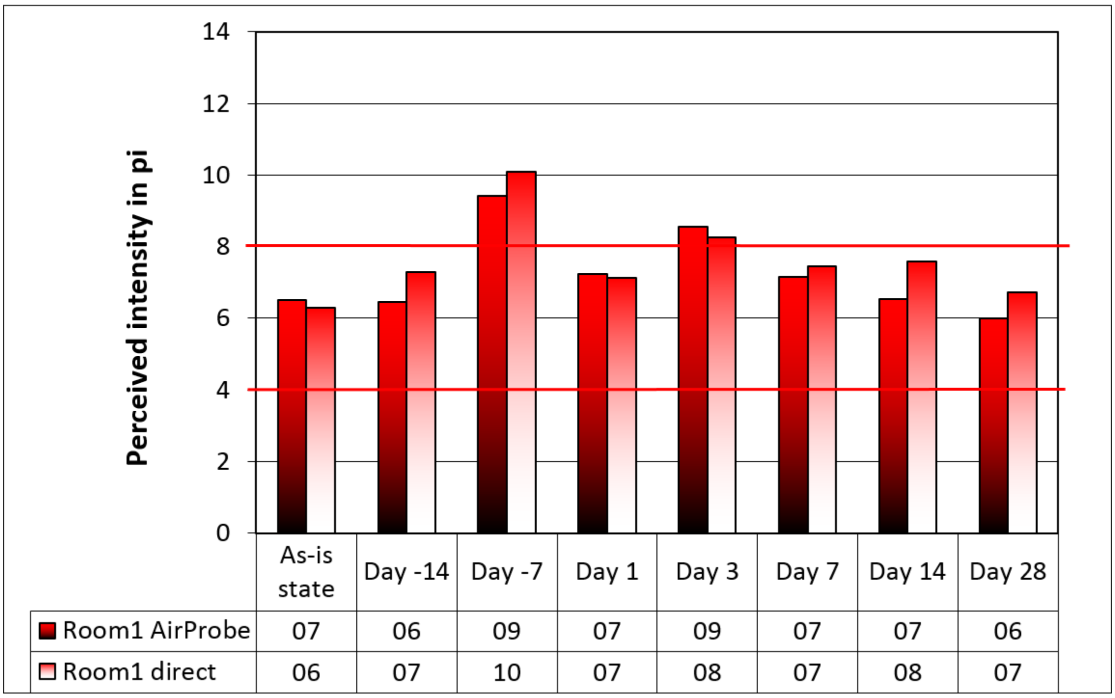
5.1.3.1 Test room 1

The following materials were introduced in the corresponding construction phases in test room 1:

- Interior wall insulation board (day -14)
- Basecoat mortar (day -7)
- Dispersion wall paint (day 1).

The following Figure 13 shows the perceived intensities of the direct and indirect (via AirProbe) evaluation method on individual test days.

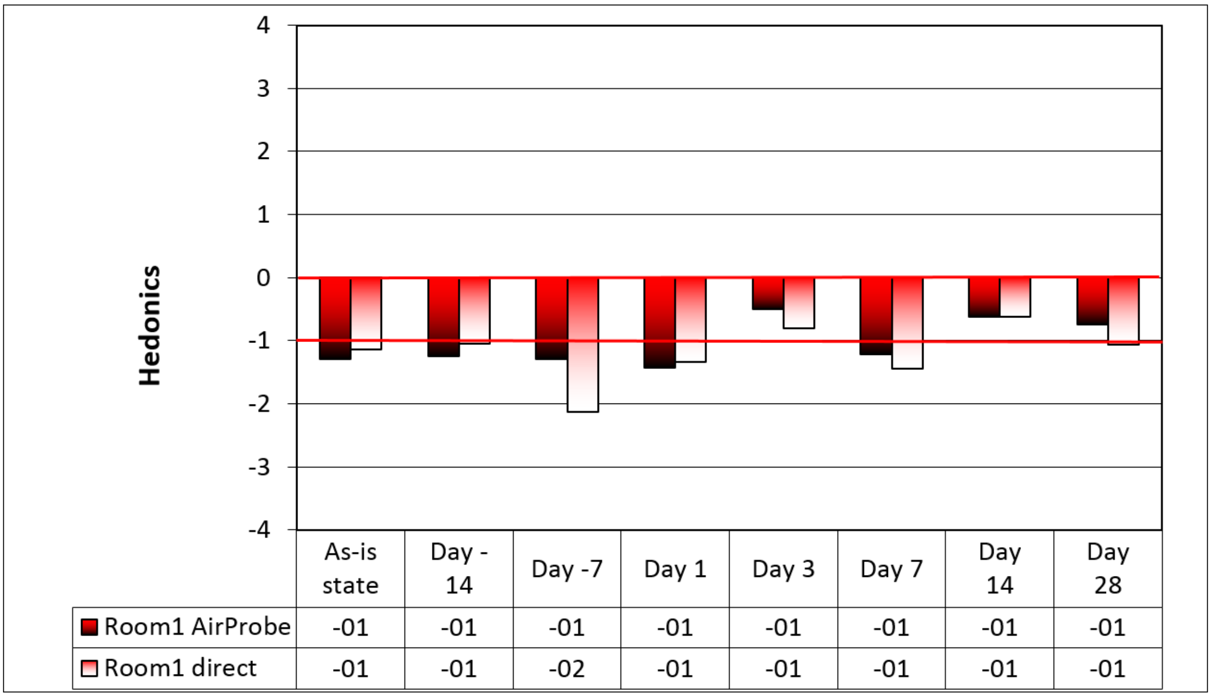
Figure 13: Intensity in room 1 (Bismarckplatz)



An intensity of 7 pi was detected in test room 1 before the start of reconstruction measures (as-is state). In the first construction phase (day -14), interior wall insulation boards were glued to the side walls, which has little effect on the intensity. In the next construction phase (day -7), basecoat mortar was applied, which noticeably increased the perceived intensity. However, a comparatively high temperature and humidity can be observed in the room on the day of the test, which can influence the high intensity (see Section 3.1.6). The walls were painted with dispersion wall paint as the last reconstruction step. The intensity on the day after (day 1) was approximately 7 pi. After a slight increase up to day 3 (high temperatures and humidity were still present), the intensity decreases to about 6 pi on day 28 to the level before the start of reconstruction and was thus in the medium range of room air quality (> 4 pi and < 8 pi).

Figure 14 shows the assessments of the hedonics for test room 1. All the determined values are in the comparable value range between -0.5 and -1.5.

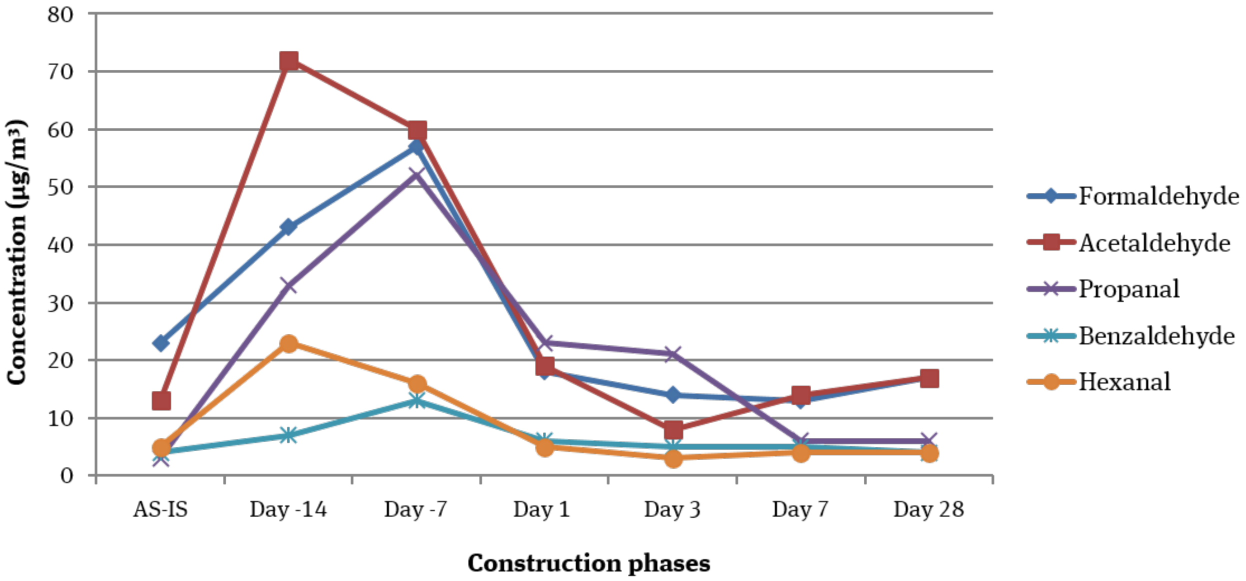
Figure 14: Hedonics in room 1 (Bismarckplatz)



Aside from odours, VOC and aldehyde concentrations were also measured in test room 1. The detailed results are presented in Annex 5.1.3 (Tables 12 and 13). Installing the interior wall insulation board (day -14) led to an increase in the D4 concentration (octamethyl cyclotetrasiloxane) from 3 µg/m^3 in the as-is state to 66 µg/m^3. After applying the dispersion wall paint, the D4 concentration remained at this level (62 µg/m^3). In addition, an increase in the values for 1-butanol, D3 (hexamethyl cyclotrisiloxane), D5 (decamethyl cyclopentasiloxane) was registered. However, an exceedance of indoor guide values was not detected. (Web page Umweltbundesamt) On day 28 after completing the reconstruction, VOC concentrations were comparable to the values in the as-is state.

Aldehyde and ketone concentration measurements using the DNPH method provided a concentration profile typical during reconstruction measures (higher concentrations in the construction phases and subsequent decreases in concentrations over time). Figure 15 shows the concentration profile of certain selected aldehydes across the construction phases. Room air concentrations increased after the installation of the interior wall insulation board, and the application of the basecoat mortar (day -7) also increased the concentration in the case of formaldehyde, propanal and benzaldehyde. The hexanal and acetaldehyde concentrations decreased as early as day -7 and reached comparable values to the as-is state on day 28. The existing indoor guide values for aldehydes were not reached or exceeded at any time. (Web page Umweltbundesamt)

Figure 15: Aldehyde concentrations in test room 1 during construction phases (DNPH method)



The chemical analysis was also influenced by temperature and relative humidity. Inaccuracies may have occurred during the evaluation of measurements from a temperature of 25°C and a relative humidity of 60%.

5.1.3.2 Test room 2

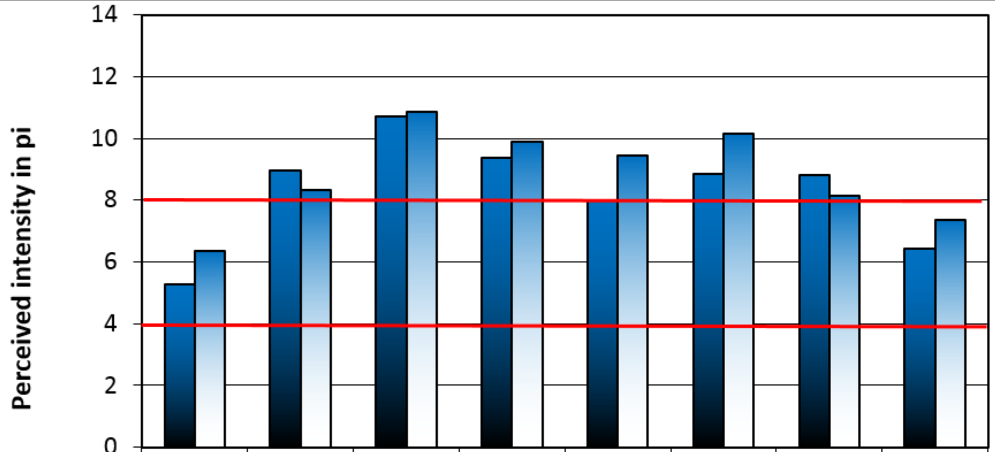
The following materials were used in test room 2:

- Interior wall insulation board (day -14)
- Plasterboard + putty (day -7)
- Dispersion wall paint (day 1).

The following Figure 16 shows the determined intensities for individual test days.

Prior to reconstruction measures, test room 2 exhibited an intensity of approximately 5 pi. In the first construction phase, insulation boards were glued to the side walls, which significantly increased the intensity (day -14). The insulation boards were covered with gypsum plasterboards and sealed with putty in the second construction phase, which increased the intensity even further (day -7). High temperature and humidity values were detected on this day as well. On completion of the construction work and thus one day after the application of the dispersion wall paint (day 1), the perceived intensity had already dropped again. On day 28 after completing the reconstruction measures, the intensity was perceived to be about 6 pi and was thus approximately in the range of the as-is state prior to reconstruction measures.

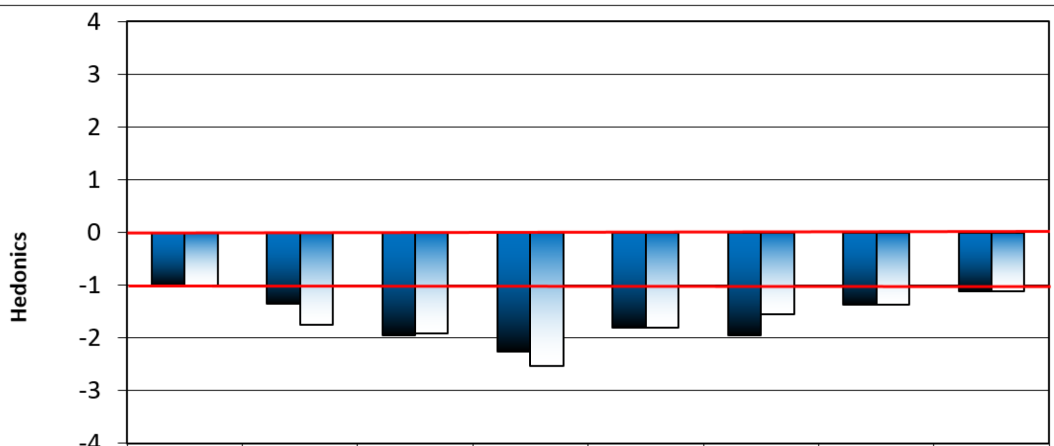
Figure 16: Intensity in room 2 (Bismarckplatz)



	As-is state	Day -14	Day -7	Day 1	Day 3	Day 7	Day 14	Day 28
Room2 AirProbe	05	09	11	09	08	09	09	06
Room2 direct	06	08	11	10	09	10	08	07
Temperature in °C	18	25	27	25	24	24	27	22
Relative humidity in %	45	67	81	76	71	70	69	66

Figure 17 shows the assessments of the hedonics in test room 2. Before the start of the construction, the hedonics of the room was rated at -1. This value deteriorated slightly during the individual construction phases and was around -2.4 on day 1 after completion of the construction work. Hedonics improved again after completing the construction (from day 3 onwards), and was in the range of the as-is state on day 28, but was still perceived as rather unpleasant.

Figure 17: Hedonics in room 2 (Bismarckplatz)

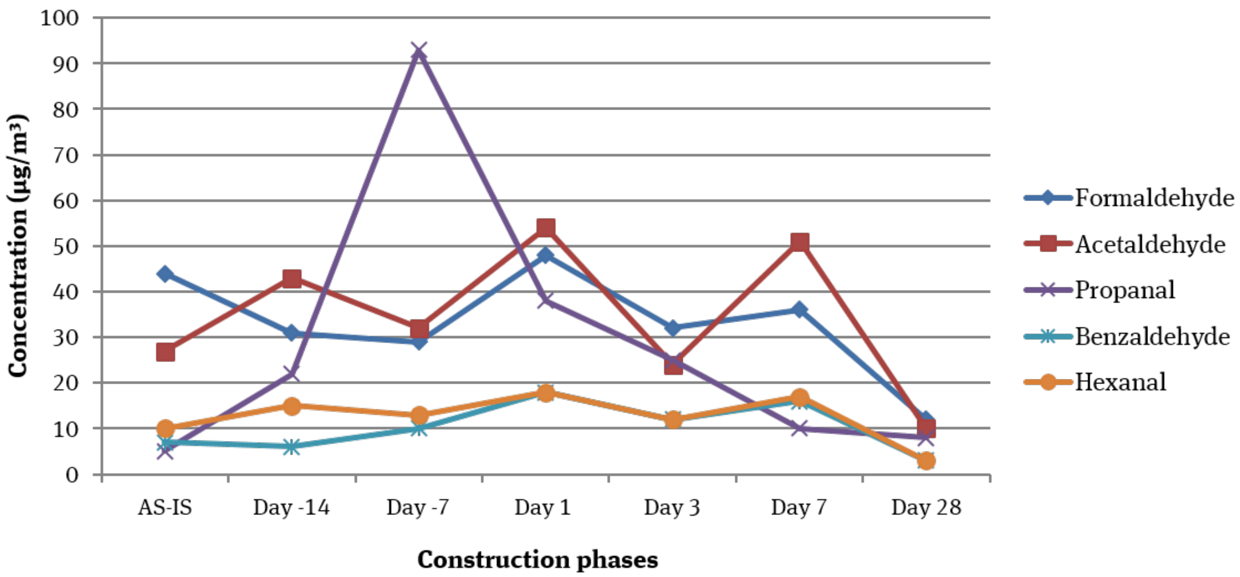


	As-is state	Day -14	Day -7	Day 1	Day 3	Day 7	Day 14	Day 28
Room2 AirProbe	-01	-01	-02	-02	-02	-02	-01	-01
Room2 direct	-01	-02	-02	-03	-02	-02	-01	-01

Aside from odours, VOC and aldehyde concentrations were also tested in test room 2. The detailed results are presented in Annex 5.1.3 (Tables 14 and 15). The room air concentrations usually increased in the construction phases as in test room 1. For example, after the application of the gypsum plasterboard and putty (day -7), the concentrations increased for the substances 1-butanol from 6 to 39 µg/m³, alpha-pinene from 7 to 24 µg/m³ and 3-carene from 4 to 15 µg/m³. By day 28, the values had subsequently dropped to the level of the as-is state. However, D4 shows a large concentration increase in the construction phases: 223 µg/m³ was measured on day -7 and 542 µg/m³ after the application of the dispersion wall paint, which means that the guide value I (GV I = 400 µg/m³ for the sum of D3 + D4 + D5) was exceeded in this case. (Web page Umweltbundesamt)

Considering the aldehyde and ketone concentrations using the DNPH method failed to show a typical concentration profile (decrease in concentration over time) in this case. Figure 18 shows this for certain selected aldehydes. A concentration increase was registered on day 7 after completion of the reconstruction measures. Only propanal showed a decrease in concentration by day 28. The existing indoor guide values for aldehydes were never exceeded. (Web page Umweltbundesamt)

Figure 18: Aldehyde concentrations in test room 2 during construction phases (DNPH method)



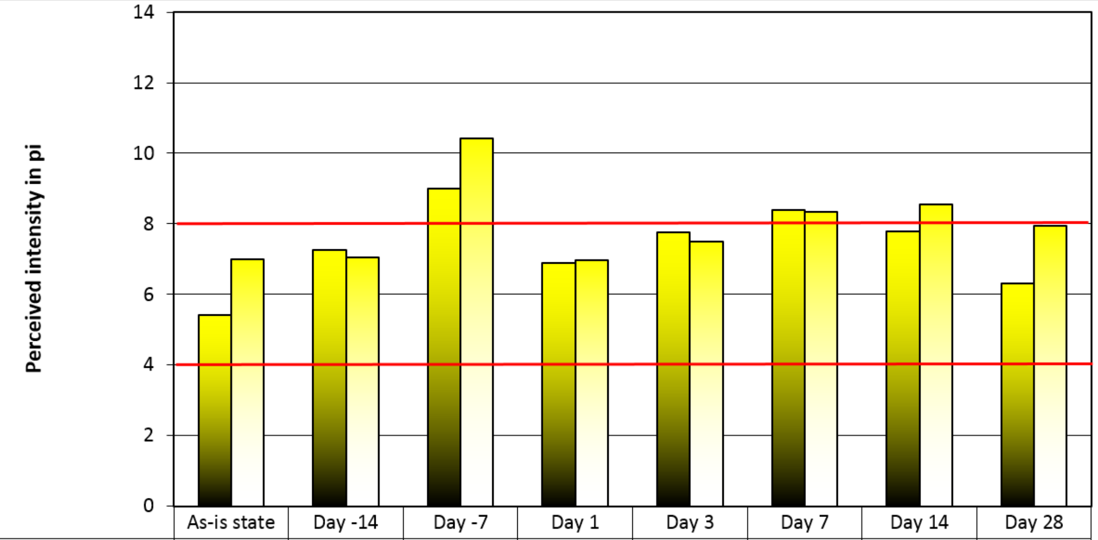
5.1.3.3 Test room 3

The following building products were installed in test room 3:

- ► Interior wall insulation board (day -14)
- ► Basecoat mortar (day -7)
- ► Flush-mounted loam and loam finishing plaster (day 1).

Figure 19 below shows the perceived intensities of the individual measuring phases.

Figure 19: Intensity in room 3 (Bismarckplatz)

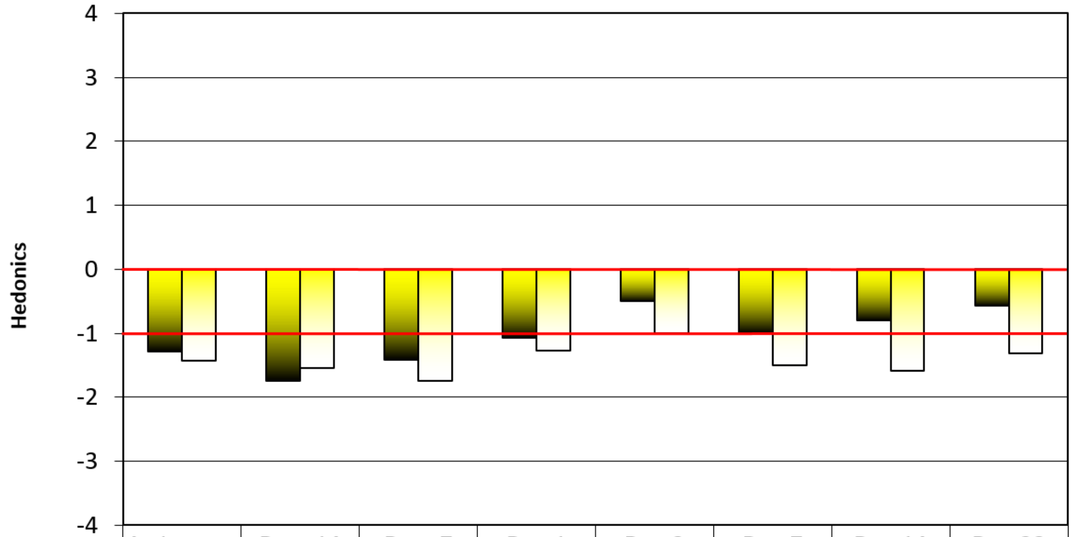


	As-is state	Day -14	Day -7	Day 1	Day 3	Day 7	Day 14	Day 28
Room3 AirProbe	05	07	09	07	08	08	08	06
Room3 direct	07	07	10	07	08	08	09	08
Temperature in °C	18	25	27	25	24	24	27	22
Relative humidity in %	46	65	84	75	78	76	60	50

Interior wall insulation boards were glued to the side walls in the first construction phase. The insulation boards were plastered with basecoat mortar in the second construction phase, which increased the perceived intensity (day -7). Same as the previous test rooms, a high temperature and humidity were observed in this room as well. On completion of the construction work and thus one day after plastering with clay plaster (day 1), the perceived intensity had already begun to drop and remained between 7 and 8 pi during the following days. On day 28, the perceived intensity was rated at about 6 pi and was therefore one unit higher than in the as-is state.

Figure 20 shows the hedonics assessments for test room 3. Prior to the start of the construction work, the hedonics was approximately -1 and deteriorated slightly during the first construction phase. It reached medium quality ranges (between 0 and -1) once more later on during the test.

Figure 20: Hedonics in room 3 (Bismarckplatz)

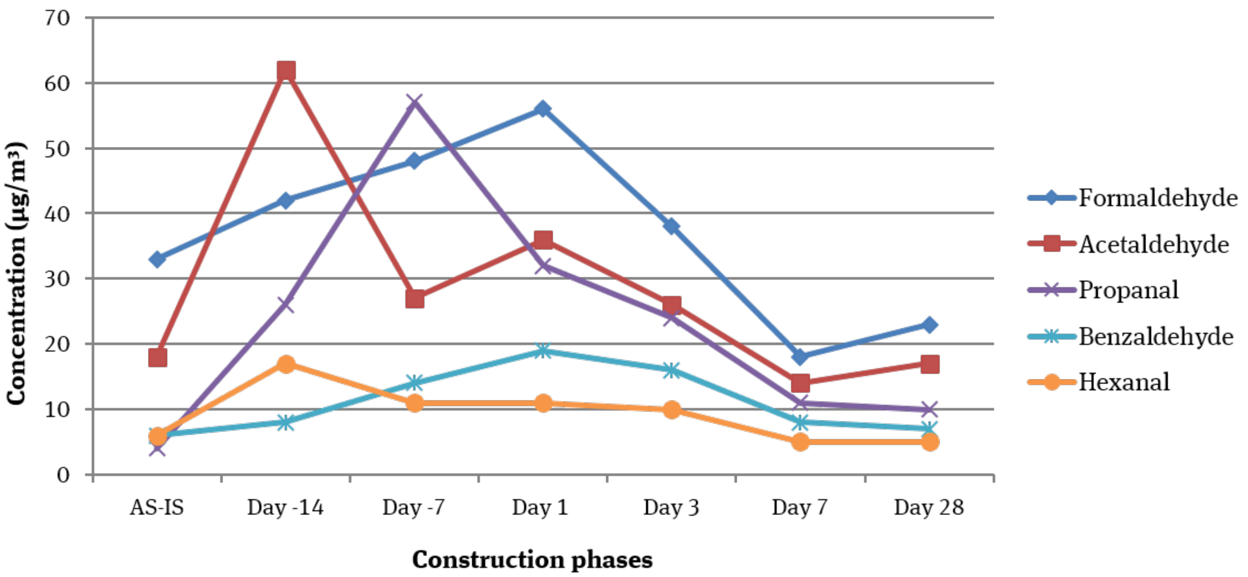


	As-is state	Day -14	Day -7	Day 1	Day 3	Day 7	Day 14	Day 28
Room3 AirProbe	-01	-02	-01	-01	-01	-01	-01	-01
Room3 direct	-01	-02	-02	-01	-01	-02	-02	-01

Aside from odours, VOC and aldehyde concentrations were also examined in test room 3. The detailed results are presented in Annex 5.1.3 (Tables 16 and 17). As in test room 1, the installation of the interior wall insulation board (day -14) led to an increase in the D4 concentration from 3 µg/m^3 in the as-is state to 55 µg/m^3. The concentration of alpha-pinene also increased from 8 to 25 µg/m^3 after this construction phase. On day -7, the D4 concentration increased once more (67 µg/m^3). On day 14, after completion of the reconstruction measures, this substance was no longer detected. The D5 concentration increased from 16 µg/m^3 on day - 7 to 28 µg/m^3 on day 14. Due to technical reasons, the day 28 value could not be determined. There was no exceedance of the indoor guide values.

The measurement of aldehyde and ketone concentrations using the DNPH method showed a concentration decrease over time from day 1 after completion of the construction work at the latest (for hexanal and propanal from day -14 and day -7 respectively) (Figure 21). A small increase in formaldehyde and acetaldehyde concentration in the room air was still recorded on day 28. The existing indoor guide values for aldehydes were not exceeded. (Web page Umweltbundesamt)

Figure 21: Aldehyde concentrations in test room 3 during construction phases (DNPH method)



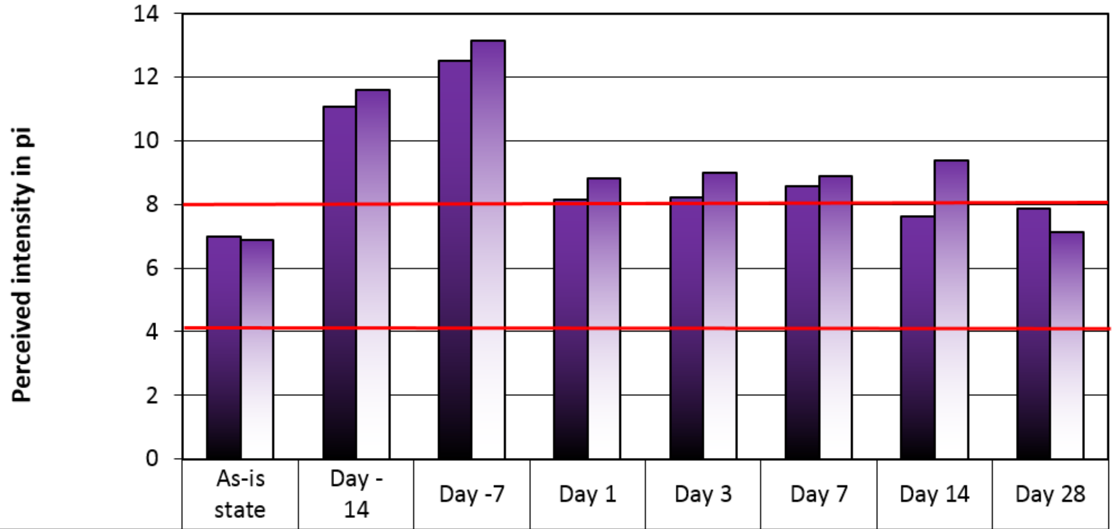
5.1.3.4 Test room 4

Test room 4 was equipped with the following building products:

- Clay insulation board (day -14)
- Flush-mounted loam and loam finishing plaster (day -7)
- Clay paint (day 1).

Figure 22 below shows the perceived intensities of this room. The results of both assessment methods are once again roughly the same. The room had an intensity of 7 pi before construction began. In the first construction phase, the side walls were covered with clay insulation boards, which increased the intensity very strongly to about 11 pi (day -14). Flush-mounted loam and loam finishing plaster were applied to the insulation boards in the second construction phase, which slightly increased the odour intensity once again. As in other test rooms, a high temperature and humidity were measured in this test room as well. However, applying the clay paint (day 1) decreased the intensity noticeably (despite high humidity) and remained in this intensity range until the end of the test. On day 28, the perceived intensity was rated at approximately 8 pi and was thus slightly higher than in the as-is state.

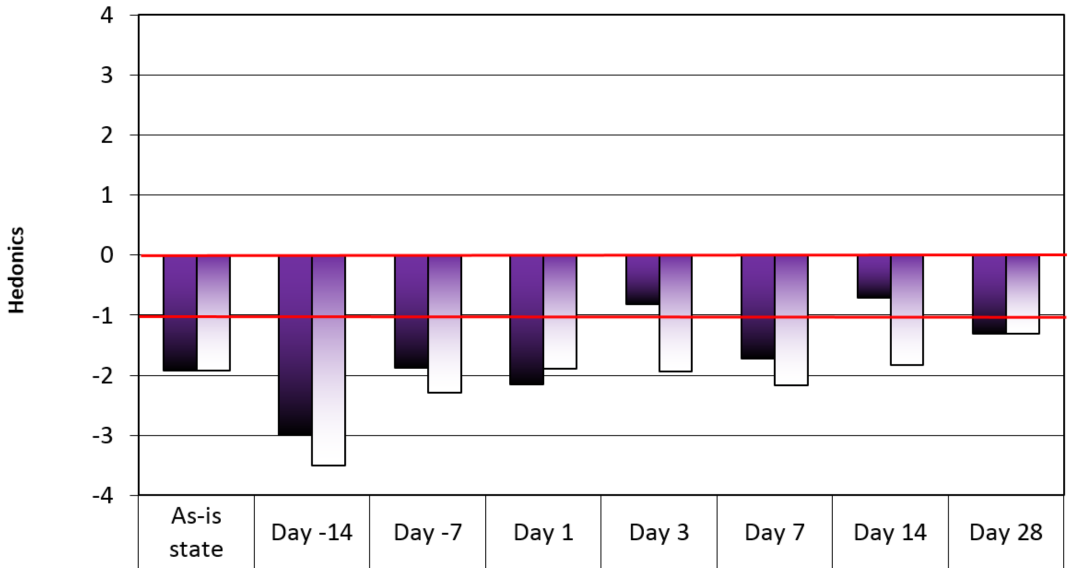
Figure 22: Intensity in room 4 (Bismarckplatz)



	As-is state	Day -14	Day -7	Day 1	Day 3	Day 7	Day 14	Day 28
Room4 AirProbe	07	11	13	08	08	09	08	08
Room4 direct	07	12	13	09	09	09	09	07
Temperature in °C	19	25	28	25	24	25	23	23
Relative humidity in %	43	70	83	76	76	71	73	52

The assessment of hedonics in Figure 23 paints a similar picture. The hedonics reached a value of -3 on the day after the application of the clay insulation boards and thus comes very close to the lowest possible value of -4, which is extremely unpleasant. However, when assessing the next construction phase (day -7), the room air was already perceived as somewhat more pleasant. Overall, the hedonics values were worse compared to the other rooms. Nevertheless, the hedonics could be improved by about half a point compared to the as-is state.

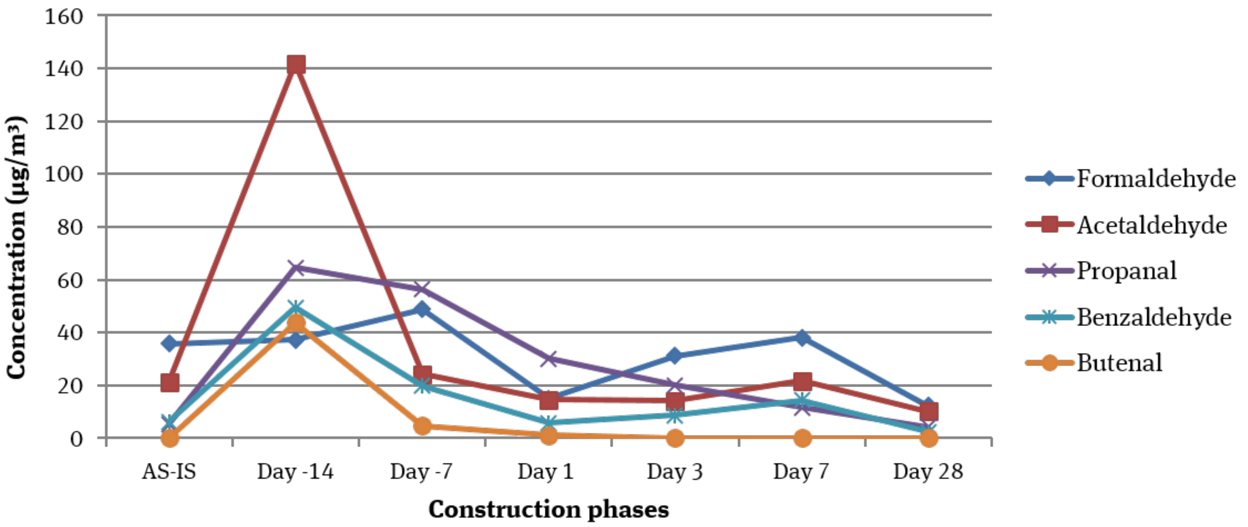
Figure 23: Hedonics in room 4 (Bismarckplatz)



	As-is state	Day -14	Day -7	Day 1	Day 3	Day 7	Day 14	Day 28
Room4 AirProbe	-02	-03	-02	-02	-01	-02	-01	-01
Room4 direct	-02	-04	-02	-02	-02	-02	-02	-01

In addition to odours, VOC and aldehyde concentrations in test room 4 were also investigated. The detailed results are presented in Annex 5.1.3 (Tables 18 and 19). In this test, the placement of the clay insulation board on day -14 led to a sharp increase in the concentration of volatile organic compounds. This can mainly be seen in the results of the measurement that used the DNPH method. Figure 24 shows selected results for some aldehydes using the DNPH method. The measured hexanal concentration reached a value of 425 µg/m³. The guide values for aliphatic aldehydes and benzaldehyde were exceeded on day -14. However, this measurement took place one day after the clay insulation board had been placed into the room and the building assembly was not yet completely dry in these conditions. The temperature was 25 °C and humidity 90% in the test room. The results of the odour tests correlated well with the analytical values (increase in the concentration of volatile organic compounds leads to higher odour intensities). In addition to the increased aldehyde values (DNPH), the concentration of terpenes also rose on day -14. The measured alpha-pinene and 3-carene concentrations were higher on day 28 than in the as-is state. In general, the concentrations of volatile organic compounds dropped over time towards day 28. (Web page Umweltbundesamt)

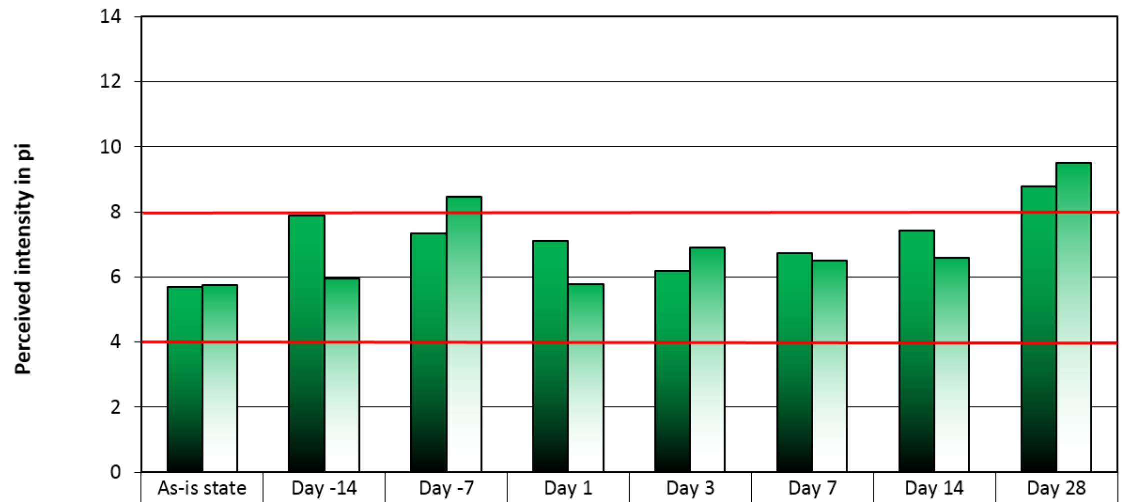
Figure 24: Aldehyde concentrations in test room 4 during the construction phases (DNPH method)



5.1.3.5 Test room 5

In test room 5 no construction work was carried out. Since the situation and properties of this room were similar to those of the other test rooms, it was tested in its unchanged state and was regarded as a reference value. Figure 25 shows the perceived intensities in the room air. They varied slightly between 6 and 8 pi over the test period. Although there were temperature differences between the individual measurement days, humidity stayed mainly in the same range (40-65%).

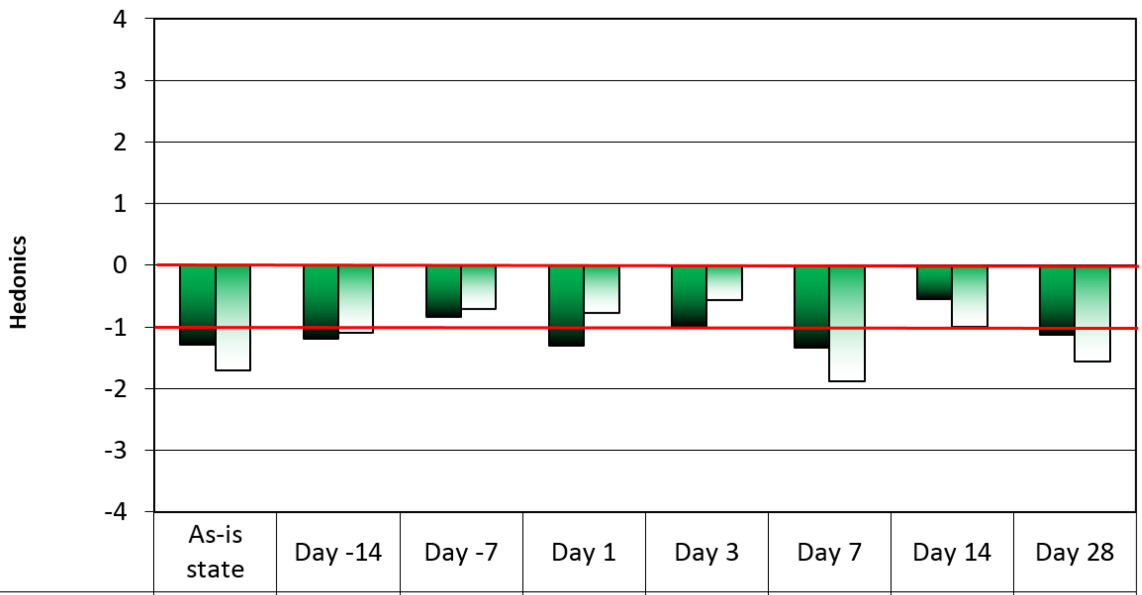
Figure 25: Intensity in room 5 (Bismarckplatz)



	As-is state	Day -14	Day -7	Day 1	Day 3	Day 7	Day 14	Day 28
Room5 AirProbe	06	08	07	07	06	07	07	09
Room5 direct	06	06	08	06	07	07	07	10
Temperature in °C	20	25	27	25	24	25	24	22
Relative humidity in %	42	66	58	57	58	53	56	49

Figure 26 shows the hedonics assessments. Again, in accordance with intensity, there were no major differences.

Figure 26: Hedonics in room 5 (Bismarckplatz)



	As-is state	Day -14	Day -7	Day 1	Day 3	Day 7	Day 14	Day 28
Room5 AirProbe	-01	-01	-01	-01	-01	-01	-01	-01
Room5 direct	-02	-01	-01	-01	-01	-02	-01	-02

No analytical tests were carried out in test room 5.

5.1.4 Product tests in the air quality laboratory

This chapter describes the test results for building products in the Bismarckplatz office building acquired in the air quality laboratory and the corresponding values of the indoor air measurements acquired using sampling (AirProbe). However, the values determined were based on different temperature and/or humidity values. The stipulated ventilation conditions in the emission chambers could not always be matched in the test room and in the room air sample.

In addition to the assessment of odour emissions, chemical concentrations (VOC and aldehydes) were also measured in the chamber air of some building products. Only the VOC emissions for days 3 and 28 were determined for the interior wall insulation board, clay putty, flush-mounted loam, loam finishing plaster and the clay paint. The measured concentrations of a few substances lay just above the limit of determination and are not shown in the report. In addition to VOC, aldehyde emissions from the clay insulation board were also measured; the concentrations of a few compounds were very low.

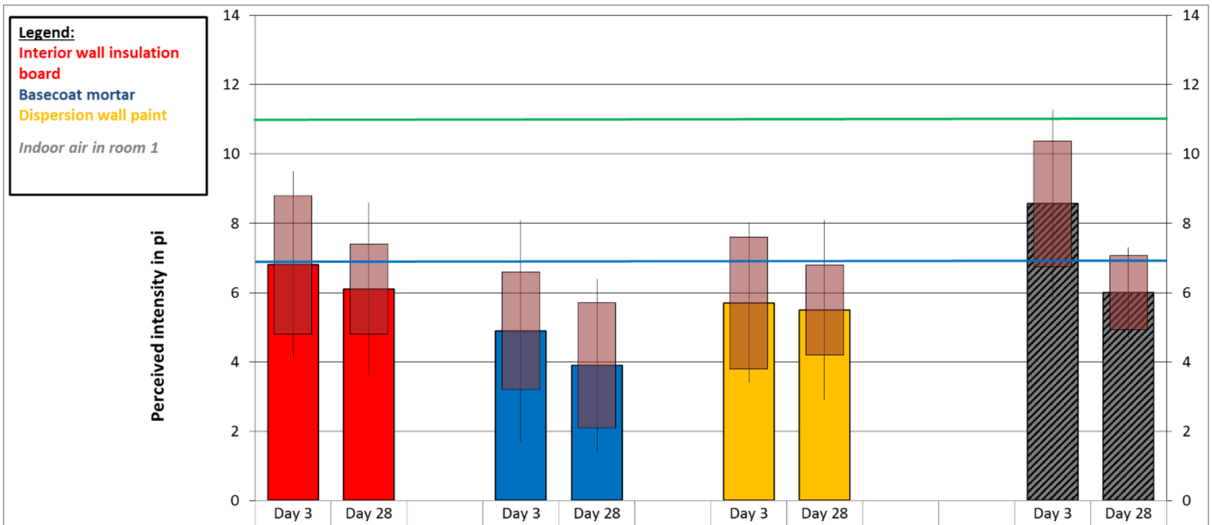
5.1.4.1 Products in test room 1

The test room 1 assembly comprises the following materials:

- Interior wall insulation board (mineral wool)
- Basecoat mortar
- Dispersion wall paint

Figure 27 below shows the intensities for the products used and in the indoor air measurements. Day 28 assessments of the individual products were all under the Blue Angel criterion (< 7 pi). The day 28 intensity of the room air (black/grey) was also within this range (6 pi).

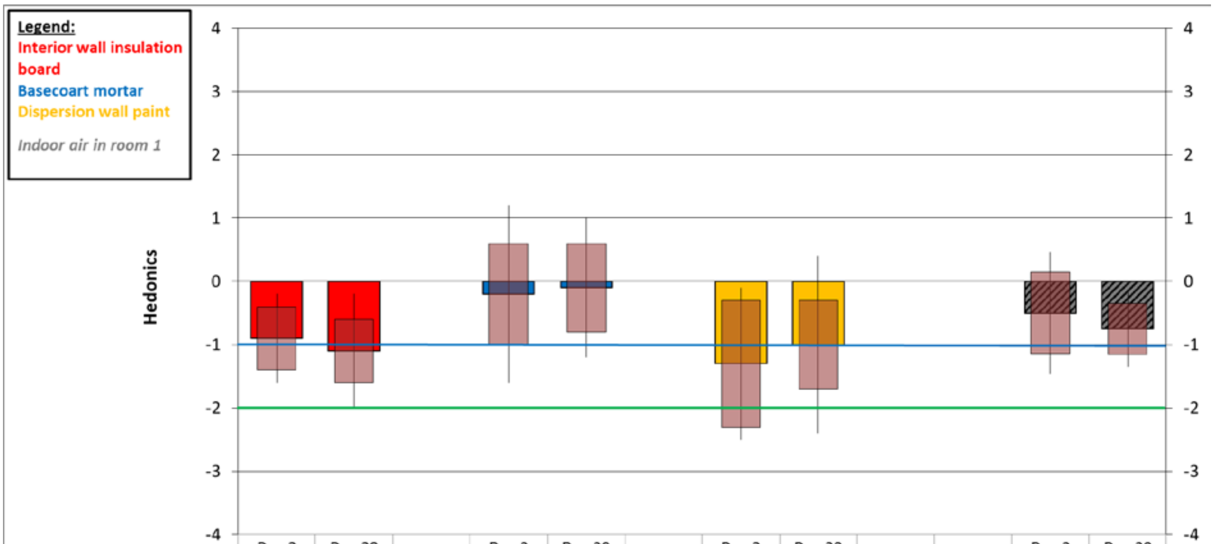
Figure 27: Product intensity in test room 1 (Bismarckplatz)



	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28
Intensity mean value	6.8	6.1	4.9	3.9	5.7	5.5	8.6	6.0
Half confidence interval	2.0	1.3	1.7	1.8	1.9	1.3	1.8	1.1
Temperature in °C	23.5	23.5	23.5	23.5	23.5	23.5	24.7	19.8
Relative humidity in %	50.0	50.0	50.0	50.0	50.0	50.0	77.5	63.0
Confidence interval min.	4.8	4.8	3.2	2.1	3.8	4.2	6.7	4.9
Standard deviation max.	9.5	8.6	8.1	6.4	8.0	8.1	11.3	7.3
Standard deviation min	4.1	3.6	1.7	1.4	3.4	2.9	5.8	4.7
Confidence interval max.	8.8	7.4	6.6	5.7	7.6	6.8	10.4	7.1

Figure 28 shows the assessment of product hedonics and room air from test room 1. There were no major differences between the results of day 3 and day 28. The products ‘interior wall insulation’ (red) and 'dispersion wall paint' (yellow) are close to the Blue Angel limit (-1) in accordance with the room air assessment. The assessment of basecoat mortar yielded values in the neutral range (approximately 0).

Figure 28: Product hedonics in test room 1 (Bismarckplatz)



	Day 3	Day 28		Day 3	Day 28		Day 3	Day 28		Day 3	Day 28
Hedonics mean value	-0.9	-1.1		-0.2	-0.1		-1.3	-1.0		-0.5	-0.8
Half confidence interval	0.5	0.5		0.8	0.7		1.0	0.7		0.6	0.4
Confidence interval min.	-1.4	-1.6		-1.0	-0.8		-2.3	-1.7		-1.1	-1.2
Standard deviation max.	-0.2	-0.2		1.2	1.0		-0.1	0.4		0.5	-0.2
Standard deviation min	-1.6	-2.0		-1.6	-1.2		-2.5	-2.4		-1.5	-1.3
Confidence interval max.	-0.4	-0.6		0.6	0.6		-0.3	-0.3		0.1	-0.3

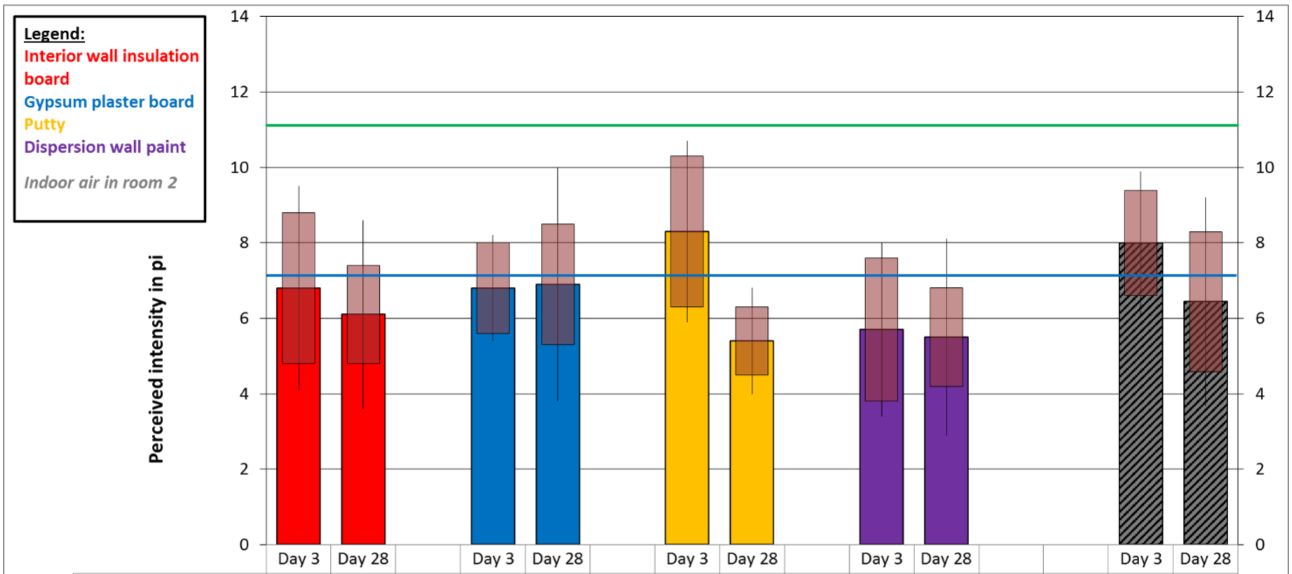
5.1.4.2 Products in test room 2

The following materials were placed in test room 2 and tested in the laboratory:

- Interior wall insulation board
- Gypsum plasterboard
- Putty
- Dispersion wall paint

Figure 29 shows the determined intensities. Here, too, it can be seen that the day 3 assessments of all products were under 7 pi except for putty (yellow). The intensity of putty (yellow) also improved towards day 28, so that all products met the proposed Blue Angel test value. The day 3 assessment of room air (grey) was 8 pi and had dropped by day 28 to approach 6 pi and was thus also within the value range of product assessments.

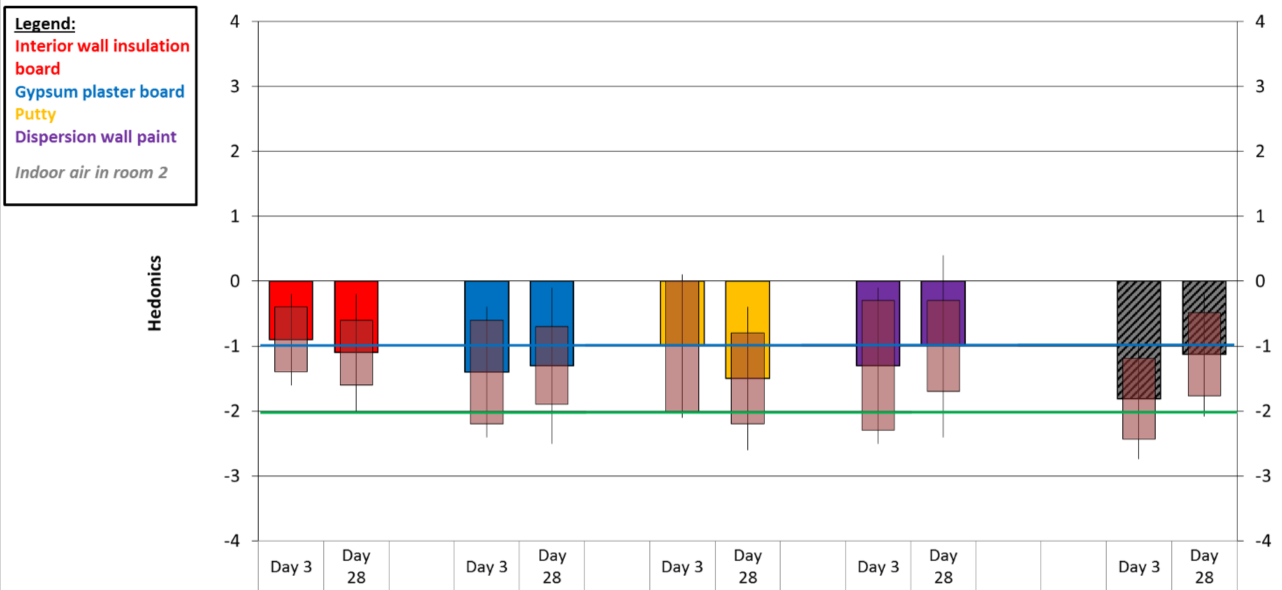
Figure 29: Product intensity in test room 2 (Bismarckplatz)



	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28		Day 3	Day 28
Intensity mean value	6.8	6.1	6.8	6.9	8.3	5.4	5.7	5.5		8.0	6.4
Half confidence interval	2.0	1.3	1.2	1.6	2.0	0.9	1.9	1.3		1.4	1.9
Temperature in °C	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5		23.5	21.8
Relative humidity in %	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0		71.0	65.6
Confidence interval min.	4.8	4.8	5.6	5.3	6.3	4.5	3.8	4.2		6.6	4.6
Standard deviation max.	9.5	8.6	8.2	10.0	10.7	6.8	8.0	8.1		9.9	9.2
Standard deviation min	4.1	3.6	5.4	3.8	5.9	4.0	3.4	2.9		6.1	3.7
Confidence interval max.	8.8	7.4	8.0	8.5	10.3	6.3	7.6	6.8		9.4	8.3

The hedonics assessments shown in Figure 30 were approximately the same. The room air assessment yielded a hedonics value of -1.8 on day 3 and -1.1 on day 28, i.e. it also was within the range of product assessments.

Figure 30: Product hedonics in test room 2 (Bismarckplatz)



	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28		Day 3	Day 28
Hedonics mean value	-0.9	-1.1	-1.4	-1.3	-1.0	-1.5	-1.3	-1.0		-1.8	-1.1
Half confidence interval	0.5	0.5	0.8	0.6	1.0	0.7	1.0	0.7		0.6	0.6
Confidence interval min.	-1.4	-1.6	-2.2	-1.9	-2.0	-2.2	-2.3	-1.7		-2.4	-1.8
Standard deviation max.	-0.2	-0.2	-0.4	-0.1	0.1	-0.4	-0.1	0.4		-0.9	-0.2
Standard deviation min	-1.6	-2.0	-2.4	-2.5	-2.1	-2.6	-2.5	-2.4		-2.7	-2.1
Confidence interval max.	-0.4	-0.6	-0.6	-0.7	0.0	-0.8	-0.3	-0.3		-1.2	-0.5

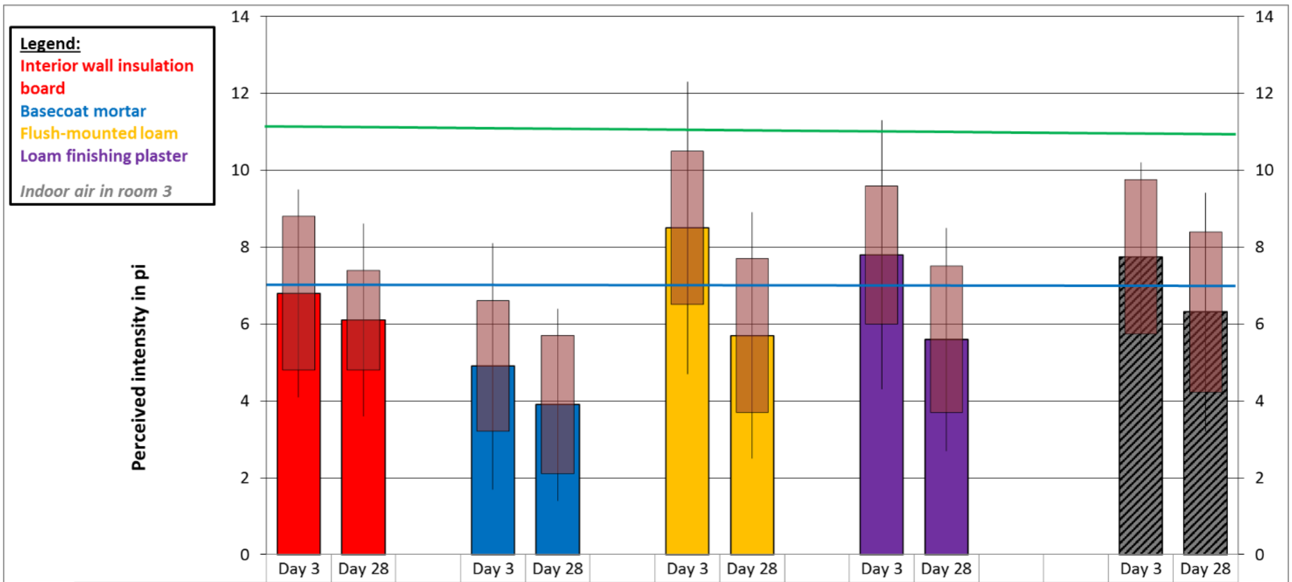
5.1.4.3 Products in test room 3

Test room 3 accommodated the following building materials:

- ► Interior wall insulation board
- ► Basecoat mortar
- ► Flush-mounted loam
- ► Loam finishing plaster

Figure 31 below shows the intensity assessments on day 3 and day 28. The insulation board (red) and the basecoat mortar (blue) exhibited low intensities as early as by day 3. However, the intensities of the loam products (yellow + purple) in this assembly were within the range of about 8 pi on day 3, which coincided with the room air assessment. During the test period the intensity of loam products and that of room air dropped to about 6 pi.

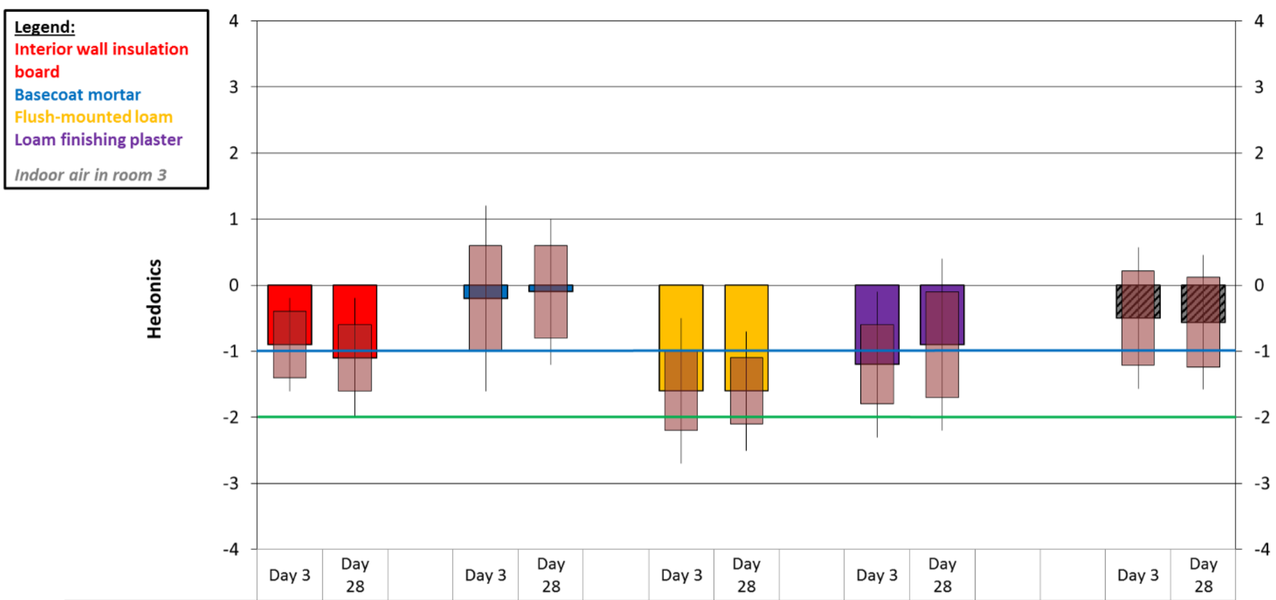
Figure 31: Product intensity in test room 3 (Bismarckplatz)



	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28
Intensity mean value	6.8	6.1	4.9	3.9	8.5	5.7	7.8	5.6	7.8	6.3
Half confidence interval	2.0	1.3	1.7	1.8	2.0	2.0	1.8	1.9	2.0	2.1
Temperature in °C	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	21.8
Relative humidity in %	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	77.9	50.2
Confidence interval min.	4.8	4.8	3.2	2.1	6.5	3.7	6.0	3.7	5.7	4.2
Standard deviation max.	9.5	8.6	8.1	6.4	12.3	8.9	11.3	8.5	10.2	9.4
Standard deviation min	4.1	3.6	1.7	1.4	4.7	2.5	4.3	2.7	5.3	3.2
Confidence interval max.	8.8	7.4	6.6	5.7	10.5	7.7	9.6	7.5	9.8	8.4

Figure 32 shows the hedonics assessment for test room 3. Hedonics of the loam finishing plaster remained unchanged (-1.6) until day 28 and was below the proposed test value for the AgBB requirements. The assessment of room air hedonics was somewhat better here than for loam products.

Figure 32: Product hedonics in test room 3 (Bismarckplatz)



	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28
Hedonics mean value	-0.9	-1.1	-0.2	-0.1	-1.6	-1.6	-1.2	-0.9	-0.5	-0.6
Half confidence interval	0.5	0.5	0.8	0.7	0.6	0.5	0.6	0.8	0.7	0.7
Confidence interval min.	-1.4	-1.6	-1.0	-0.8	-2.2	-2.1	-1.8	-1.7	-1.2	-1.2
Standard deviation max.	-0.2	-0.2	1.2	1.0	-0.5	-0.7	-0.1	0.4	0.6	0.5
Standard deviation min	-1.6	-2.0	-1.6	-1.2	-2.7	-2.5	-2.3	-2.2	-1.6	-1.6
Confidence interval max.	-0.4	-0.6	0.6	0.6	-1.0	-1.1	-0.6	-0.1	0.2	0.1

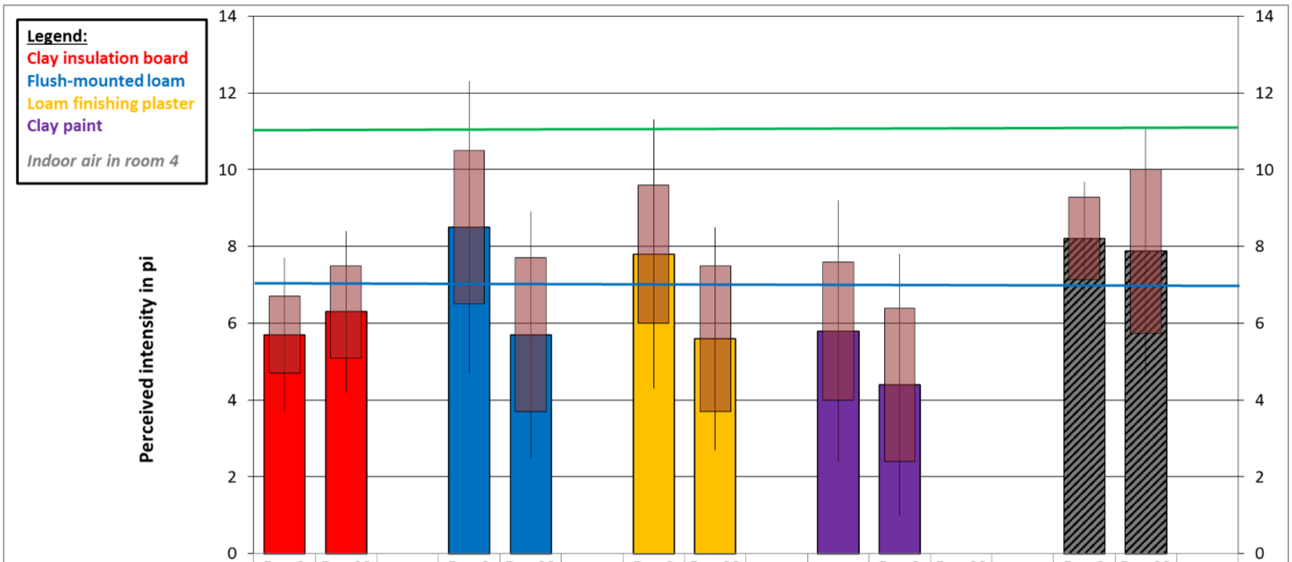
5.1.4.4 Products in test room 4

Test room 4 accommodated a large number of clay products:

- Clay wall insulation board
- Flush-mounted loam
- Loam finishing plaster
- Clay paint

As shown in Figure 33, intensities of the clay insulation board (red) and clay paint (purple) were less than 7 pi as early as by day 3. Loam plasters had slightly higher values (as explained in connection with the previous set-up). On test day 28, all product intensities were in the range between 4 and 6 pi while room air assessment still provided a value of about 8 pi. This can be explained by the higher relative humidity in the room during the test period.

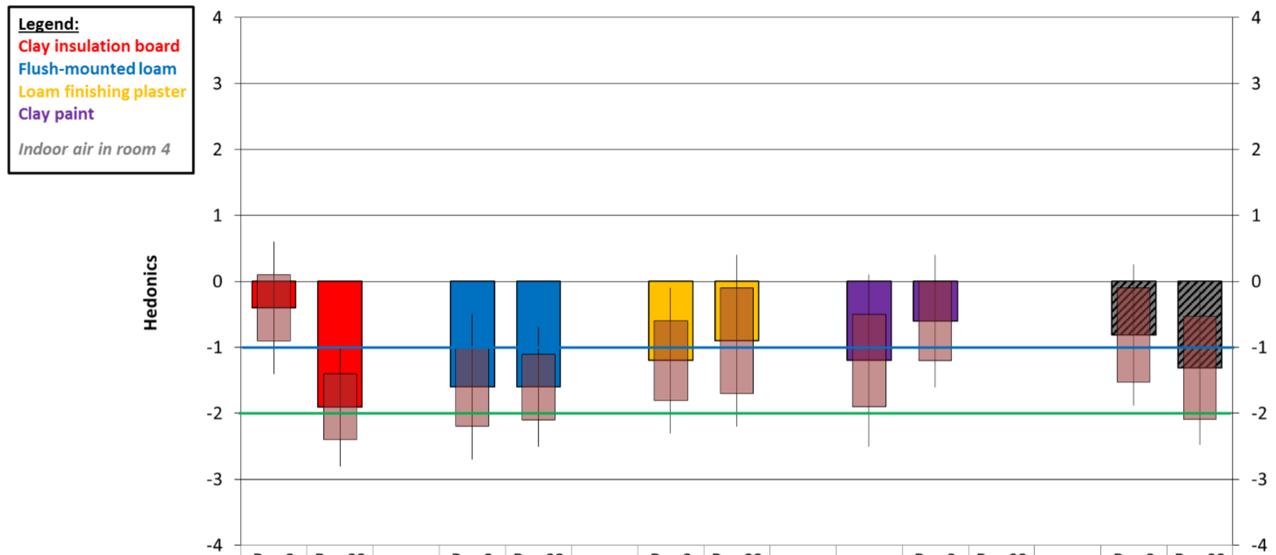
Figure 33: Product intensity in test room 4 (Bismarckplatz)



	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28		Day 3	Day 28	Day 3	Day 28
Intensity mean value	5.7	6.3	8.5	5.7	7.8	5.6	5.8	4.4		8.2	7.9
Half confidence interval	1.0	1.2	2.0	2.0	1.8	1.9	1.8	2.0		1.1	2.1
Temperature in °C	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5		24.0	22.7
Relative humidity in %	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0		76.0	51.5
Confidence interval min.	4.7	5.1	6.5	3.7	6.0	3.7	4.0	2.4		7.1	5.7
Standard deviation max.	7.7	8.4	12.3	8.9	11.3	8.5	9.2	7.8		9.7	11.1
Standard deviation min	3.7	4.2	4.7	2.5	4.3	2.7	2.4	1.0		6.7	4.7
Confidence interval max.	6.7	7.5	10.5	7.7	9.6	7.5	7.6	6.4		9.3	10.0

Figure 34 shows the results of hedonics assessments. Here, the difference between the assessments on clay insulation board on days 3 (-0.4) and 28 (-1.9) is conspicuous. The clay insulation board and the flush-mounted plaster met the proposed AgBB requirements on day 28, the loam finishing plaster and clay paint even met the Blue Angel test values. Room air hedonics had slightly deteriorated by day 28 compared to day 3.

Figure 34: Product hedonics in test room 4 (Bismarckplatz)



	Day 3	Day 28		Day 3	Day 28		Day 3	Day 28			Day 3	Day 28		Day 3	Day 28
Hedonics mean value	-0.4	-1.9		-1.6	-1.6		-1.2	-0.9		-1.2	-0.6			-0.8	-1.3
Half confidence interval	0.5	0.5		0.6	0.5		0.6	0.8		0.7	0.6			0.7	0.8
Confidence interval min.	-0.9	-2.4		-2.2	-2.1		-1.8	-1.7		-1.9	-1.2			-1.5	-2.1
Standard deviation max.	0.6	-1.0		-0.5	-0.7		-0.1	0.4		0.1	0.4			0.3	-0.1
Standard deviation min	-1.4	-2.8		-2.7	-2.5		-2.3	-2.2		-2.5	-1.6			-1.9	-2.5
Confidence interval max.	0.1	-1.4		-1.0	-1.1		-0.6	-0.1		-0.5	0.0			-0.1	-0.5

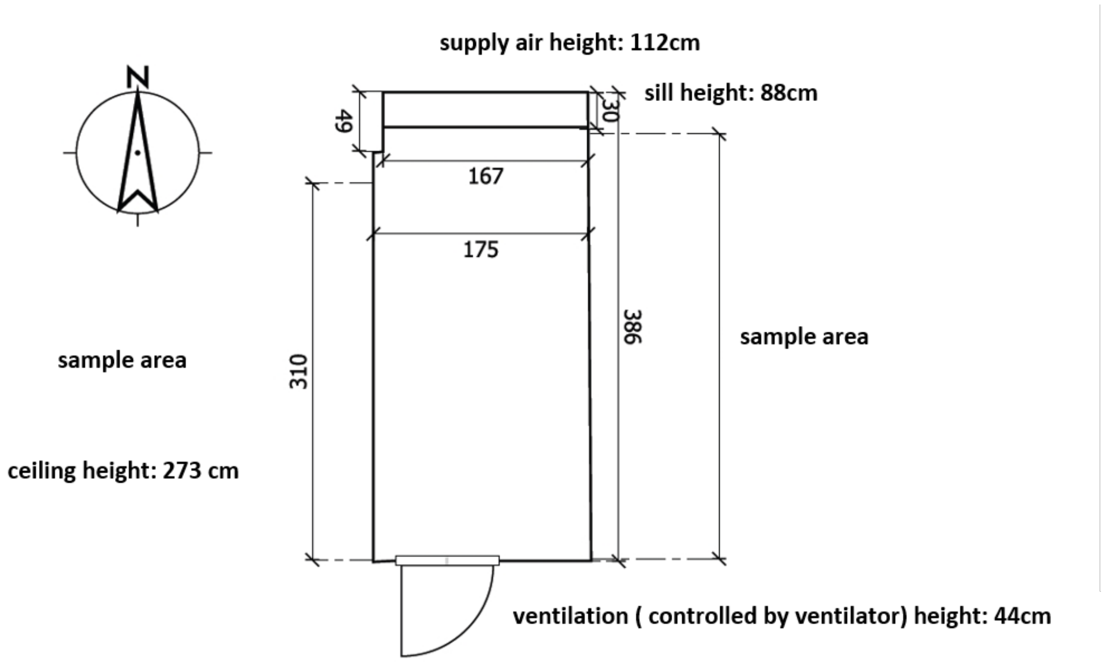
5.2 Test rooms of eco-INSTITUT in Cologne

5.2.1 Test description

Four different wall and floor assemblies were tested for their odour and chemicals emissions in this part of the project. For this purpose, the assemblies to be tested were placed into two identical test rooms at eco-INSTITUT in Cologne.

The volume of the two test rooms was 17.9 m^3. The load was identical in both test rooms: 1 m^2/m^3 and air exchange was adjusted to 0.5 h-1. The test rooms were not air-conditioned, which means that temperature and relative humidity could not be influenced.

Figure 35: Test room scheme of eco-INSTITUT (Kühn 2013)



The assemblies were always placed into the test rooms on a Friday. Test day 1 was the next Monday to allow the materials to dry. The room air was assessed directly in the room and also by using air sample containers (AirProbe) by eco-INSTITUT panellists on day 3 and 28. It should be noted that the eco-INSTITUT panel that performed this test series was different from the one that carried out the other tests described in this report. In parallel to the sensory-based evaluations, the eco-INSTITUT also performed the analytical tests.

In addition, the building materials used in the assemblies underwent sensory-based assessments individually and in combination in the HTW air quality laboratory. These assessments took place on day 3, day 7, day 14 and day 28 after placing the products into the laboratory and were performed by the HTW panel. An analytical evaluation of building materials was only carried out on day 28. For this purpose, air samples were taken which were then analysed by the eco-INSTITUT.

Finally, the assessments of the room air (test rooms) were compared with the assessments of the individual building products, or a combination of these.

Tables 5 and 6 below show the composition of the individual wall or floor assemblies as well as the test number of each individual product. Products that from experience do not have any odour impacts were not examined individually. The detailed results of the olfactory tests can be found in the Annex.

Table 5: Overview of wall assemblies at the eco-INSTITUT Cologne

Material	Wall assembly 1	Wall assembly 2	Wall assembly 3	Wall assembly 4
1	Insulation wool HTW 12.004	Special adhesive HTW 12.005	Mineral wool insulation board HTW 13.013	Spray plaster insulation boards HTW 13.020
2	Insulation board HTW 12.008	Plasterboard with EPS insulation HTW 12.003	Adhesive and base-coat mortar HTW 13.024	Adhesive and base-coat mortar HTW 13.026
3	Vapour barrier sheet HTW 13.004	Putty HTW 13.002	Lime felt plaster HTW 13.025	Universal primer HTW 13.027
4	Plasterboard HTW 12.007	Deep penetrating primer HTW 13.001		Float finish HTW 13.032
5	Putty HTW 13.002	Wall paint HTW 12.006		

Table 6: Overview of floor assemblies at the eco-INSTITUT Cologne

Material	Floor assembly 1	Floor assembly 2	Floor assembly 3	Floor assembly 4
1	Screed element *HTW 13.012*	Screed element *HTW 13.012*	Screed element *HTW 13.012*	Screed element *HTW 13.012*
2	Thin screed *HTW 13.028*	Wood levelling compound *HTW 13.021*	Adhesive primer *HTW 13.023*	Primer *HTW 13.031*
3	Linoleum covering *HTW 13.015*	Carpet/linoleum adhesive *HTW 13.019*	Tile filler *HTW 13.029*	Design floor *HTW 13.030*
4		PVC Design covering *HTW 13.014*	Parquet adhesive *HTW 13.022*	

5.2.2 Test assembly

This section describes the individual wall and floor assemblies in detail.

5.2.2.1 Wall assembly 1

Wall assembly 1 was a multi-layered wall assembly consisting of the following components:

- Insulation wool
- Insulation board

- Vapour barrier
- Gypsum plasterboard
- Putty

First, the primary insulation layer was applied and fastened to the wall underneath using a few screws. Metal studs were subsequently fastened to the ceiling and floor in a way that enabled the second installation to be mounted approximately 10 mm away from the first insulation layer. The vapour barrier film was applied to overlap on all sides and was secured tightly with adhesive tape. The plasterboards were screwed on and finally filled with putty over the entire surface. The components that were not examined were completely covered with odourless film to minimise their influence on the results. Figure 36 below shows images of the introduced assembly in the test room.

Figure 36: Photos of wall assembly 1 (Kühn 2013)

5.2.2.2 Wall assembly 2

Wall assembly 2 consisted of the following components:

- Special adhesive to apply composite boards
- Gypsum plasterboard composite panel with EPS insulation
- Putty
- Deep penetrating primer
- Wall paint

The composite boards were applied to the wall using individual adhesive points (special adhesive). Since the substrate (aluminium composite film) was not load-bearing, the composite boards were additionally fixed to the substrate with a few screws. After drying overnight, putty was then applied to the entire surface and painted with deep penetrating primer. Following a short drying time, two coats of interior silicate paint were applied. The components that were not examined were completely covered with odourless film to minimise their influence on the results. (Figure 37)

Figure 37: Photos of wall assembly 2 (Kühn 2013)

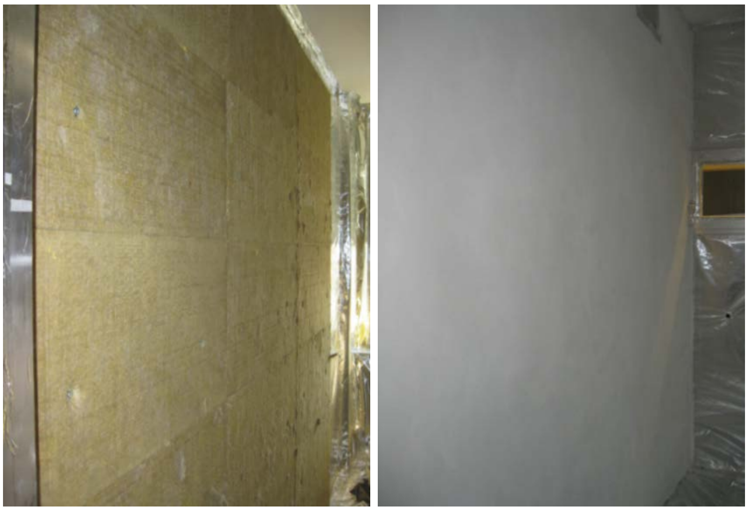
5.2.2.3 Wall assembly 3

Wall assembly 3 consisted of the following components:

- Mineral wool insulation board
- Adhesive and basecoat mortar
- Lime felt plaster

First, the mineral wool insulation board was applied and fastened to the wall underneath using a few screws. Reinforcing fabric was glued to the insulation panel using adhesive and basecoat mortar. After drying, the assembly was plastered with lime felt plaster.

Figure 38: Photos of wall assembly 3 (Kühn 2013)



5.2.2.4 Wall assembly 4

The following components were used in wall assembly 4:

- Prefabricated spray plaster insulation boards
- Adhesive and basecoat mortar

- Universal primer
- Float finish

The prefabricated spray plaster insulation boards were screwed to the wall underneath, followed by the application of coarse-meshed reinforcing fabric with adhesive and basecoat mortar. Universal primer was applied after drying and covered with a float finish. The components that were not examined were completely covered with odourless film to minimise their influence on the results.

Figure 39: Photos of wall assembly 4 (Kühn 2013)

5.2.2.5 Floor assembly 1

Floor assembly 1 manufactured in the test room consisted of the following products:

- Screed element
- Thin screed
- Linoleum covering

Figure 40: Photo of floor assembly 1 (Kühn 2013)

5.2.2.6 Floor assembly 2

Floor assembly 2 was composed of the following materials:

- Screed element
- Wood levelling compound
- Carpet/linoleum adhesive
- PVC design covering

Figure 41: Photo of floor assembly 2 (Kühn 2013)

5.2.2.7 Floor assembly 3

Floor assembly 3 was a multi-layered assembly consisting of the following components:

- Screed element
- Adhesive primer
- Tile putty
- Parquet adhesive

The following image shows the finished floor assembly in the test room.

Figure 42: Photo of floor assembly 3 (Kühn 2013)

5.2.2.8 Floor assembly 4

Floor assembly 4 was composed of the following products:

- Screed element
- Primer
- Design floor

Figure 43: Photo of floor assembly 4 (Kühn 2013)

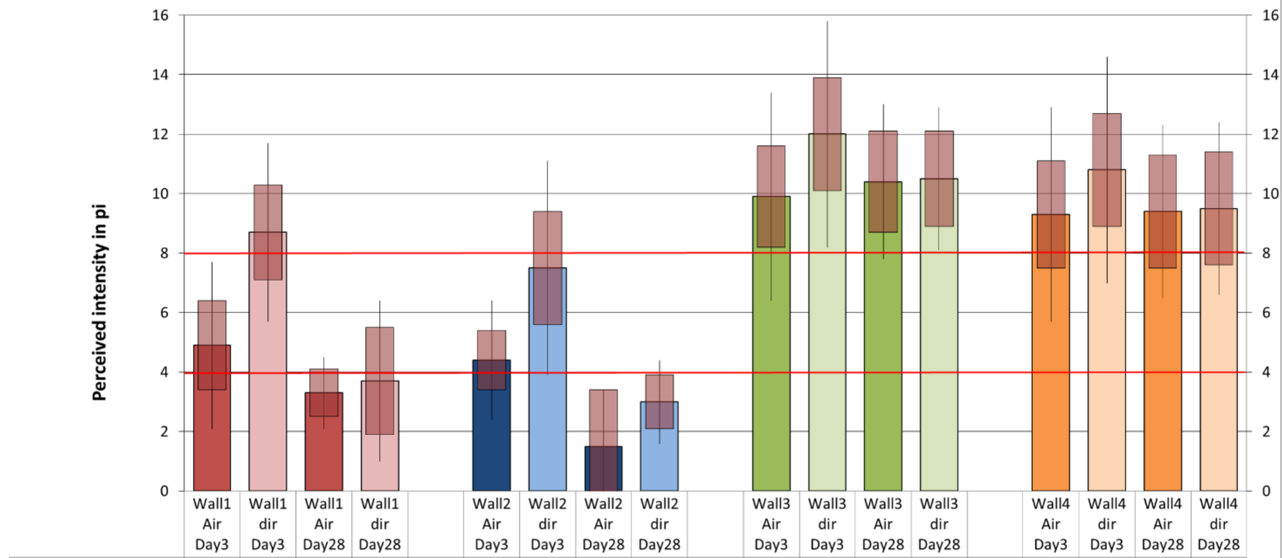
5.2.3 Indoor air measurements

The olfactory assessment of the room air in the test rooms was carried out by the eco-INSTITUT Cologne, for which they used their own test panel. The assessment was carried out both through sampling (AirProbe) and directly. The results of the assemblies are compared with each other in the following diagrams.

5.2.3.1 Wall assemblies

Figure 44 below shows the perceived intensities of the room air assessments of the various wall assemblies. Assessments were carried out on day 3 and day 28 after completing the test assemblies. The dark shaded bars show the results of the sampling (Air) while the lighter bars show the results of direct assessment in the room (dir).

Figure 44: Intensity of indoor air measurements for wall assemblies



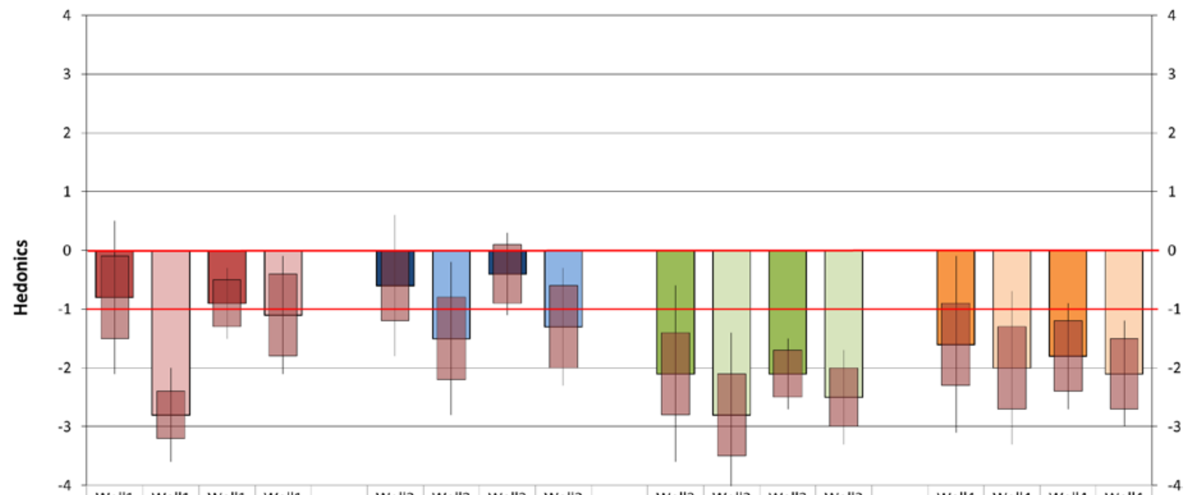
	Wall1 Air Day3	Wall1 dir Day3	Wall1 Air Day28	Wall1 dir Day28	Wall2 Air Day3	Wall2 dir Day3	Wall2 Air Day28	Wall2 dir Day28	Wall3 Air Day3	Wall3 dir Day3	Wall3 Air Day28	Wall3 dir Day28	Wall4 Air Day3	Wall4 dir Day3	Wall4 Air Day28	Wall4 dir Day28
Mean value	4.9	8.7	3.3	3.7	4.4	7.5	1.5	3.0	9.9	12.0	10.4	10.5	9.3	10.8	9.4	9.5
Half confindence interval	1.5	1.6	0.8	1.8	1.0	1.9	1.9	0.9	1.7	1.9	1.7	1.6	1.8	1.9	1.9	1.9
Temperature in °C	23.5	23.5	19.9	19.9	23.5	23.5	19.8	19.8	19.2	19.2	18.8	18.8	19.3	19.3	18.7	18.7
Relative humidity in %	51	51	44	44	51	51	43	43	73	73	41	41	92	92	71	71
Confidence interval min.	3.4	7.1	2.5	1.9	3.4	5.6	-0.4	2.1	8.2	10.1	8.7	8.9	7.5	8.9	7.5	7.6
Standard deviation max.	7.7	11.7	4.5	6.4	6.4	11.1	2.4	4.4	13.4	15.8	13.0	12.9	12.9	14.6	12.3	12.4
Standard deviation min.	2.1	5.7	2.1	1.0	2.4	3.9	0.6	1.6	6.4	8.2	7.8	8.1	5.7	7.0	6.5	6.6
Confidence interval max.	6.4	10.3	4.1	5.5	5.4	9.4	3.4	3.9	11.6	13.9	12.1	12.1	11.1	12.7	11.3	11.4

At first glance the representation singles out a slightly bigger difference between the direct (dir) and the indirect (Air) assessment for wall assemblies 1 and 2 on day 3. The direct method assessed the intensity as somewhat higher. It must be taken into account that the odour assessments at the eco-INSTITUT had just been introduced and the filling and provision of the air in the sample containers also had to be tested. These differences no longer occurred in later measurements (wall assemblies 3 and 4 and following).

Furthermore, it is also noticeable that in the case of wall assemblies 1 (red) and 2 (blue), the intensities decreased during the course of the test period and were within the good room air quality range on day 28. However, in the case of wall assemblies 3 (green) and 4 (orange), there was no detectable decrease in intensity, which is why they still showed a poor room air quality on day 28. In addition, very high humidity could in part be detected in these assemblies on the test days, which influenced the assessments.

Figure 45 below paints a similar picture. Wall assemblies 3 and 4 only had assessments in the poor quality range.

Figure 45: Hedonics of indoor air measurements for wall assemblies

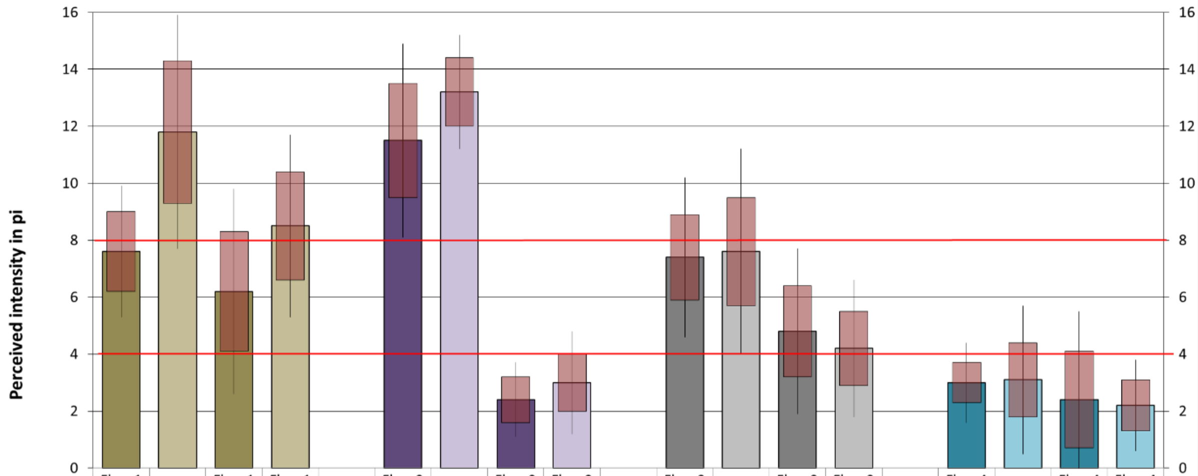


	Wall1 Air Day3	Wall1 dir Day3	Wall1 Air Day28	Wall1 dir Day28	Wall2 Air Day3	Wall2 dir Day3	Wall2 Air Day28	Wall2 dir Day28	Wall3 Air Day3	Wall3 dir Day3	Wall3 Air Day28	Wall3 dir Day28	Wall4 Air Day3	Wall4 dir Day3	Wall4 Air Day28	Wall4 dir Day28
Mean value	-0.8	-2.8	-0.9	-1.1	-0.6	-1.5	-0.4	-1.3	-2.1	-2.8	-2.1	-2.5	-1.6	-2.0	-1.8	-2.1
Half confindence interval	0.7	0.4	0.4	0.7	0.6	0.7	0.5	0.7	0.7	0.7	0.4	0.5	0.7	0.7	0.6	0.6
Temperature in °C	23.5	23.5	19.9	19.9	23.5	23.5	19.8	19.8	19.2	19.2	18.8	18.8	19.3	19.3	18.7	18.7
Relative humidity in %	51	51	44	44	51	51	43	43	73	73	41	41	92	92	71	71
Confidence interval min.	-1.5	-3.2	-1.3	-1.8	-1.2	-2.2	-0.9	-2.0	-2.8	-3.5	-2.5	-3.0	-2.3	-2.7	-2.4	-2.7
Standard deviation max.	0.5	-2.0	-0.3	-0.1	0.6	-0.2	0.3	-0.3	-0.6	-1.4	-1.5	-1.7	-0.1	-0.7	-0.9	-1.2
Standard deviation min.	-2.1	-3.6	-1.5	-2.1	-1.8	-2.8	-1.1	-2.3	-3.6	-4.2	-2.7	-3.3	-3.1	-3.3	-2.7	-3.0
Confidence interval max.	-0.1	-2.4	-0.5	-0.4	0.0	-0.8	0.1	-0.6	-1.4	-2.1	-1.7	-2.0	-0.9	-1.3	-1.2	-1.5

5.2.3.2 Floor assemblies

The following illustration (Figure 46) shows the assessments of the perceived intensity of the floor assemblies. The strong drop in intensity between day 3 and day 28 stands out for floor assembly 2 (purple). Assemblies 1 and 3 showed a slight decrease in the intensities throughout the test period. Floor assembly 4 (light blue) shows very low intensities in the good quality range as early as by day 3 after the materials were placed into the test room.

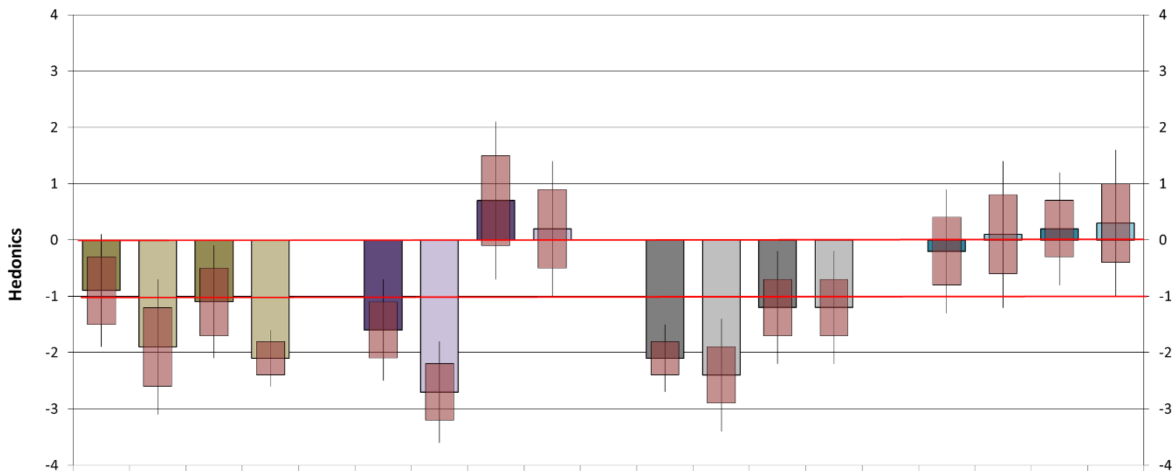
Figure 46: Intensity of indoor air measurements for floor assemblies



	Floor1 Air Day3	Floor1 dir Day3	Floor1 Air Day28	Floor1 dir Day28	Floor2 Air Day3	Floor2 dir Day3	Floor2 Air Day28	Floor2 dir Day28	Floor3 Air Day3	Floor3 dir Day3	Floor3 Air Day28	Floor3 dir Day28	Floor4 Air Day3	Floor4 dir Day3	Floor4 Air Day28	Floor4 dir Day28
Mean value	7.6	11.8	6.2	8.5	11.5	13.2	2.4	3.0	7.4	7.6	4.8	4.2	3.0	3.1	2.4	2.2
Half confidence interval	1.4	2.5	2.1	1.9	2.0	1.2	0.8	1.0	1.5	1.9	1.6	1.3	0.7	1.3	1.7	0.9
Temperature in °C	16	16	18.1	18.1	17.9	17.9	19.5	19.5	17.6	17.6	22.3	22.3	17.6	17.6	20.8	20.8
Relative humidity in %	37	37	41	41	36	36	38	38	36	36	21	21	42	42	29	29
Confidence interval min.	6.2	9.3	4.1	6.6	9.5	12.0	1.6	2.0	5.9	5.7	3.2	2.9	2.3	1.8	0.7	1.3
Standard deviation max.	9.9	15.9	9.8	11.7	14.9	15.2	3.7	4.8	10.2	11.2	7.7	6.6	4.4	5.7	5.5	3.8
Standard deviation min.	5.3	7.7	2.6	5.3	8.1	11.2	1.1	1.2	4.6	4.0	1.9	1.8	1.6	0.5	-0.7	0.6
Confidence interval max.	9.0	14.3	8.3	10.4	13.5	14.4	3.2	4.0	8.9	9.5	6.4	5.5	3.7	4.4	4.1	3.1

The assessment results of the hedonics are shown in Figure 47. Same as for intensity, floor assembly 2 (purple) showed a strong improvement over the course of the test period. Once again, it must be noted that the temperature and humidity of the test rooms were outside the normal range. (ISO 16000-28 2012)

Figure 47: Hedonics of indoor air measurements for floor assemblies



	Floor1 Air Day3	Floor1 dir Day3	Floor1 Air Day28	Floor1 dir Day28	Floor2 Air Day3	Floor2 dir Day3	Floor2 Air Day28	Floor2 dir Day28	Floor3 Air Day3	Floor3 dir Day3	Floor3 Air Day28	Floor3 dir Day28	Floor4 Air Day3	Floor4 dir Day3	Floor4 Air Day28	Floor4 dir Day28
Mean value	-0.9	-1.9	-1.1	-2.1	-1.6	-2.7	0.7	0.2	-2.1	-2.4	-1.2	-1.2	-0.2	0.1	0.2	0.3
Half confidence interval	0.6	0.7	0.6	0.3	0.5	0.5	0.8	0.7	0.3	0.5	0.5	0.5	0.6	0.7	0.5	0.7
Temperature in °C	16	16	18.1	18.1	17.9	17.9	19.5	19.5	17.6	17.6	22.3	22.3	17.6	17.6	20.8	20.8
Relative humidity in %	37	37	41	41	36	36	38	38	36	36	21	21	42	42	29	29
Confidence interval min.	-1.5	-2.6	-1.7	-2.4	-2.1	-3.2	-0.1	-0.5	-2.4	-2.9	-1.7	-1.7	-0.8	-0.6	-0.3	-0.4
Standard deviation max.	0.1	-0.7	-0.1	-1.6	-0.7	-1.8	2.1	1.4	-1.5	-1.4	-0.2	-0.2	0.9	1.4	1.2	1.6
Standard deviation min.	-1.9	-3.1	-2.1	-2.6	-2.5	-3.6	-0.7	-1.0	-2.7	-3.4	-2.2	-2.2	-1.3	-1.2	-0.8	-1.0
Confidence interval max.	-0.3	-1.2	-0.5	-1.8	-1.1	-2.2	1.5	0.9	-1.8	-1.9	-0.7	-0.7	0.4	0.8	0.7	1.0

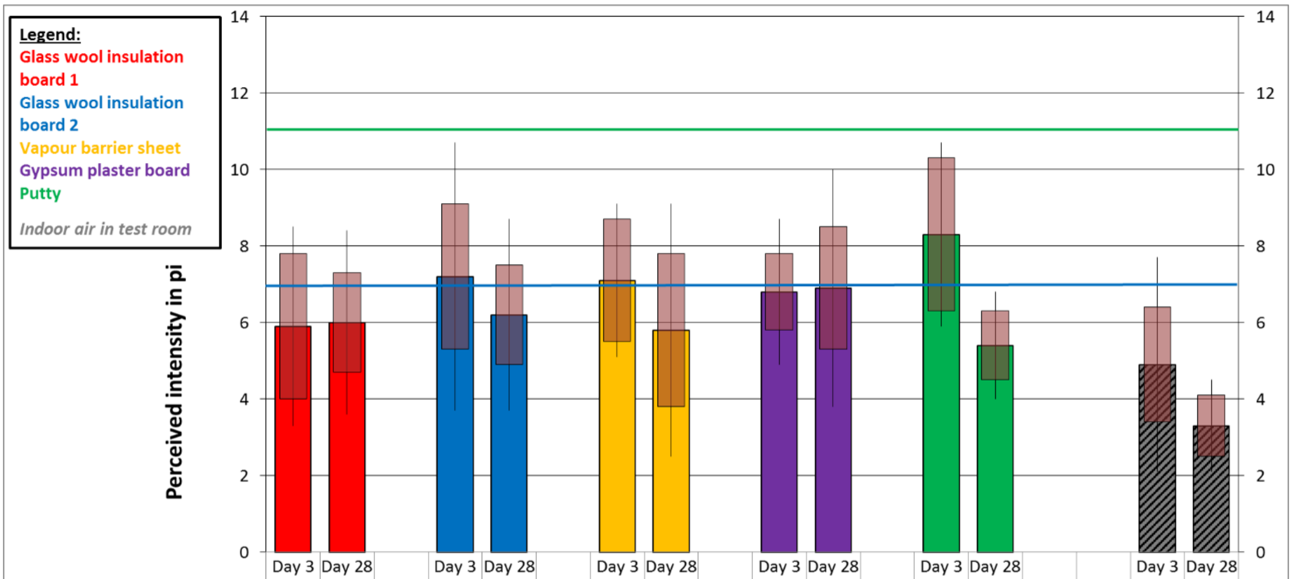
5.2.4 Product tests

This section analyses the products used for the individual assemblies from an olfactory and analytical perspective. If technically possible, the combination of the individual products were also placed into the emission chamber and assessed. The subsequent evaluations in the illustrations also present the corresponding results from the indoor air measurement (Section 5.2.3) and compare them with the results of the product tests. In addition, the figures regarding intensity also show temperature and relative humidity because these are in part different in the indoor air measurements than in the emission chambers. The individual results of the product tests can be found in the Annex.

5.2.4.1 Wall assembly 1

The following illustrations compare the results from the assessments of the room air and the individual tests of the applied building materials. Due to material thicknesses, a combination of the individual products could not be placed into CLIMPAQ and therefore could not be tested. Figure 48 lists the assessments from day 3 and day 28 after the placement of the material.

Figure 48: Intensity for wall assembly 1 (eco)

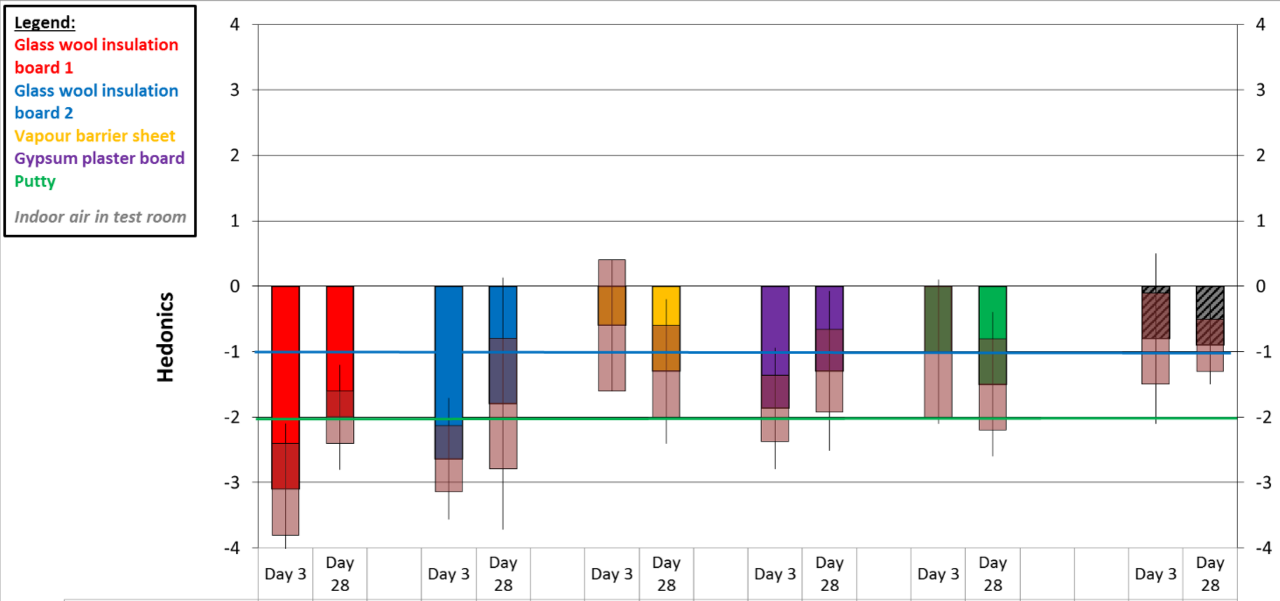


	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28
Intensity mean value	5.9	6.0	7.2	6.2	7.1	5.8	6.8	6.9	8.3	5.4	4.9	3.3
Half confidence interval	1.9	1.3	1.9	1.3	1.6	2.0	1.0	1.6	2.0	0.9	1.5	0.8
Temperature in °C	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	19.9
Relative humidity in %	50	50	50	50	50	50	50	50	50	50	51	44
Confidence interval min.	4.0	4.7	5.3	4.9	5.5	3.8	5.8	5.3	6.3	4.5	3.4	2.5
Standard deviation max.	8.5	8.4	10.7	8.7	9.1	9.1	8.7	10.0	10.7	6.8	7.7	4.5
Standard deviation min	3.3	3.6	3.7	3.7	5.1	2.5	4.9	3.8	5.9	4.0	2.1	2.1
Confidence interval max.	7.8	7.3	9.1	7.5	8.7	7.8	7.8	8.5	10.3	6.3	6.4	4.1

When comparing the intensities in Figure 48, it is noticeable that the assessed room air from the test room (black/grey hatching) yielded somewhat lower values than the individual intensities of the applied building products. However, it must once again be pointed out that the tests were carried out at different locations (Cologne and Berlin) and with different groups of panellists. Furthermore, it can be established that all products used for this assembly were rated under the proposed Blue Angel test value (< 7 pi) on day 28.

The assessment of the hedonics in Figure 49 paints a similar picture. The room air is also perceived to be the most pleasant in this case. On day 28, all products reached the proposed AgBB scheme criterion (green line) but were above the Blue Angel (blue line) test value.

Figure 49: Hedonics for wall assembly 1 (eco)



	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28
Hedonics mean value	-3.1	-2.0	-2.6	-1.8	-0.6	-1.3	-1.9	-1.3	-1.0	-1.5	-0.8	-0.9
Half confidence interval	0.7	0.4	0.5	1.0	1.0	0.7	0.5	0.6	1.0	0.7	0.7	0.4
Confidence interval min.	-3.8	-2.4	-3.1	-2.8	-1.6	-2.0	-2.4	-1.9	-2.0	-2.2	-1.5	-1.3
Standard deviation max.	-2.1	-1.2	-1.7	0.1	0.4	-0.2	-0.9	-0.1	0.1	-0.4	0.5	-0.3
Standard deviation min	-4.1	-2.8	-3.6	-3.7	-1.6	-2.4	-2.8	-2.5	-2.1	-2.6	-2.1	-1.5
Confidence interval max.	-2.4	-1.6	-2.1	-0.8	0.4	-0.6	-1.4	-0.7	0.0	-0.8	-0.1	-0.5

Table 7 below shows a summary of the analytical test results of the room air for this assembly. In this assembly, the individual products were not tested analytically. The detailed test reports can be viewed in the Annex.

Table 7: Analysis for wall assembly 1 (Kühn 2013)

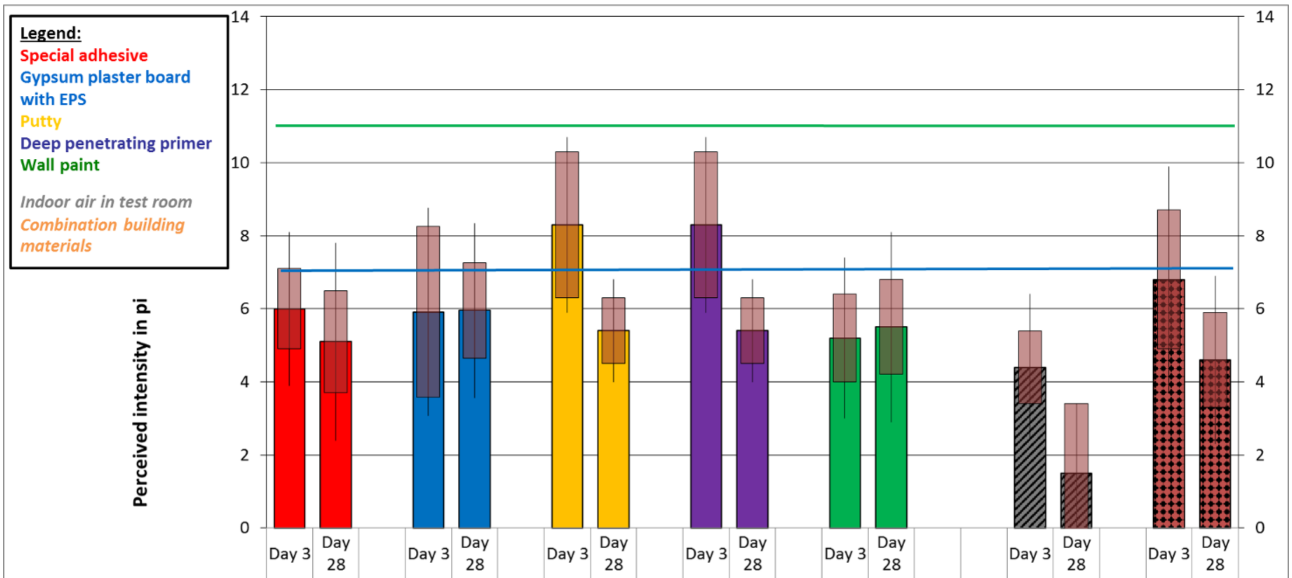
Detected substances	CAS No.	Day 3 Concentration in µg/m³	Day 28 Concentration in µg/m³
TVOC		13	2
Toluene	108-88-3	5	2
Styrene	100-42-5	8	n. d.
Formaldehyde	50-00-0	30	11
Acetaldehyde	75-07-0	15	10

The detected compounds decreased over time.

5.2.4.2 Wall assembly 2

Figure 50 below shows the perceived intensities for wall assembly 2.

Figure 50: Intensity for wall assembly 2 (eco)

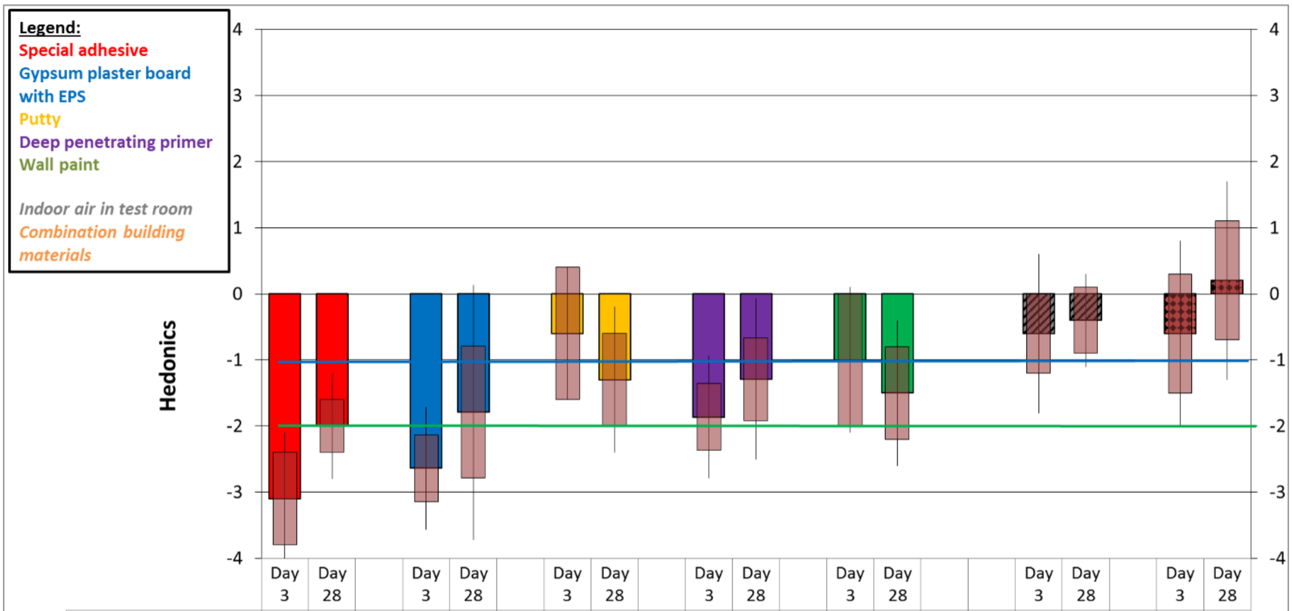


	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28
Intensity mean value	6.0	5.1	5.9	6.0	8.3	5.4	8.3	5.4	5.2	5.5	4.4	1.5	6.8	4.6
Half confidence interval	1.1	1.4	2.3	1.3	2.0	0.9	2.0	0.9	1.2	1.3	1.0	1.9	1.9	1.3
Temperature in °C	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	19.8	23.5	23.5
Relative humidity in %	50	50	50	50	50	50	50	50	50	50	51	43	50	50
Confidence interval min.	4.9	3.7	3.6	4.6	6.3	4.5	6.3	4.5	4.0	4.2	3.4	-0.4	4.9	3.3
Standard deviation max.	8.1	7.8	8.8	8.3	10.7	6.8	10.7	6.8	7.4	8.1	6.4	2.4	9.9	6.9
Standard deviation min	3.9	2.4	3.1	3.6	5.9	4.0	5.9	4.0	3.0	2.9	2.4	0.6	3.7	2.3
Confidence interval max.	7.1	6.5	8.2	7.3	10.3	6.3	10.3	6.3	6.4	6.8	5.4	3.4	8.7	5.9

Here, the very low assessment value of the room air (black/grey hatching) is noticeable. In addition to the individual products, this assembly was also assessed as a combination of all individual products. The intensity of the combination (red/black chequered) was approximately in the same range as the assessment of the individual products on day 28. On day 3, the intensity from the putty (yellow) and deep penetrating primer (purple) was somewhat higher than that from the combination.

In the hedonics assessment (Figure 51 below), the combination of the individual products on day 28 showed the best assessment and it was even in the positive range. The values of the test room air were also perceived as more pleasant than those of the individual products. The products “putty” (yellow) and “wall paint” (green) were perceived as somewhat more unpleasant after a prolonged stay in the emission chamber.

Figure 51: Hedonics for wall assembly 2 (eco)



	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28
Hedonics mean value	-3.1	-2.0	-2.6	-1.8	-0.6	-1.3	-1.9	-1.3	-1.0	-1.5	-0.6	-0.4	-0.6	0.2
Half confidence interval	0.7	0.4	0.5	1.0	1.0	0.7	0.5	0.6	1.0	0.7	0.6	0.5	0.9	0.9
Confidence interval min.	-3.8	-2.4	-3.1	-2.8	-1.6	-2.0	-2.4	-1.9	-2.0	-2.2	-1.2	-0.9	-1.5	-0.7
Standard deviation max.	-2.1	-1.2	-1.7	0.1	0.4	-0.2	-0.9	-0.1	0.1	-0.4	0.6	0.3	0.8	1.7
Standard deviation min	-4.1	-2.8	-3.6	-3.7	-1.6	-2.4	-2.8	-2.5	-2.1	-2.6	-1.8	-1.1	-2.0	-1.3
Confidence interval max.	-2.4	-1.6	-2.1	-0.8	0.4	-0.6	-1.4	-0.7	0.0	-0.8	0.0	0.1	0.3	1.1

Table 8 below summarises the results of the analytical tests for this assembly. In addition to the room air, the combination of the individual products was also tested analytically in the CLIMPAQ (on day 28). The detailed test reports can be viewed in the Annex.

Table 8: Analysis for wall assembly 2 (Kühn 2013)

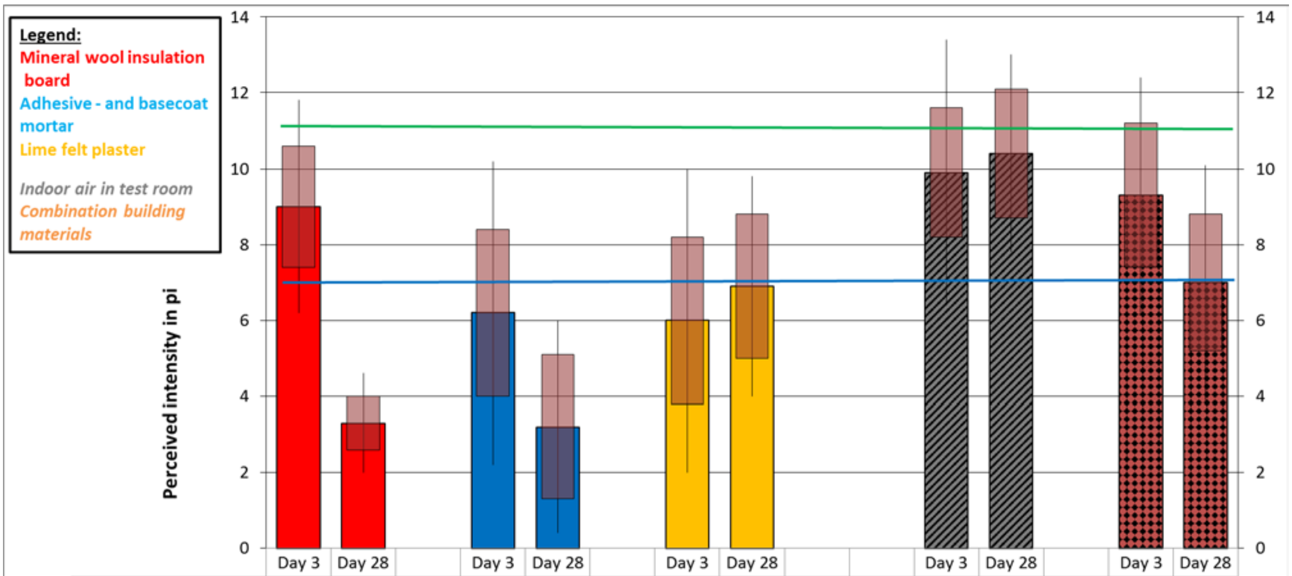
Detected substances	CAS No.	Room air Day 3 Concentration in µg/m³	Room air Day 28 Concentration in µg/m³	Combination Day 28 Concentration in µg/m³
TVOC		96	125	47
Toluene	108-88-3	10	9	1
Styrene	100-42-5	11	80	31
1-Butanol	71-36-3	25	5	n. d.
Formaldehyde	50-00-0	16	13	n. a.
Acetaldehyde	75-07-0	13	10	n. a.

A large number of volatile organic compounds were detected in very low concentrations. The concentration of 1-butanol decreased towards day 28 while the concentration of styrene noticeably increased. The concentration from the combination of individual products had slightly lower values compared to the room air.

5.2.4.3 Wall assembly 3

Figure 52 below compares the intensities determined for this assembly.

Figure 52: Intensities for wall assembly 3 (eco)

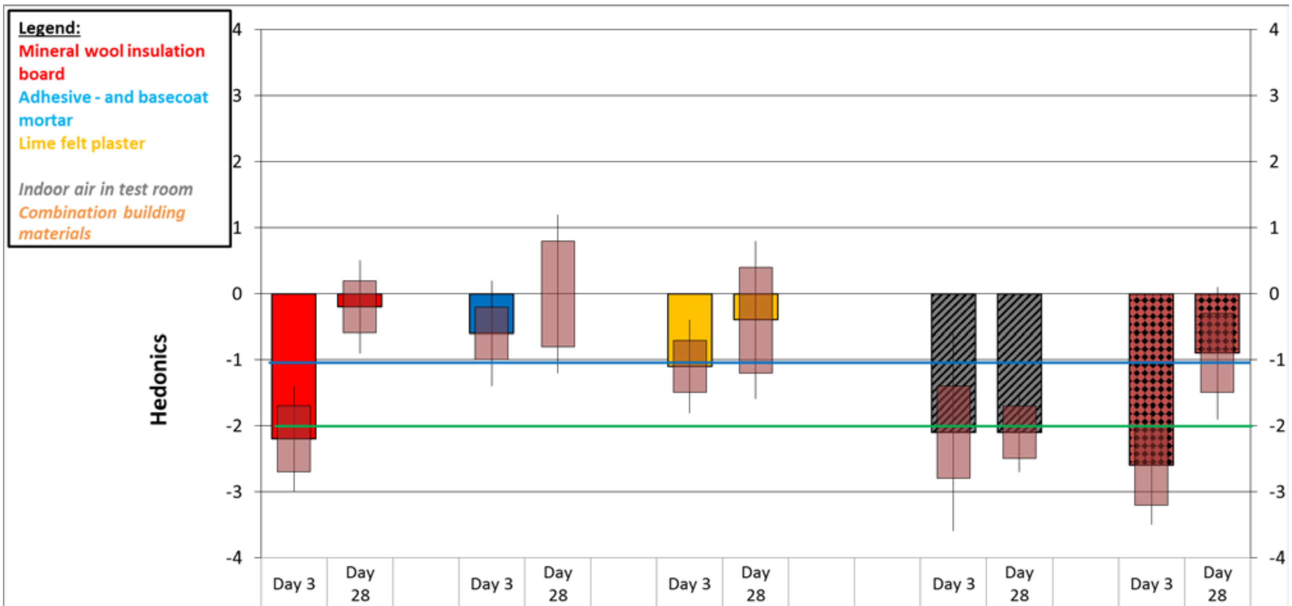


	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28
Intensity mean value	9.0	3.3	6.2	3.2	6.0	6.9	9.9	10.4	9.3	7.0
Half confidence interval	1.6	0.7	2.2	1.9	2.2	1.9	1.7	1.7	1.9	1.8
Temperature in °C	23.5	23.5	23.5	23.5	23.5	23.5	19.2	18.8	23.5	23.5
Relative humidity in %	50	50	50	50	50	50	73	41	50	50
Confidence interval min.	7.4	2.6	4.0	1.3	3.8	5.0	8.2	8.7	7.4	5.2
Standard deviation max.	11.8	4.6	10.2	6.0	10.0	9.8	13.4	13.0	12.4	10.1
Standard deviation min	6.2	2.0	2.2	0.4	2.0	4.0	6.4	7.8	6.2	3.9
Confidence interval max.	10.6	4.0	8.4	5.1	8.2	8.8	11.6	12.1	11.2	8.8

Here the room air assessment showed the highest intensities. It is noticeable that the temperature and humidity values were in the unfavourable range. The intensity of the combination was in the same range as the mineral wool insulation board (red) on day 3. On day 28, the assessment of the combination was comparable to the intensity of the top layer (yellow). The assessments of the individual products and of the combination were all below the Blue Angel proposed test value (blue line) on day 28.

The same can be observed for hedonics in Figure 53 below. The room air here was also found to be very unpleasant. The combination of building products was of a similar level on day 3, but was assessed as being much more pleasant over time.

Figure 53: Hedonics for wall assembly 3 (eco)



	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28
Hedonics mean value	-2.2	-0.2	-0.6	0.0	-1.1	-0.4	-2.1	-2.1	-2.6	-0.9
Half confidence interval	0.5	0.4	0.4	0.8	0.4	0.8	0.7	0.4	0.6	0.6
Confidence interval min.	-2.7	-0.6	-1.0	-0.8	-1.5	-1.2	-2.8	-2.5	-3.2	-1.5
Standard deviation max.	-1.4	0.5	0.2	1.2	-0.4	0.8	-0.6	-1.5	-1.7	0.1
Standard deviation min	-3.0	-0.9	-1.4	-1.2	-1.8	-1.6	-3.6	-2.7	-3.5	-1.9
Confidence interval max.	-1.7	0.2	-0.2	0.8	-0.7	0.4	-1.4	-1.7	-2.0	-0.3

Table 9 below shows a summary of the analytical test for this assembly. The detailed test reports can be viewed in the Annex.

Table 9: Analysis for wall assembly 3 (Kühn 2013)

Detected substances Concentration in µg/m³	Room air		Mineral wool 13.013	Basecoat mortar 13.024	Lime felt plaster 13.024	Combination
	Day 3	Day 28	Day 28	Day 28	Day 28	Day 28
TVOC	164	41	4	11	9	23
Toluene	12	3	n. d.	1	n. d.	2
Styrene	7	4	n. d.	n. d.	n. d.	n. d.
Methylcyclohexane	16	2	n. d.	n. d.	n. d.	n. d.
Hexanal	30	8	n. d.	n. d.	n. d.	3
Formaldehyde	8	12	n. a.	n. a.	n. a.	n. a.
Acetaldehyde	34	12	n. a.	n. a.	n. a.	n. a.

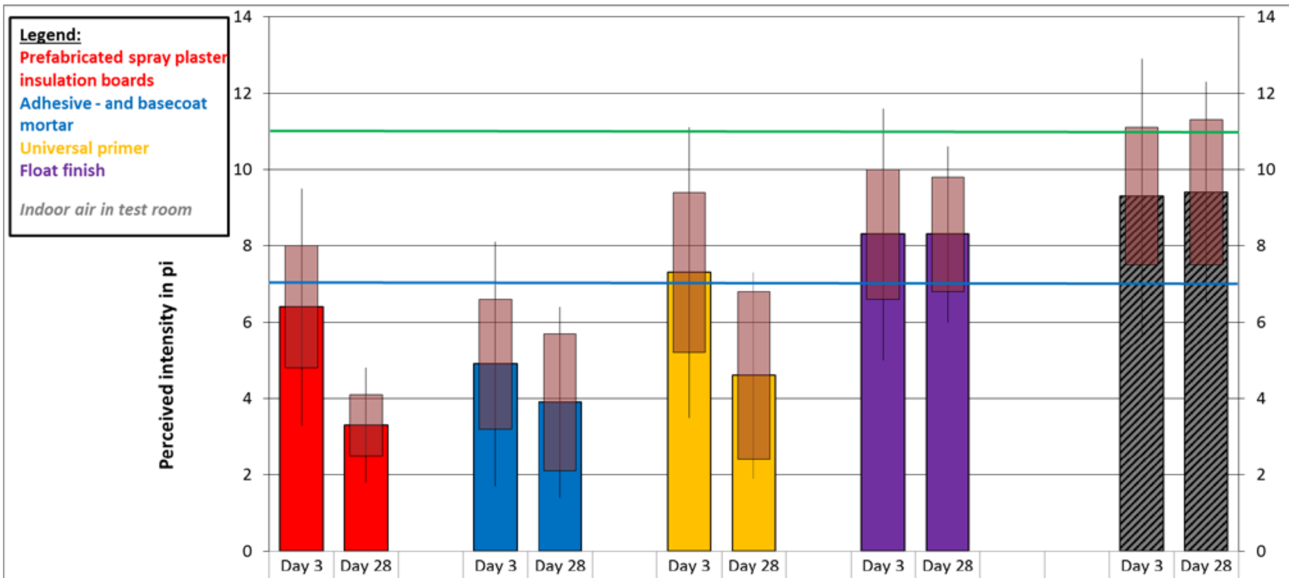
CAS No.: Toluene 108-88-3, styrene 100-42-5, methylcyclohexane 108-87-2, hexanal 66-25-1, formaldehyde 50-00-0, acetaldehyde 75-07-0

A large number of volatile organic compounds were detected in very low concentrations. Toluene, styrene, methylcyclohexane and hexanal were most frequently present but their concentrations decreased during the test. The analytical tests of the individual products only detected very low or non-detectable (n. d.) concentrations in the emission chambers on day 28. In general, the individual products only emitted very small amounts of compounds.

5.2.4.4 Wall assembly 4

Figure 54 shows that the intensity of the room air was found to be slightly higher than the intensities of the individual products. However, very high moisture values were again detected during the test. The float finish (purple) exhibited the highest intensity among the individual products: it was 8.3 pi which was below the suggested AgBB scheme test value. The three other products had an intensity well below 7 pi, thus fulfilling the Blue Angel criterion.

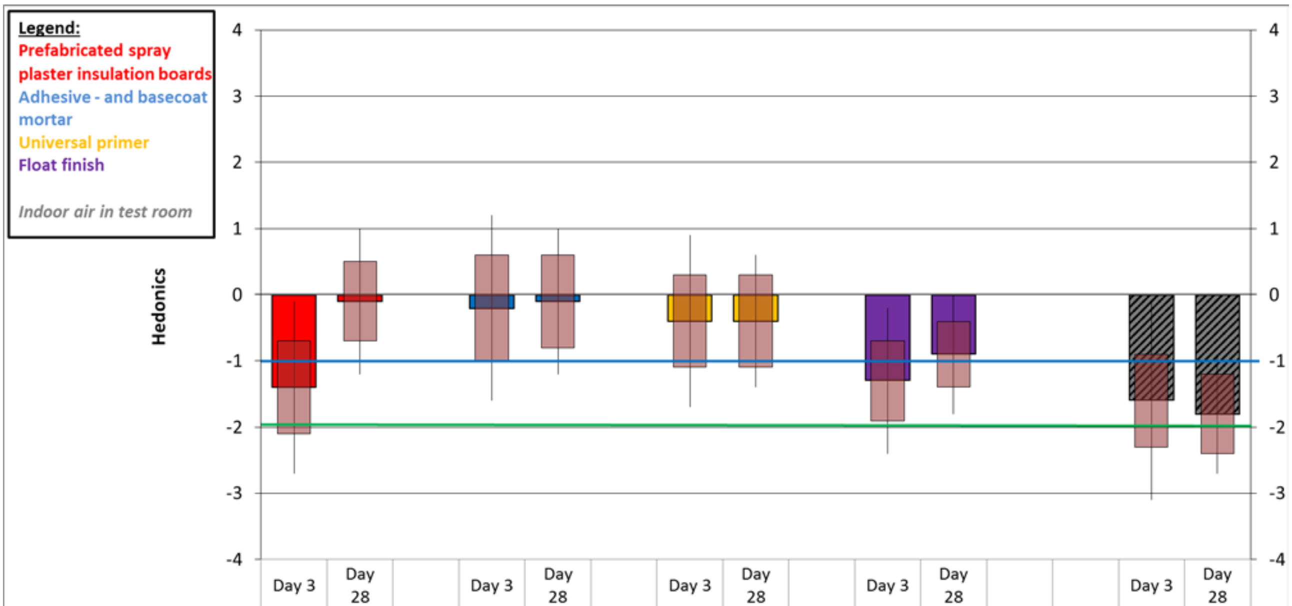
Figure 54: Intensity for wall assembly 4 (eco)



	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28
Intensity mean value	6.4	3.3	4.9	3.9	7.3	4.6	8.3	8.3	9.3	9.4
Half confidence interval	1.6	0.8	1.7	1.8	2.1	2.2	1.7	1.5	1.8	1.9
Temperature in °C	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	19.3	18.7
Relative humidity in %	50	50	50	50	50	50	50	50	92	71
Confidence interval min.	4.8	2.5	3.2	2.1	5.2	2.4	6.6	6.8	7.5	7.5
Standard deviation max.	9.5	4.8	8.1	6.4	11.1	7.3	11.6	10.6	12.9	12.3
Standard deviation min	3.3	1.8	1.7	1.4	3.5	1.9	5.0	6.0	5.7	6.5
Confidence interval max.	8.0	4.1	6.6	5.7	9.4	6.8	10.0	9.8	11.1	11.3

Figure 55 below shows the hedonics assessments. Here too, the room air displayed the worst results, which may be due to the high relative humidity of the room air as already mentioned. On the other hand, all individual products met the Blue Angel criterion on day 28.

Figure 55: Hedonics for wall assembly 4 (eco)



	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28
Hedonics mean value	-1.4	-0.1	-0.2	-0.1	-0.4	-0.4	-1.3	-0.9	-1.6	-1.8
Half confidence interval	0.7	0.6	0.8	0.7	0.7	0.7	0.6	0.5	0.7	0.6
Confidence interval min.	-2.1	-0.7	-1.0	-0.8	-1.1	-1.1	-1.9	-1.4	-2.3	-2.4
Standard deviation max.	-0.1	1.0	1.2	1.0	0.9	0.6	-0.2	0.0	-0.1	-0.9
Standard deviation min	-2.7	-1.2	-1.6	-1.2	-1.7	-1.4	-2.4	-1.8	-3.1	-2.7
Confidence interval max.	-0.7	0.5	0.6	0.6	0.3	0.3	-0.7	-0.4	-0.9	-1.2

Table 10 below summarises the results of the analytical tests for this assembly. The detailed test reports can be viewed in the Annex.

Table 10: Analysis for wall assembly 4 (Kühn 2013)

Detected substances (in µg/m³)	Room air		Basecoat mortar 13.026	Primer 13.024	Float finish 13.032
	Day 3	Day 28	Day 28	Day 28	Day 28
TVOC	194	97	6	10	3
Toluene	14	4	n. d.	n. d.	n. d.
Styrene	18	40	n. d.	n. d.	n. d.
Limonene	1	15	n. d.	n. d.	n. d.
Cyclohexanol	29	5	n. d.	n. d.	n. d.
2-Ethyl-1-hexanol	61	2	n. d.	4	n. d.
Hexanal	14	5	n. d.	n. d.	n. d.
Formaldehyde	8	11	n. a.	n. a.	n. a.
Acetaldehyde	50	22	n. a.	n. a.	n. a.

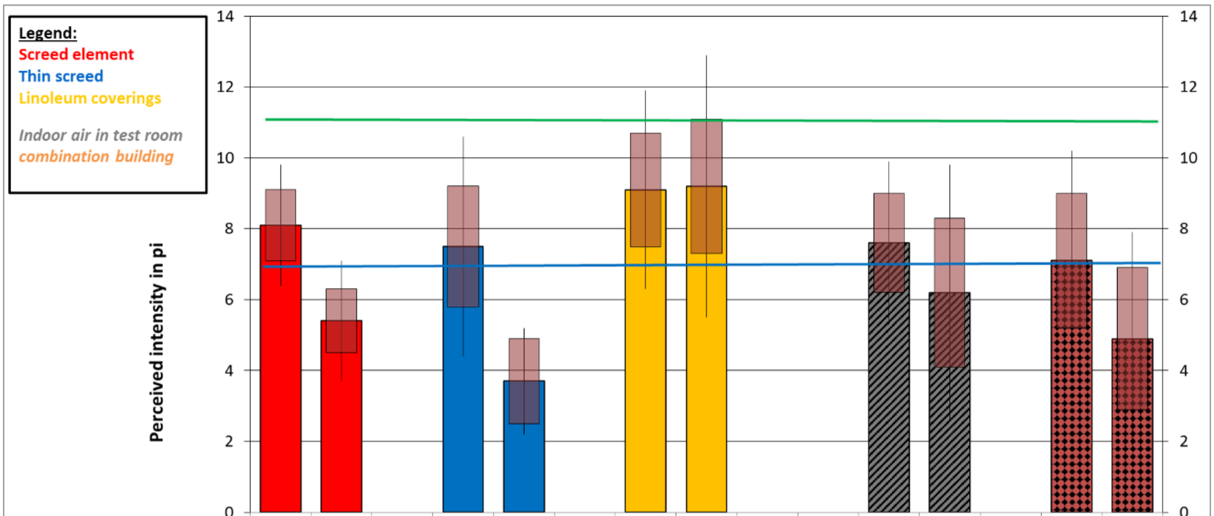
CAS No.: Toluene 108-88-3, styrene 100-42-5, limonene 138-86-3, cyclohexanol 108-93-0, 2-ethyl-1-hexanol 104-76-7, hexanal 66-25-1, formaldehyde 50-00-0, acetaldehyde 75-07-0

A large number of volatile organic compounds were detected in very low concentrations in the room air. The compounds with the highest concentrations are listed in Table 10. While most concentrations decreased over time, those of styrene, limonene and formaldehyde increased slightly. These concentrations were not detected in connection with the individual products analysed.

5.2.4.5 Floor assembly 1

Figure 56 below shows a comparison of the intensities for floor structure 1. It should be noted that the combination of the individual products was assessed without including linoleum, this is why it was approximately in the same range of values as the two products 'screed element' (red) and 'thin screed' (blue). Linoleum was placed as the top assembly layer in the test room, which had a stronger intensity of approximately 9 pi than the other two products. On day 28, the screed element (red) and the thin screed (blue) were below the recommended Blue Angel test value. Linoleum (yellow) failed to show any decrease in odour intensity during the test period. This product only fulfils the recommended AgBB scheme test value (cf. Chapter 3.1.5).

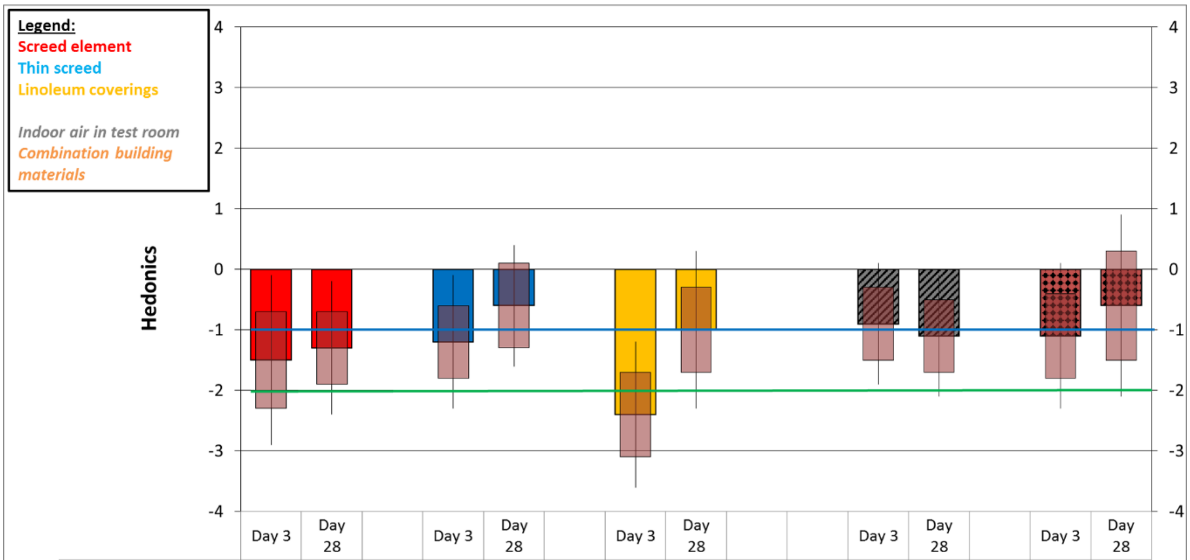
Figure 56: Intensity for floor assembly 1 (eco)



	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28
Intensity mean value	8.1	5.4	7.5	3.7	9.1	9.2	7.6	6.2	7.1	4.9
Half confidence interval	1.0	0.9	1.7	1.2	1.6	1.9	1.4	2.1	1.9	2.0
Temperature in °C	23.5	23.5	23.5	23.5	23.5	23.5	16.0	18.1	23.5	23.5
Relative humidity in %	50	50	50	50	50	50	37	41	50	50
Confidence interval min.	7.1	4.5	5.8	2.5	7.5	7.3	6.2	4.1	5.2	2.9
Standard deviation max.	9.8	7.1	10.6	5.2	11.9	12.9	9.9	9.8	10.2	7.9
Standard deviation min	6.4	3.7	4.4	2.2	6.3	5.5	5.3	2.6	4.0	1.9
Confidence interval max.	9.1	6.3	9.2	4.9	10.7	11.1	9.0	8.3	9.0	6.9

Figure 57 shows the hedonics assessments for floor assembly 1. The linoleum covering yielded a poor value with -2.4 on day 3, which was not detected in the assessment of the room air (-0.9). On day 28, the values of the top layer (linoleum) were in the same range as the assessment of the room air (about -1).

Figure 57: Hedonics for floor assembly 1 (eco)



	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28
Hedonics mean value	-1.5	-1.3	-1.2	-0.6	-2.4	-1.0	-0.9	-1.1	-1.1	-0.6
Half confidence interval	0.8	0.6	0.6	0.7	0.7	0.7	0.6	0.6	0.7	0.9
Confidence interval min.	-2.3	-1.9	-1.8	-1.3	-3.1	-1.7	-1.5	-1.7	-1.8	-1.5
Standard deviation max.	-0.1	-0.2	-0.1	0.4	-1.2	0.3	0.1	-0.1	0.1	0.9
Standard deviation min	-2.9	-2.4	-2.3	-1.6	-3.6	-2.3	-1.9	-2.1	-2.3	-2.1
Confidence interval max.	-0.7	-0.7	-0.6	0.1	-1.7	-0.3	-0.3	-0.5	-0.4	0.3

Linoleum is particularly conspicuous in the analytical assessment for this floor assembly (see Table 11).

Table 11: Analysis for floor assembly 1 (Kühn 2013)

Detected substances (in µg/m³)[1]	Room air		Thin screed 13.028	Linoleum 13.015	Combination (without linoleum)
	Day 3	Day 28	Day 28	Day 28	Day 28
TVOC	163	64	22	261	23
Acetic acid	41	22	n. d.	88	n. d.
Propionic acid	16	6	n. d.	35	n. d.
n-Capronic acid	15	5	n. d.	26	n. d.
n-Octanoic acid	7	3	n. d.	26	n. d.

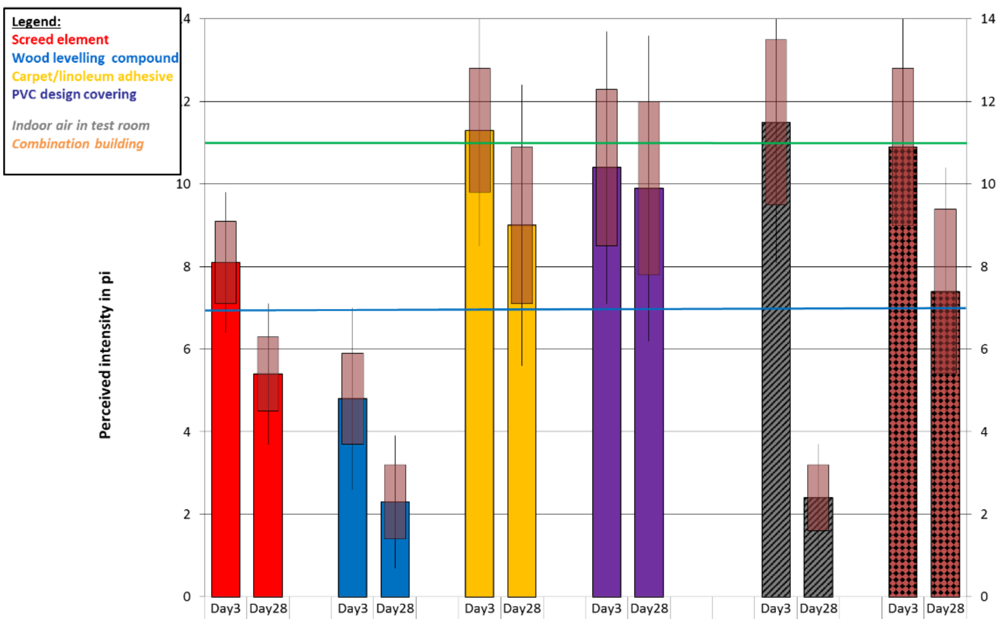
All compounds detected in the room air decreased over time. Linoleum yielded comparatively high emissions. Since other products and their combinations (without linoleum) hardly had any emissions, it can be assumed that the volatile organic compounds in the test room mainly originated from the top layer i.e. linoleum.

[1] CAS No.: Acetic acid 64-19-7, propionic acid 79-09-4, n-capronic acid 142-62-1, n-octanoic acid 124-07-2

5.2.4.6 Floor assembly 2

Figure 58 shows the intensities for floor assembly 2. Again, it should be noted that the assessment of the combination was performed without including a PVC covering. Nevertheless, the combination provided a value above the Blue Angel test value, matching the values of carpet/linoleum adhesive i.e. this assembly's top layer. The considerable drop in the intensity of the test room air (cf. Chapter 5.2.3), as already mentioned in the indoor air tests, cannot be explained even when compared to the building products. It should be assumed that the PVC covering displays a similar value since the same material was also used in the test room. However, such a low intensity of 2.4 pi is rather unlikely in this case, therefore it must have been a measurement error in the assessment of the room air on day 28.

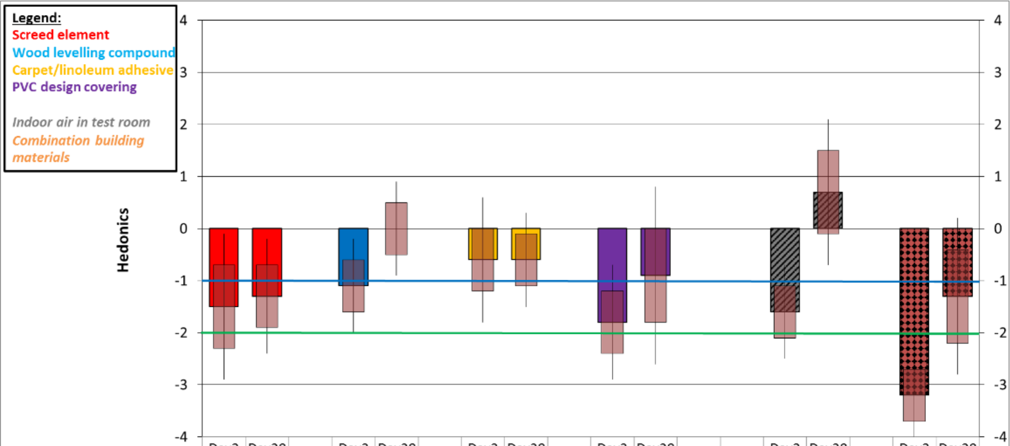
Figure 58: Intensity for floor assembly 2 (eco)



	Day3	Day28	Day3	Day28	Day3	Day28	Day3	Day28	Day3	Day28	Day3	Day28
Intensity mean value	8.1	5.4	4.8	2.3	11.3	9.0	10.4	9.9	11.5	2.4	10.9	7.4
Half confidence interval	1.0	0.9	1.1	0.9	1.5	1.9	1.9	2.1	2.0	0.8	1.9	2.0
Temperature in °C	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	17.9	19.5	23.5	23.5
Relative humidity in %	50	50	50	50	50	50	50	50	36	38	50	50
Confidence interval min.	7.1	4.5	3.7	1.4	9.8	7.1	8.5	7.8	9.5	1.6	9.0	5.4
Standard deviation max.	9.8	7.1	7.0	3.9	14.1	12.4	13.7	13.6	14.9	3.7	14.0	10.4
Standard deviation min	6.4	3.7	2.6	0.7	8.5	5.6	7.1	6.2	8.1	1.1	7.8	4.4
Confidence interval max.	9.1	6.3	5.9	3.2	12.8	10.9	12.3	12.0	13.5	3.2	12.8	9.4

Figure 59 shows the hedonics assessments of the floor assembly. Again, the good value of the room air on day 28 does not match other results, which indicates an assumed measurement error (in accordance with intensity). Furthermore, it is noticeable that the combination (red/black chequered) was found somewhat more unpleasant than the building product "carpet/linoleum adhesive" (yellow) on its surface.

Figure 59: Hedonics for floor assembly 2 (eco)



	Day3	Day28	Day3	Day28	Day3	Day28	Day3	Day28	Day3	Day28	Day3	Day28
Hedonics mean value	-1.5	-1.3	-1.1	0.0	-0.6	-0.6	-1.8	-0.9	-1.6	0.7	-3.2	-1.3
Half confidence interval	0.8	0.6	0.5	0.5	0.6	0.5	0.6	0.9	0.5	0.8	0.5	0.9
Confidence interval min.	-2.3	-1.9	-1.6	-0.5	-1.2	-1.1	-2.4	-1.8	-2.1	-0.1	-3.7	-2.2
Standard deviation max.	-0.1	-0.2	-0.2	0.9	0.6	0.3	-0.7	0.8	-0.7	2.1	-2.4	0.2
Standard deviation min	-2.9	-2.4	-2.0	-0.9	-1.8	-1.5	-2.9	-2.6	-2.5	-0.7	-4.0	-2.8
Confidence interval max.	-0.7	-0.7	-0.6	0.5	0.0	-0.1	-1.2	0.0	-1.1	1.5	-2.7	-0.4

The table below shows the results of the analytical assessment.

Table 12: Analysis for floor assembly 2 (Kühn 2013)

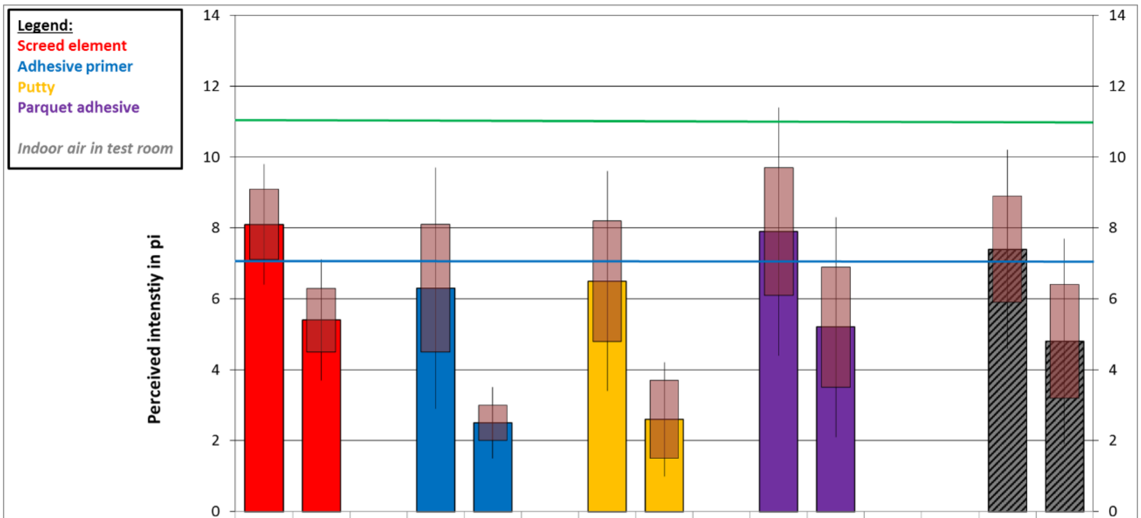
Detected sub-stances (in µg/m³)	CAS No.	Room air		PVC covering 13.014	Combination (without PVC covering)
		Day 3	Day 28	Day 28	Day 28
TVOC		92	14	19	8
Naphthalene	91-20-3	16	2	10	n.d.
Formaldehyde	50-00-0	6	<3	n.a.	n.a.
Acetaldehyde	75-07-0	13	<3	n.a.	n.a.

Very low concentrations of some volatile organic compounds were detected in the room air of the test room. Only naphthalene was more noticeable in this case and was also detected in the PVC coating. However, this compound was not detected in the combination of individual products (without PVC covering). It is therefore safe to assume that this compound was emitted from the PVC coating.

5.2.4.7 Floor assembly 3

Figure 60 below compares the perceived intensities for this assembly.

Figure 60: Intensity for floor assembly 3 (eco)

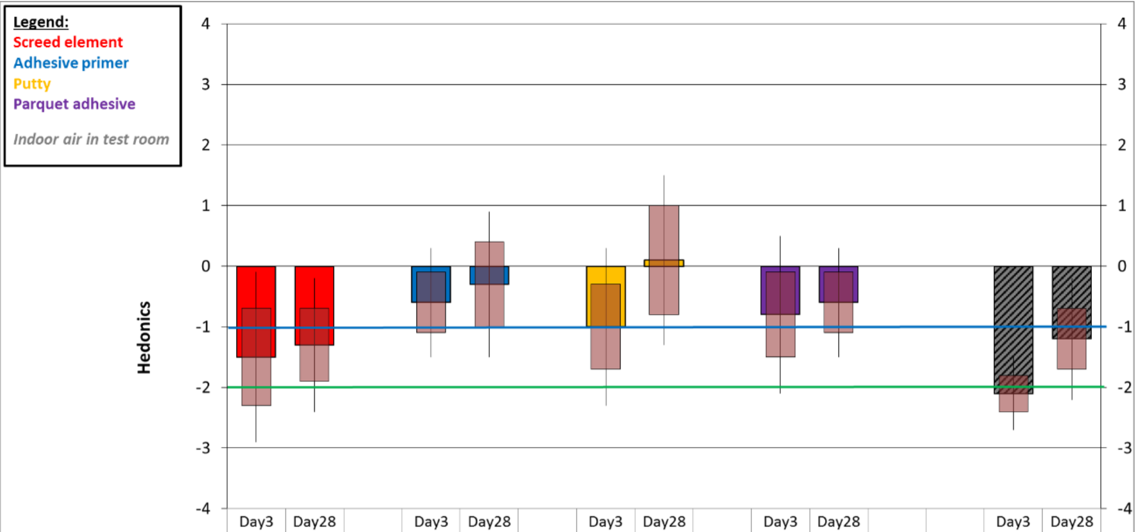


	Day3	Day28	Day3	Day28	Day3	Day28	Day3	Day28	Day3	Day28
Intensity mean value	8.1	5.4	6.3	2.5	6.5	2.6	7.9	5.2	7.4	4.8
Half confidence interval	1.0	0.9	1.8	0.5	1.7	1.1	1.8	1.7	1.5	1.6
Temperature in °C	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	17.6	22.3
Relative humidity in %	50	50	50	50	50	50	50	50	36	21
Confidence interval min.	7.1	4.5	4.5	2.0	4.8	1.5	6.1	3.5	5.9	3.2
Standard deviation max.	9.8	7.1	9.7	3.5	9.6	4.2	11.4	8.3	10.2	7.7
Standard deviation min	6.4	3.7	2.9	1.5	3.4	1.0	4.4	2.1	4.6	1.9
Confidence interval max.	9.1	6.3	8.1	3.0	8.2	3.7	9.7	6.9	8.9	6.4

The figure shows that all intensities on day 28 were distinctly lower than on day 3 and thus fulfil the Blue Angel criteria. The intensity of the test room air (grey/black) lay in the range of the product "parquet adhesive" (purple).

Figure 61 shows the hedonics assessments. The room air was rated slightly poorer than the topmost product (purple). Except for the screed element (red), all individual products used adhered to the Blue Angel test value.

Figure 61: Hedonics for floor assembly 3 (eco)



	Day3	Day28	Day3	Day28	Day3	Day28	Day3	Day28	Day3	Day28
Hedonics mean value	-1.5	-1.3	-0.6	-0.3	-1.0	0.1	-0.8	-0.6	-2.1	-1.2
Half confidence interval	0.8	0.6	0.5	0.7	0.7	0.9	0.7	0.5	0.3	0.5
Confidence interval min.	-2.3	-1.9	-1.1	-1.0	-1.7	-0.8	-1.5	-1.1	-2.4	-1.7
Standard deviation max.	-0.1	-0.2	0.3	0.9	0.3	1.5	0.5	0.3	-1.5	-0.2
Standard deviation min	-2.9	-2.4	-1.5	-1.5	-2.3	-1.3	-2.1	-1.5	-2.7	-2.2
Confidence interval max.	-0.7	-0.7	-0.1	0.4	-0.3	1.0	-0.1	-0.1	-1.8	-0.7

The following table shows the results of the analytical assessment of the test room air. There were no analytical assessments of individual products in this assembly.

Table 13: Analysis for floor assembly 3 (Kühn 2013)

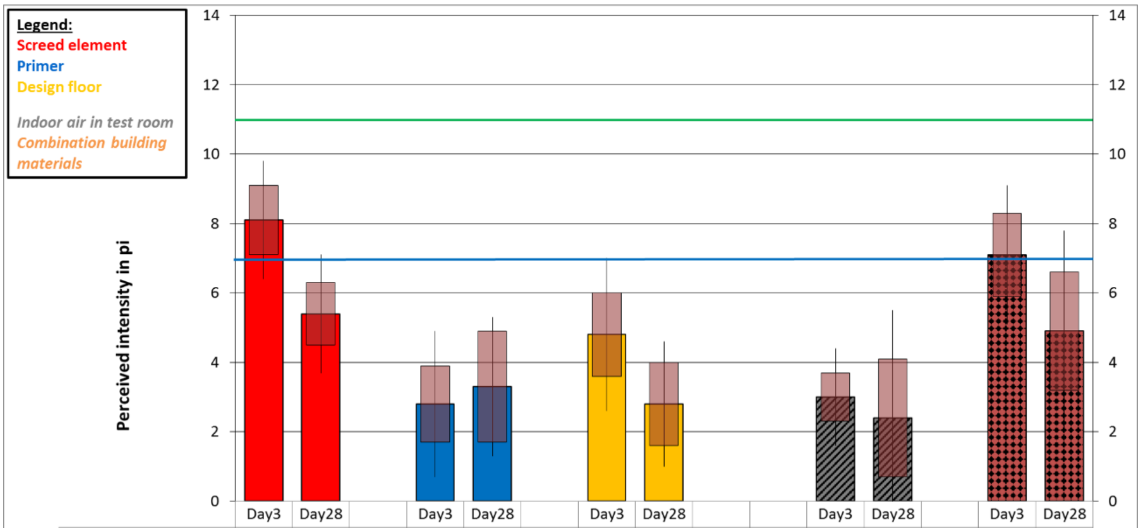
Detected substances	CAS No.	Day 3 concentration in µg/m³	Day 28 concentration in µg/m³
TVOC		111	29
Glycol compound		52	22
Formaldehyde	50-00-0	3	3
Acetaldehyde	75-07-0	6	4

Low concentrations of some volatile organic compounds were detected in the test room equipped with floor assembly 3. Only one unknown glycol compound was measured in higher concentrations, which nevertheless decreased throughout the course of the test.

5.2.4.8 Floor assembly 4

Figure 62 compares the intensities for floor assembly 4. The intensities of the assessed room air were in the very low range and approximated to the values of the design flooring (yellow). The combination was slightly higher, but also reached the Blue Angel test value.

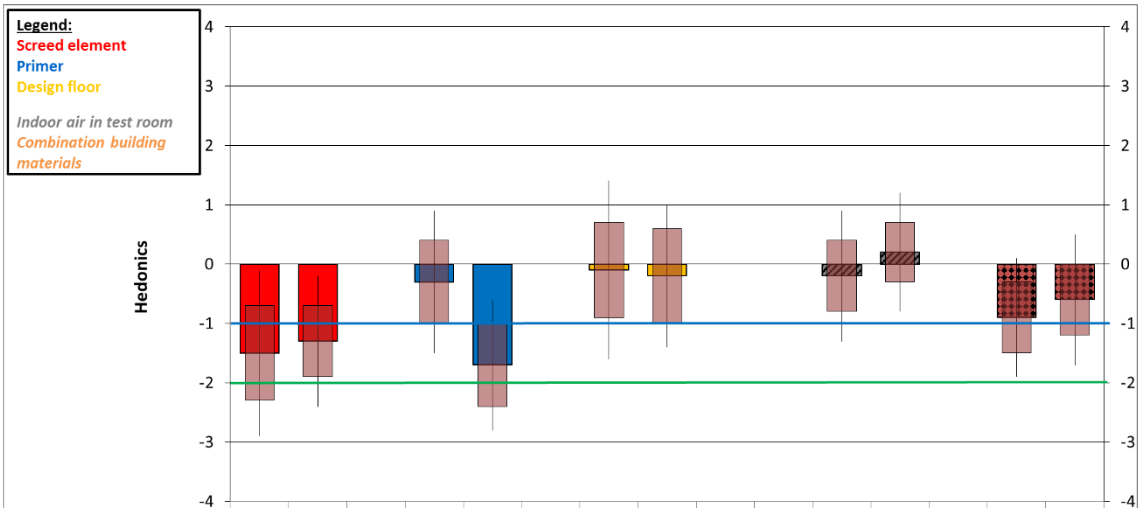
Figure 62: Intensity for floor assembly 4 (eco)



	Day3	Day28	Day3	Day28	Day3	Day28	Day3	Day28	Day3	Day28
Intensity mean value	8.1	5.4	2.8	3.3	4.8	2.8	3.0	2.4	7.1	4.9
Half confidence interval	1.0	0.9	1.1	1.6	1.2	1.2	0.7	1.7	1.2	1.7
Temperature in °C	23.5	23.5	23.5	23.5	23.5	23.5	17.6	20.8	23.5	23.5
Relative humidity in %	50	50	50	50	50	50	42	29	50	50
Confidence interval min.	7.1	4.5	1.7	1.7	3.6	1.6	2.3	0.7	5.9	3.2
Standard deviation max.	9.8	7.1	4.9	5.3	7.0	4.6	4.4	5.5	9.1	7.8
Standard deviation min	6.4	3.7	0.7	1.3	2.6	1.0	1.6	-0.7	5.1	2.0
Confidence interval max.	9.1	6.3	3.9	4.9	6.0	4.0	3.7	4.1	8.3	6.6

The same applies to the observation of hedonics in Figure 63 below. The assessment of the room air also revealed the best values in this case. The assessment of the combination was likewise within the Blue Angel range, although some individual products (red, blue) failed to reach this test value.

Figure 63: Hedonics for floor assembly 4 (eco)



	Day3	Day28	Day3	Day28	Day3	Day28	Day3	Day28	Day3	Day28
Hedonics mean value	-1.5	-1.3	-0.3	-1.7	-0.1	-0.2	-0.2	0.2	-0.9	-0.6
Half confidence interval	0.8	0.6	0.7	0.7	0.8	0.8	0.6	0.5	0.6	0.6
Confidence interval min.	-2.3	-1.9	-1.0	-2.4	-0.9	-1.0	-0.8	-0.3	-1.5	-1.2
Standard deviation max.	-0.1	-0.2	0.9	-0.6	1.4	1.0	0.9	1.2	0.1	0.5
Standard deviation min	-2.9	-2.4	-1.5	-2.8	-1.6	-1.4	-1.3	-0.8	-1.9	-1.7
Confidence interval max.	-0.7	-0.7	0.4	-1.0	0.7	0.6	0.4	0.7	-0.3	0.0

The following table shows the results of the analytical assessment of the test room air.

Table 14: Analysis for floor assembly 4 (Kühn 2013)

Detected substances (in µg/m³)	CAS No.	Room air		Primer 13.031	Design flooring 13.030	Combination
		Day 3	Day 28	Day 28	Day 28	Day 28
TVOC		55	29	22	3	23
Decamethyl cyclopenta-siloxane	541-02-6	18	1	n.d.	n.d.	n.d.
Phthalate		n.d.	n.d.	n.d.	19	n.d.
Formaldehyde	50-00-0	8	6	n.a.	n.a.	n.a.
Acetaldehyde	95-07-0	9	5	n.a.	n.a.	n.a.

Low concentrations of some volatile organic compounds were detected in the test room with floor assembly 4. The analysis of the individual products revealed an unknown phthalate from the design flooring, which was not detected in the room air or combination. Otherwise, the results of the combination and the room air on day 28 were in the same range.

5.3 Interim conclusions

The indoor air measurements in the Bismarckplatz test rooms showed that very high perceived intensities occurred during and/or between the individual reconstruction steps. However, they dropped quite rapidly after the constructions were completed and were within the range of the as-is state of the respective room on day 28.

The tests of the applied products in the air quality laboratory established that all materials received good assessments in the range of the proposed Blue Angel test value.

The chemical analysis of the indoor air in the test rooms generally showed an increase in VOC and aldehyde concentrations during construction, but the values decreased with time. Hardly any emissions were detected in the evaluated products.

Direct and indirect assessment methods were used in the measurements of the eco-INSTITUT test rooms in Cologne. For the most part, both assessment methods led to similar results.

The assessments of the products used as well as their combination led to good results and were largely in the range of the Blue Angel recommendation. Similar to the tests at Bismarckplatz, good individual product assessments led to good assessments of the combination. These investigations established that the assessments of the materials did not always correspond to the respective evaluations of the indoor air in the test room (unlike for Bismarckplatz). As already explained, the reasons for this were the different room air conditions (temperature and relative humidity), the varying level of experience of the panellists and management staff and different laboratory equipment.

Most of the products used were low-emission and the measured concentrations of volatile organic compounds were negligible. The results of the indoor air measurements also show low VOC concentrations.

6 Tests on UBA Haus 2019

6.1 Object description

A zero energy house with 31 office workplaces and three meeting rooms was built in Berlin-Marienfelde between 2011 and 2013. The building was given the title of "Haus 2019" because it is already expected to meet the stipulations of the European Building Directive which requires public sector buildings to have balanced energy budget over the year as of 2019. The barrier-free wood panelled construction aims to achieve the "gold" standard according to the Assessment System for the Sustainable Building of German Federal buildings. A photovoltaic system placed on the roof provides electrical power. A heat pump extracts heat or cold from the ground water to regulate the temperature of the building. The entire shell and façade were made from a renewable raw material (wood). Thermal insulation consists of cellulose fibres obtained from recycled waste paper. A regulated ventilation system with heat recovery minimises heat losses caused by ventilation. The required electricity (lighting, office machines etc.) for on-site energy supply (primarily circulatory pumps) and during the use of the building is produced by photovoltaic tiles on the roof. Highly efficient equipment and devices were therefore used in all installation parts. Lighting is generated by particularly effective luminaries.

6.2 Indoor air measurements

Olfactory and analytical assessments of the indoor air were carried out at specific intervals during the construction work on the interior as well as after starting to use the rooms. Table 15 gives a chronological overview of the various test days:

Table 15: Timeline of indoor air measurement in the UBA Haus 2019

Construction phase	Date	Description
CP 1	12.04.2013	Assessment of 10 indoor air samples after application of floor screed
CP 2	17.07.2013	Assessment of 10 indoor air samples after completing the construction
CP 3	02.09.2013	Assessment of 10 indoor air samples after furnishing, but prior to use
CP 4	30.10.2013	Assessment of 10 indoor air samples after approximately two months of use
CP 5	04.12.2013	Assessment of 10 indoor air samples after approximately three months of use
CP 6	05.03.2014	Assessment of 9 indoor air samples after approximately six months of use

All 10 (or 9) indoor air samples were olfactorily tested. Due to capacity reasons, analytical measurements were carried out on only 3 air samples. Based on the experience from test offices in UBA Bismarckplatz and the local conditions, UBA Haus 2019 was only assessed using the sampling by means of the AirProbe and assessment in the HTW air quality laboratory. Every measurement day (CP 1-6) sampled the same rooms from a selection of 5 rooms on the ground floor and 5 rooms on the upper floor. The respective room air temperatures and humidity values on the test days are shown in the corresponding diagram.

Table 16 shows the room overview:

Table 16: Room overview in UBA Haus 2019

Room	Room description	CP 1	CP 2	CP 3	CP 4	CP 5	CP 6
1	First-aid room	Empty, no door	Empty	Furniture	Unused	Unused, stuffy	Unused, stuffy
2	Office	Empty, no door	Empty	Furniture	used	Unused	used, stuffy
3	Office	Empty, no door	Empty, construction odour	Furniture	Unused	Unused	unused
4	Archive	Empty, no door	Empty, construction odour	Furniture	Used	Used	Used
5	Parent-child office	Empty, no door	Empty, construction odour	Furniture, toys	Unused	Unused	Unused
6	Office	Empty, no door	Empty	Furniture	Used (coffee)	Used	Used
7	Office	Empty, no door	Empty, construction odour	Furniture	Unused	Unused	Unused
8	Office	Empty, no door	Empty, construction odour	Furniture	Used	Used	Used (perfume)
9	Office with access door	Empty, no door	Empty, construction odour	Furniture	Unused	Used	Used (perfume)
10	Meeting room	Empty, no door	empty	Empty, cool	Unused	Used	N/A (foreign odours)

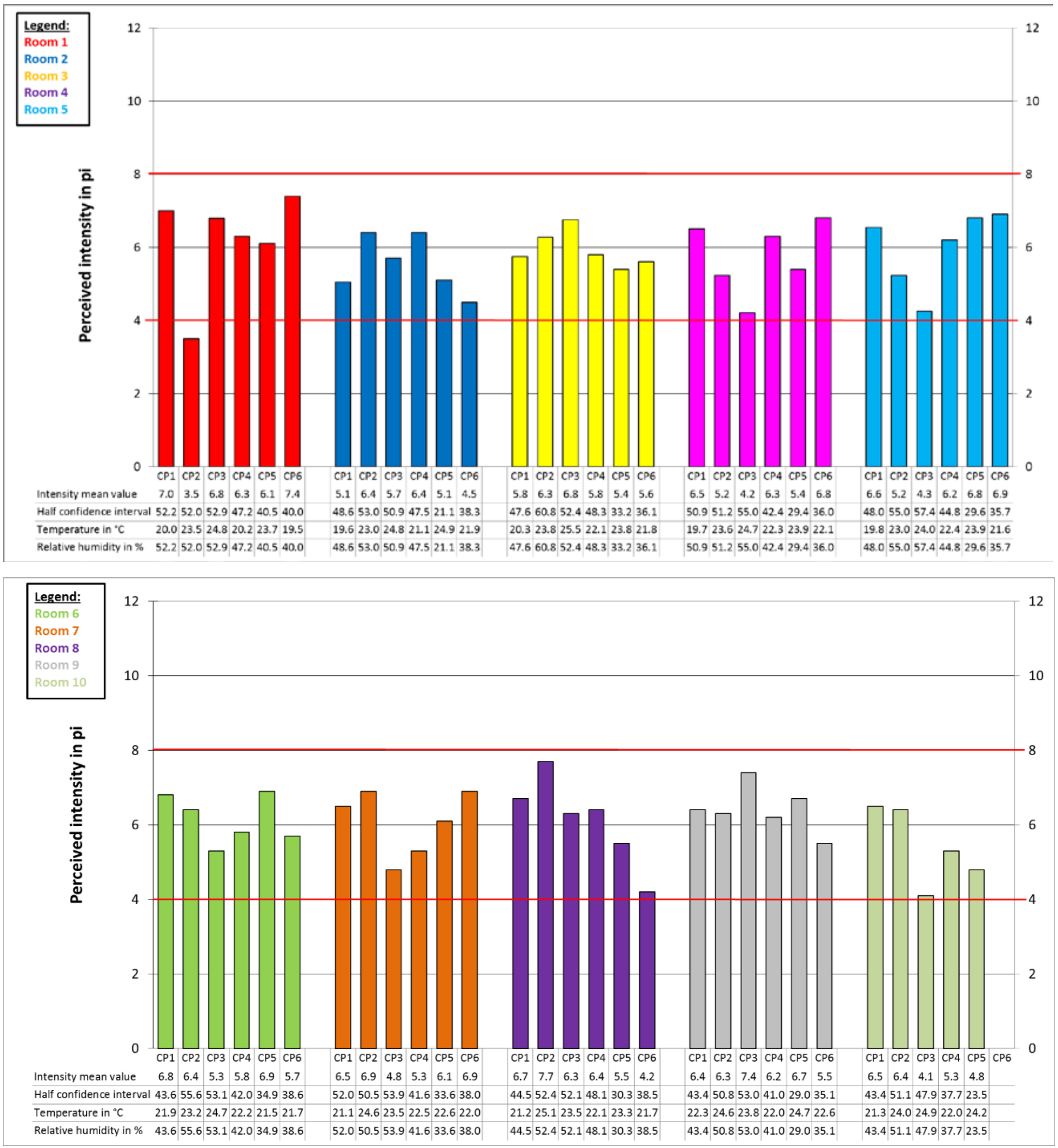
The table describes the condition of the rooms on individual test days (CPs). The building was still being renovated during CP 1 and the individual rooms had no closable doors. Therefore, it is safe to assume that both the room air of the individual rooms and the ambient air was recorded.

The building was used by employees from CP 4 onwards. The table uses the descriptions "used" and "unused". "Used" means that someone was in the room on the day of the test. "Unused" means that no one was in the room before and during sampling on the day of the test. The terms in the brackets describe the odour detected during sampling. Room 10 was not tested at CP 6 because it hosted a meeting and strong foreign smells were detectable.

The VOC sampling in the three rooms (2, 7 and 8) was carried out actively. The aldehyde samplings were carried out actively during the first three construction phases. In order to reduce the strain on users, aldehyde sampling was carried out passively in the last construction phases.

Figure 64 shows the perceived intensities of the test rooms on various measurement days (construction phases).

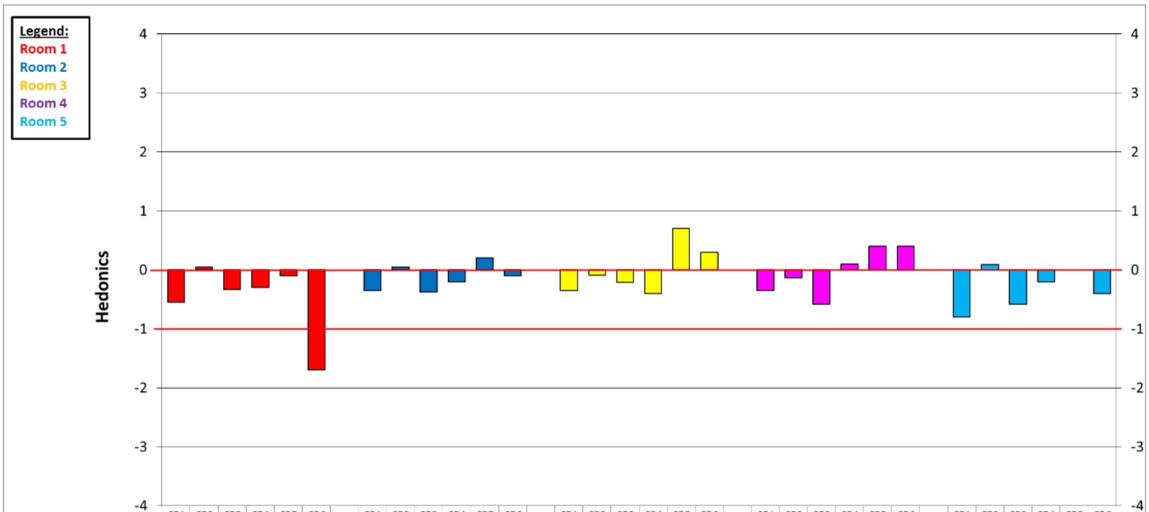
Figure 64: Intensity for room air (UBA Haus 2019)



The majority of all perceived room intensities were rated in the medium quality range. During construction work, i.e. before the use of the rooms (CP1-3), the perceived intensities for rooms 2 (blue), 3 (yellow) and 9 (grey) increased slightly, but decreased for the other rooms.

The intensities for rooms 2 (blue), 3 (yellow), 8 (purple) and 9 (grey) remained roughly the same or decreased slightly during continued use of the rooms (CP 4-6). The low intensities in the other rooms increased again after completion of the construction work (CP 3) and during use (CP 4-6). This leads to the conclusion that using the rooms introduced further odours that influenced the odour quality of the rooms independently from the construction work (see Table 16, e.g. coffee).

Figure 65: Hedonics for room air (UBA Haus 2019)



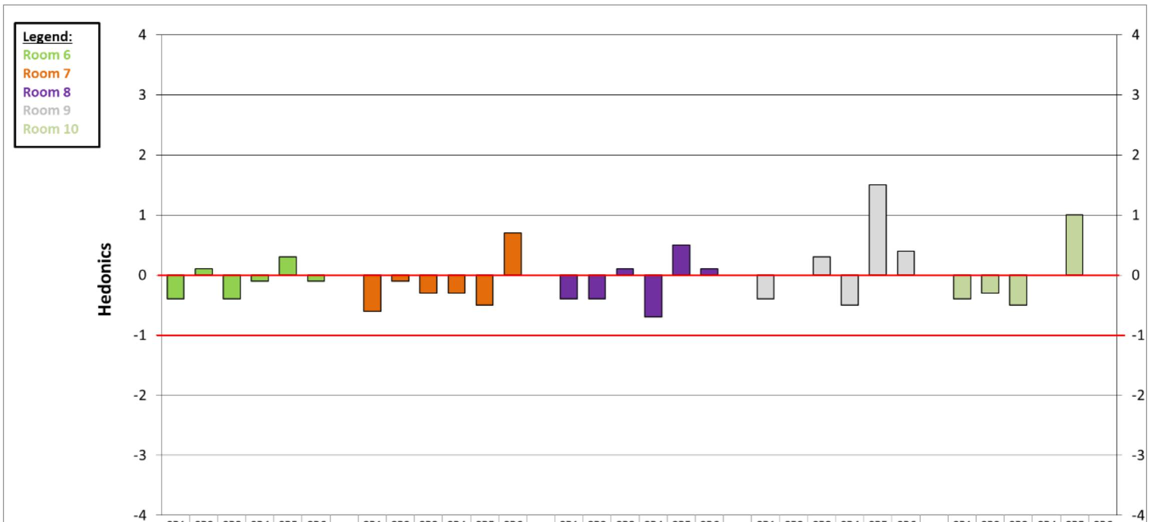
	CP1	CP2	CP3	CP4	CP5	CP6
Hedonics mean value	-0.6	0.0	-0.3	-0.3	-0.1	-1.7
Half confidence interval	52.2	52.0	52.9	47.2	40.5	40.0
Temperature in °C	20.0	23.5	24.8	20.2	23.7	19.5
Relative humidity in %	52.2	52.0	52.9	47.2	40.5	40.0

	CP1	CP2	CP3	CP4	CP5	CP6
Hedonics mean value	-0.4	0.0	-0.4	-0.2	0.2	-0.1
Half confidence interval	48.6	53.0	50.9	47.5	21.1	38.3
Temperature in °C	19.6	23.0	24.8	21.1	24.9	21.9
Relative humidity in %	48.6	53.0	50.9	47.5	21.1	38.3

	CP1	CP2	CP3	CP4	CP5	CP6
Hedonics mean value	-0.4	-0.1	-0.2	-0.4	0.7	0.3
Half confidence interval	47.6	60.8	52.4	48.3	33.2	36.1
Temperature in °C	20.3	23.8	25.5	22.1	23.8	21.8
Relative humidity in %	47.6	60.8	52.4	48.3	33.2	36.1

	CP1	CP2	CP3	CP4	CP5	CP6
Hedonics mean value	-0.4	-0.1	-0.6	0.1	0.4	0.4
Half confidence interval	50.9	51.2	55.0	42.4	29.4	36.0
Temperature in °C	19.7	23.6	24.7	22.3	23.9	22.1
Relative humidity in %	50.9	51.2	55.0	42.4	29.4	36.0

	CP1	CP2	CP3	CP4	CP5	CP6
Hedonics mean value	-0.8	0.1	-0.6	-0.2	0.0	-0.4
Half confidence interval	48.0	55.0	57.4	44.8	29.6	35.7
Temperature in °C	19.8	23.0	24.0	22.4	23.9	21.6
Relative humidity in %	48.0	55.0	57.4	44.8	29.6	35.7



	CP1	CP2	CP3	CP4	CP5	CP6
Hedonics mean value	-0.4	0.1	-0.4	-0.1	0.3	-0.1
Half confidence interval	43.6	55.6	53.1	42.0	34.9	38.6
Temperature in °C	21.9	23.2	24.7	22.2	21.5	21.7
Relative humidity in %	43.6	55.6	53.1	42.0	34.9	38.6

	CP1	CP2	CP3	CP4	CP5	CP6
Hedonics mean value	-0.6	-0.1	-0.3	-0.3	-0.5	0.7
Half confidence interval	52.0	50.5	53.9	41.6	33.6	38.0
Temperature in °C	21.1	24.6	23.5	22.5	22.6	22.0
Relative humidity in %	52.0	50.5	53.9	41.6	33.6	38.0

	CP1	CP2	CP3	CP4	CP5	CP6
Hedonics mean value	-0.4	-0.4	0.1	-0.7	0.5	0.1
Half confidence interval	44.5	52.4	52.1	48.1	30.3	38.5
Temperature in °C	21.2	25.1	23.5	22.1	23.3	21.7
Relative humidity in %	44.5	52.4	52.1	48.1	30.3	38.5

	CP1	CP2	CP3	CP4	CP5	CP6
Hedonics mean value	-0.4	0.0	0.3	-0.5	1.5	0.4
Half confidence interval	43.4	50.8	53.0	41.0	29.0	35.1
Temperature in °C	22.3	24.6	23.8	22.0	24.7	22.6
Relative humidity in %	43.4	50.8	53.0	41.0	29.0	35.1

	CP1	CP2	CP3	CP4	CP5	CP6
Hedonics mean value	-0.4	-0.3	-0.5	0.0	1.0	
Half confidence interval	43.4	51.1	47.9	37.7	23.5	
Temperature in °C	21.3	24.0	24.9	22.0	24.2	
Relative humidity in %	43.4	51.1	47.9	37.7	23.5	

Figure 65 shows the results of hedonics assessment for the test rooms. The hedonics were mainly in the neutral range between -0.5 and +0.5. Room 1 (red) exhibited comparatively poor hedonics (-1.6) over CP 6. It was the first-aid room that was rarely used. The office rooms of the building "UBA Haus 2019" were equipped with motion detectors. When they are not in use or windows are opened, the ventilation switches off. This means that rooms that are not used are also not aired (unless a window is open). Conference rooms are equipped with CO_2 sensors to enable ventilation when needed. Furthermore, room 9 (grey) provided +1.5 over CP 5 – a room air quality perceived comparatively as very pleasant. This can be explained by the fact that the room smelled slightly of perfume on the test day which had a positive effect on the hedonics assessment (see Table 16). Also of interest are the hedonics assessments of room 4 (pink) that were deemed more pleasant than during the construction work although intensities increased. Furthermore, it is noticeable that many rooms that were being used had an indoor climate perceived as pleasant. This can be attributed to the introduction of pleasant odours (e.g. perfume) regardless of the building materials.

VOC and aldehyde concentrations were measured in rooms 2, 7 and 8. The detailed results are presented in Annex 6.2 (Tables 28-33).

High concentrations were measured in the indoor air during the first construction phases, but this is not unusual because of the construction work undertaken. No doors were fitted in the rooms during the initial measurement and the air was distributed throughout the building. The results of the second measurement in July 2013 showed high concentrations of VOCs, especially for some aromatic hydrocarbons such as o-, m-, p-xylene, ethylbenzene and toluene (Figure 67, Figure 69 and Figure 71). These substances are used as solvents in the industry. At the time of measurement, the ventilation system was switched off. The room air also showed typical "wood emissions" such as terpenes and hexanal. Terpene concentrations were relatively low over the entire test period; alpha-pinene was also detected in concentrations around 100 µg/m^3 6 months after use (the ventilation system was handled under normal operating conditions) (Figure 66 and Figure 70).

Figure 66: Room 2 – indoor air concentrations of VOCs in the test period

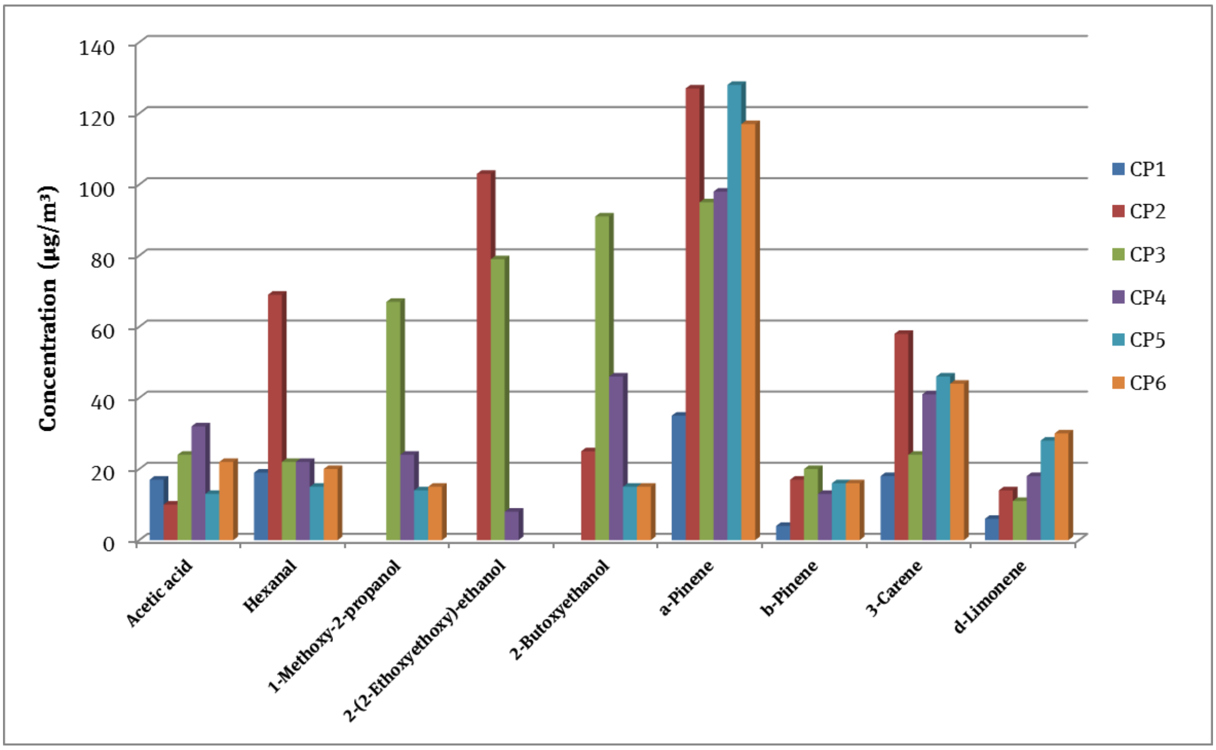


Figure 67: Room 2 – indoor air concentrations of aromatic hydrocarbons

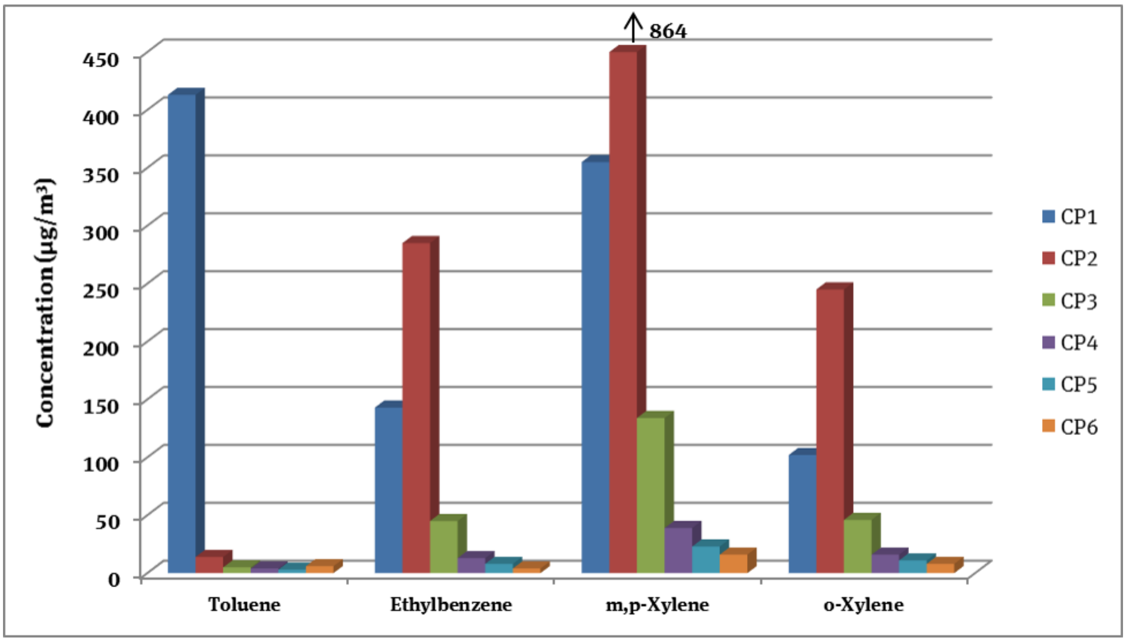


Figure 68: Room 7 – indoor air concentrations of VOCs in the test period

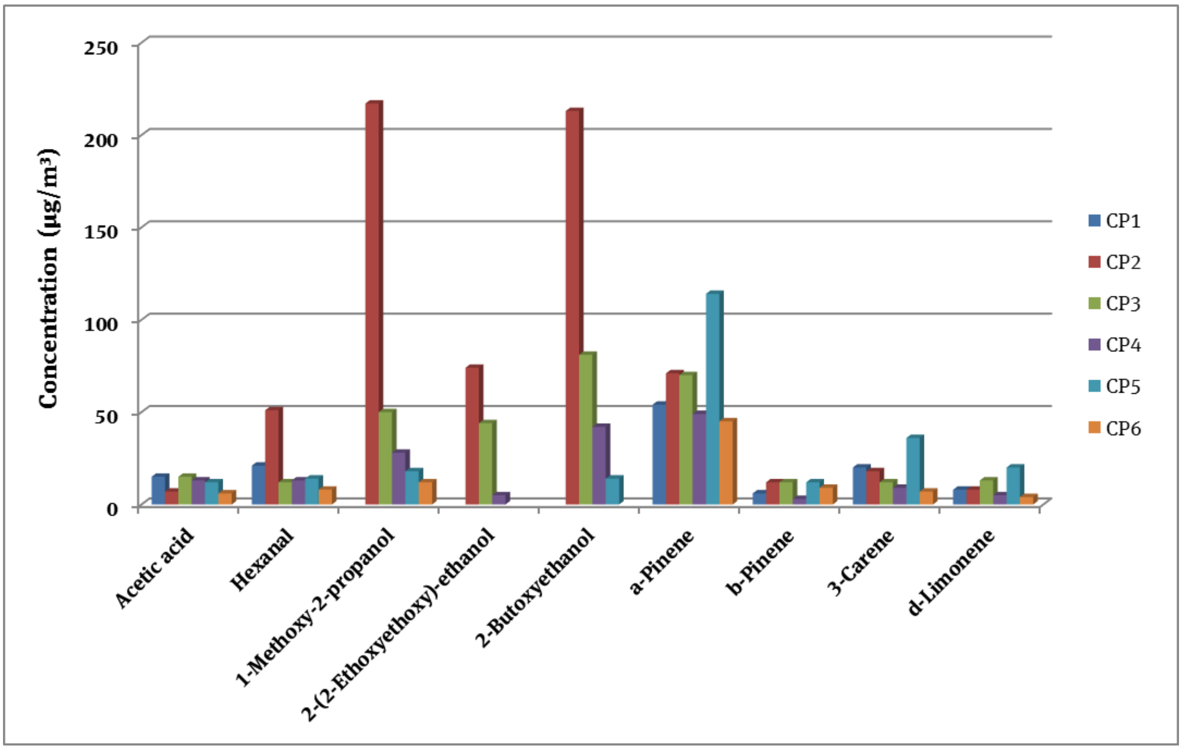


Figure 69: Room 7 – indoor air concentrations of aromatic hydrocarbons

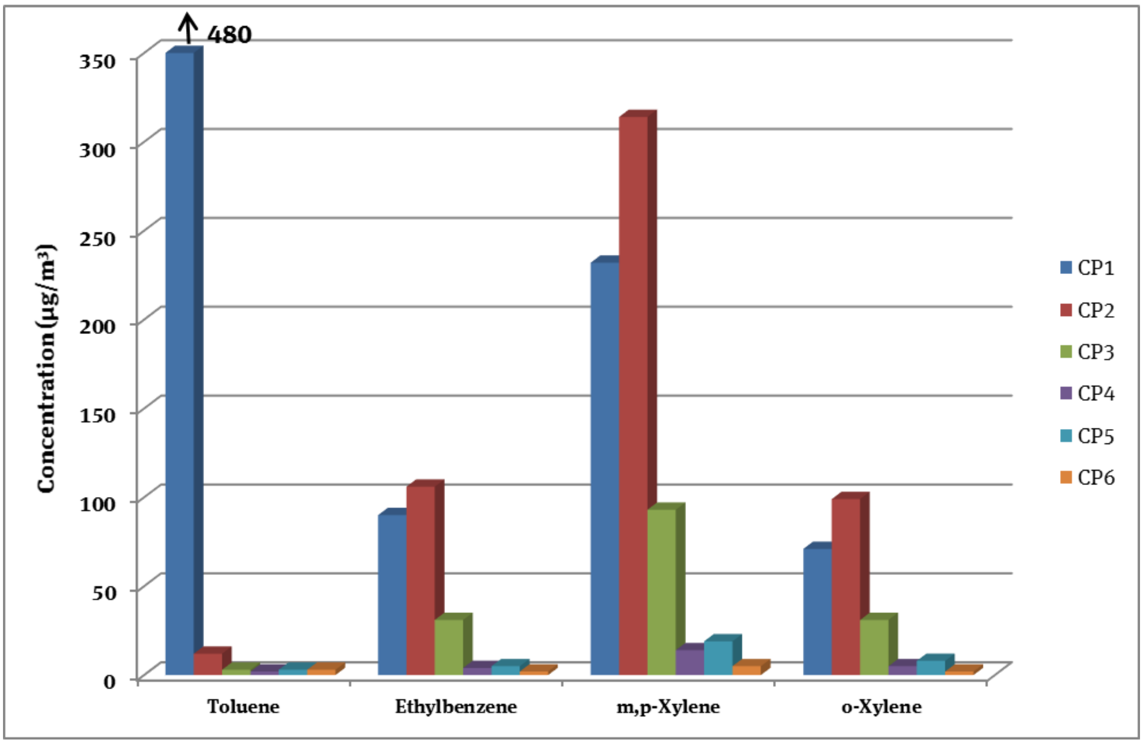


Figure 70: Room 8 – indoor air concentrations of VOCs in the test period

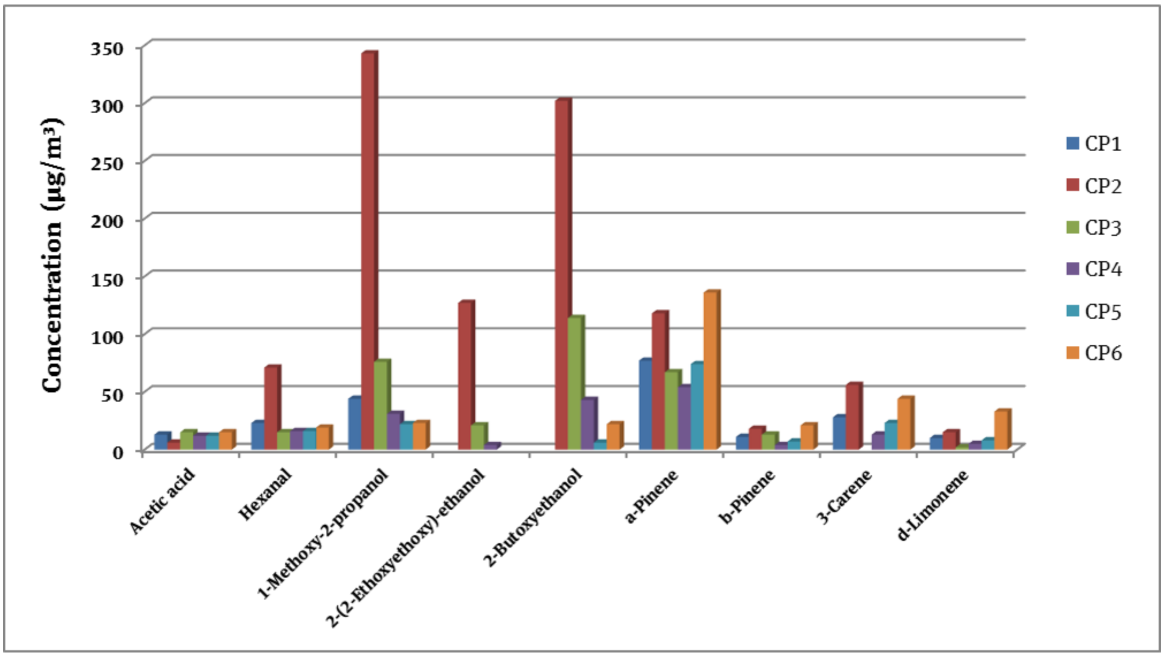
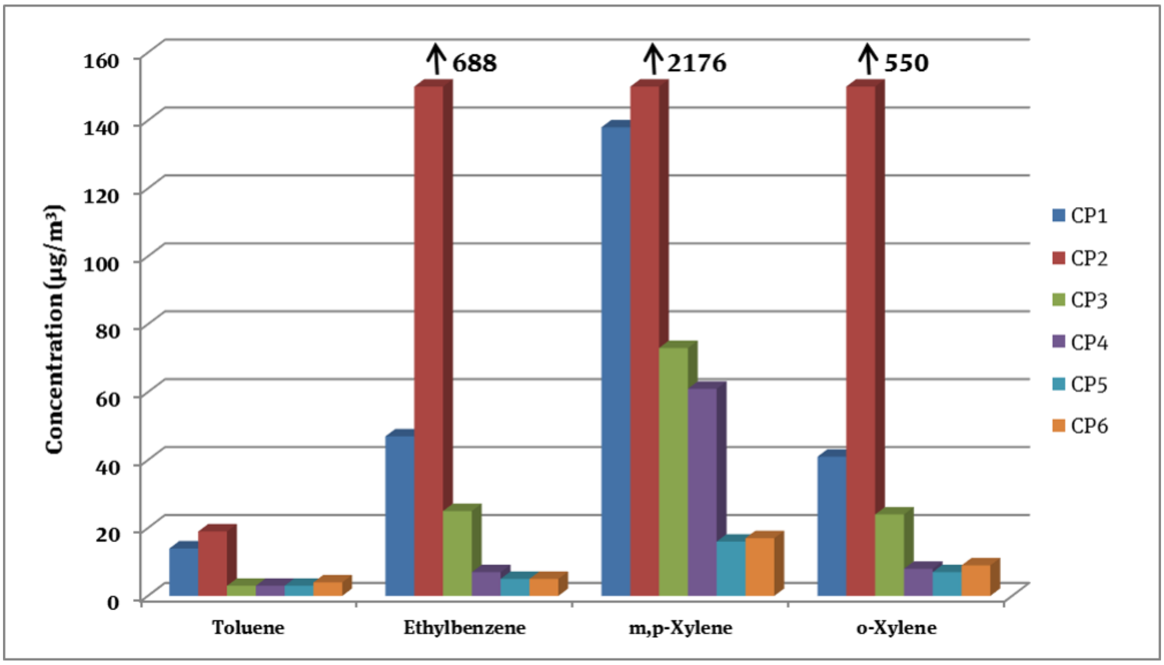
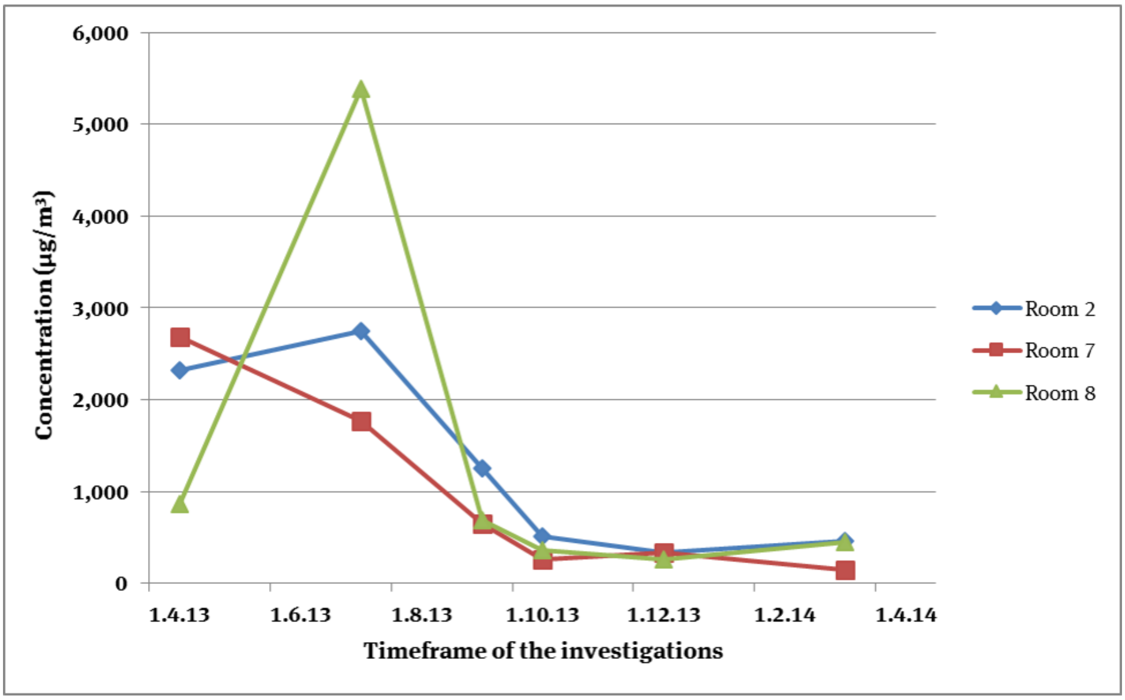


Figure 71: Room 8 – indoor air concentrations of aromatic hydrocarbons



When considering the TVOC values in the rooms, a typical trend can be seen during the construction phases (Figure 72). The strong increase in the TVOC value in room 8 on the second day of investigation is due to the high m-, p-xylene concentration. This measurement however, took place in the summer shortly after completion of the main construction measures and without the ventilation system operating. The TVOC concentrations decreased over time and reached values between 153 and 466 µg/m³ 6 months after using the building (ventilation system was activated under normal operating conditions).

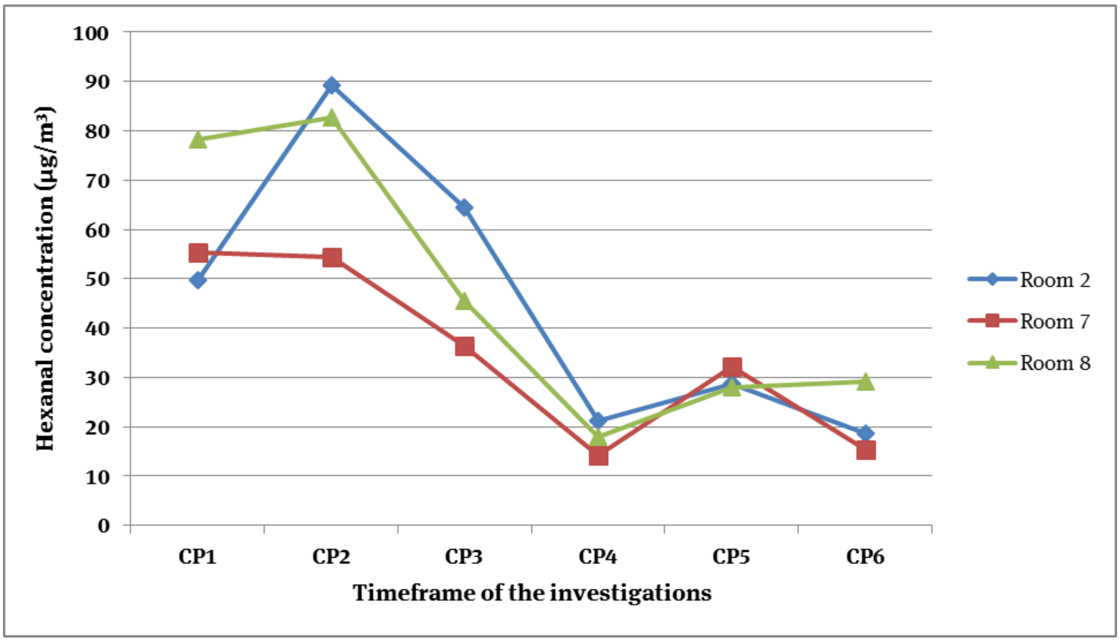
Figure 72: TVOC values in rooms 2, 7 and 8 in the test period



The results of the aldehyde tests using the DNPH method generally show low formaldehyde concentrations over the test period (see Annex 6.2 Tables 29, 31 and 33), despite the use of the renewable raw material wood for the entire shell and façade. For “UBA Haus 2019”, special wood-based panels that were glued free of formaldehyde, were used. Thus the formaldehyde concentrations at the end of the tests were between 7 and 15 µg/m³ (ventilation system was activated under normal operating conditions).

Hexanal, an odorous substance and typical of wood emissions, was conspicuous during these tests. Up to 90 µg/m³ was measured during the building measures, but the concentrations decreased over time in the rooms and reached values between 15 and 30 µg/m³ by 6 months after use (Figure 73). Since hexanal has a low odour threshold, these concentrations could have contributed to the smell impression. Hexanal concentration can also be determined using the VOC Tenax method. The values in this project showed comparable results (see Annex 6.2, Tables 28-33).

Figure 73: Hexanal concentrations during building measures (UBA Haus 2019, DNPH method)



VOC and aldehyde measurements on the last day of the test, 6 months after using the “UBA Haus 2019”, failed to exceed the existing guide values of the German Committee on Indoor Guide Values for individual substances and their groups. (Web page Umweltbundesamt)

The TVOC levels in rooms 2 and 8 were classified as Level 2 (> 0.3-1 mg/m³) of the indoor air TVOC reference values table of the German Committee on Indoor Guide Values. TVOC values in this level are regarded as hygienically harmless as long as there are no indications that individual substances or substance groups exceed the guide values (this is not the case here). (Web page Umweltbundesamt)

In general, there is no direct link between the chemical analytical results and the odour assessment. For instance, in room 7, the perceived intensity of the odour increased in the last three construction phases while the TVOC concentrations decreased.

6.3 Product tests in the air quality laboratory

In addition to testing indoor air samples, selected building materials and their combinations used in the “UBA Haus 2019” were olfactorily and analytically tested in HTW’s test chambers. In this case, a comparison with the results of the indoor air measurements is not expedient since the room air is not only influenced by the respective component to be tested (no test room conditions). The following table shows the composition of the assemblies:

Table 17: Product assessment (UBA Haus 2019)

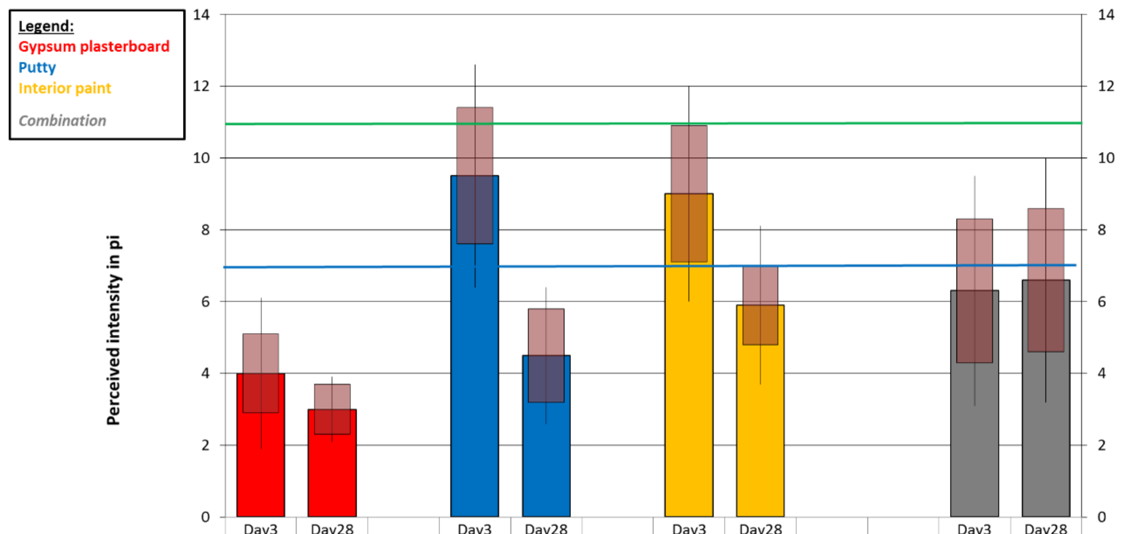
Material layer	Interior wall	Floor	Parquet
1	Interior paint	Cement screed	Sealing
2	Putty	Screed insulation board	Industrial parquet
3	Gypsum plasterboard	Footfall sound insulation mineral wool	Parquet adhesive
4			Screed and levelling compound
5			Primer

In addition to the individual products, the combinations of these products were also tested.

6.3.1 Interior wall

Figure 74 shows the intensities of the interior wall products and their combination.

Figure 74: Intensity for interior walls (UBA Haus 2019)

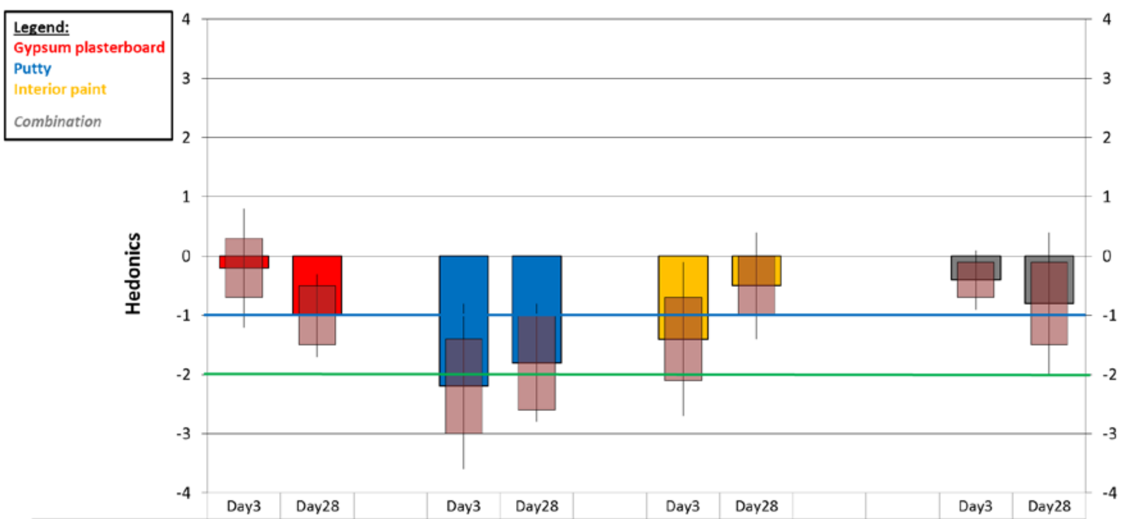


	Day3	Day28	Day3	Day28	Day3	Day28	Day3	Day28
Intensity mean value	4.0	3.0	9.5	4.5	9.0	5.9	6.3	6.6
Half confidence interval	1.1	0.7	1.9	1.3	1.9	1.1	2.0	2.0
Confidence interval min.	2.9	2.3	7.6	3.2	7.1	4.8	4.3	4.6
Standard deviation max.	6.1	3.9	12.6	6.4	12.0	8.1	9.5	10.0
Standard deviation min	1.9	2.1	6.4	2.6	6.0	3.7	3.1	3.2
Confidence interval max.	5.1	3.7	11.4	5.8	10.9	7.0	8.3	8.6

The intensity for the gypsum plasterboard showed a very low value as early as on day 3. The products putty (blue) and interior paint (yellow) showed an intensity of approx. 9 pi on day 3. The intensities of the products dropped below 7 pi by day 28. The intensity of the combination, on the other hand, did not change, but was in the area of the outermost material layer (interior paint).

Figure 75 shows the hedonics assessments. The slightly poorer assessment of putty (blue) was noticeable. However, this did not affect the combination of the products (grey) which was at -0.8 by day 28 and thus fulfilled the Blue Angel criterion.

Figure 75: Hedonics for interior walls (UBA Haus 2019)



	Day3	Day28	Day3	Day28	Day3	Day28	Day3	Day28
Hedonics mean value	-0.2	-1.0	-2.2	-1.8	-1.4	-0.5	-0.4	-0.8
Half confidence interval	0.5	0.5	0.8	0.8	0.7	0.5	0.3	0.7
Confidence interval min.	-0.7	-1.5	-3.0	-2.6	-2.1	-1.0	-0.7	-1.5
Standard deviation max.	0.8	-0.3	-0.8	-0.8	-0.1	0.4	0.1	0.4
Standard deviation min	-1.2	-1.7	-3.6	-2.8	-2.7	-1.4	-0.9	-2.0
Confidence interval max.	0.3	-0.5	-1.4	-1.0	-0.7	0.0	-0.1	-0.1

The detailed results of the VOC and aldehyde measurements are presented in Annex 6.2 (Tables 33-41). The measured concentrations of the emitting substances were negligible and far below the respective LCI values of the AgBB scheme.

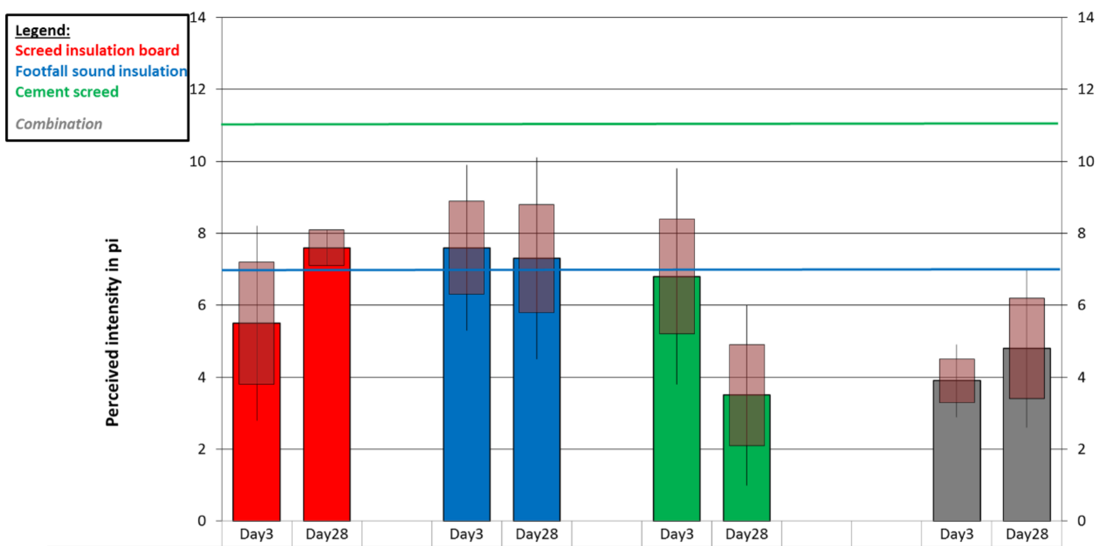
6.3.2 Floor

The floor assembly consists of the following products:

- Cement screed
- Screed insulation board
- Footfall sound insulation mineral wool

Figure 76 below shows the perceived intensities of these products and their combination. The combination of the individual products (grey) had a lower intensity on day 3 than the individual products. The perceived intensities of the combination and the top assembly layer cement screed (green) were comparable on day 28.

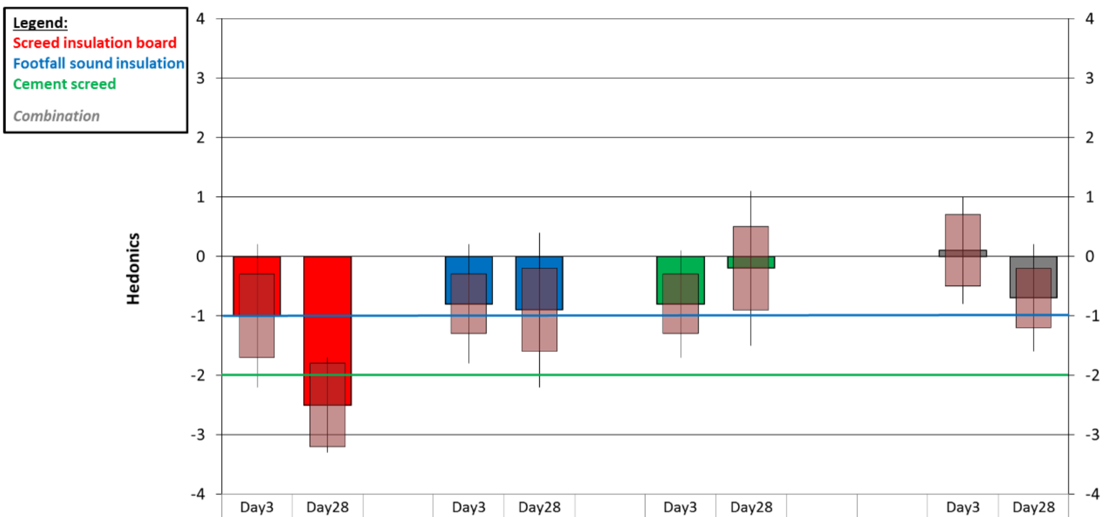
Figure 76: Intensity for floors (UBA Haus 2019)



	Day3	Day28		Day3	Day28		Day3	Day28			Day3	Day28
Intensity mean value	5.5	7.6		7.6	7.3		6.8	3.5			3.9	4.8
Half confidence interval	1.7	0.5		1.3	1.5		1.6	1.4			0.6	1.4
Confidence interval min.	3.8	7.1		6.3	5.8		5.2	2.1			3.3	3.4
Standard deviation max.	8.2	8.1		9.9	10.1		9.8	6.0			4.9	7.0
Standard deviation min	2.8	7.1		5.3	4.5		3.8	1.0			2.9	2.6
Confidence interval max.	7.2	8.1		8.9	8.8		8.4	4.9			4.5	6.2

Figure 77 shows the relevant hedonics assessments. The poor assessment of the screed element (red) on day 28 is noticeable. The combination was also found as being slightly worse over the test period but, like the other two individual products (blue, green), was below the Blue Angel test value.

Figure 77: Hedonics for floors (UBA Haus 2019)



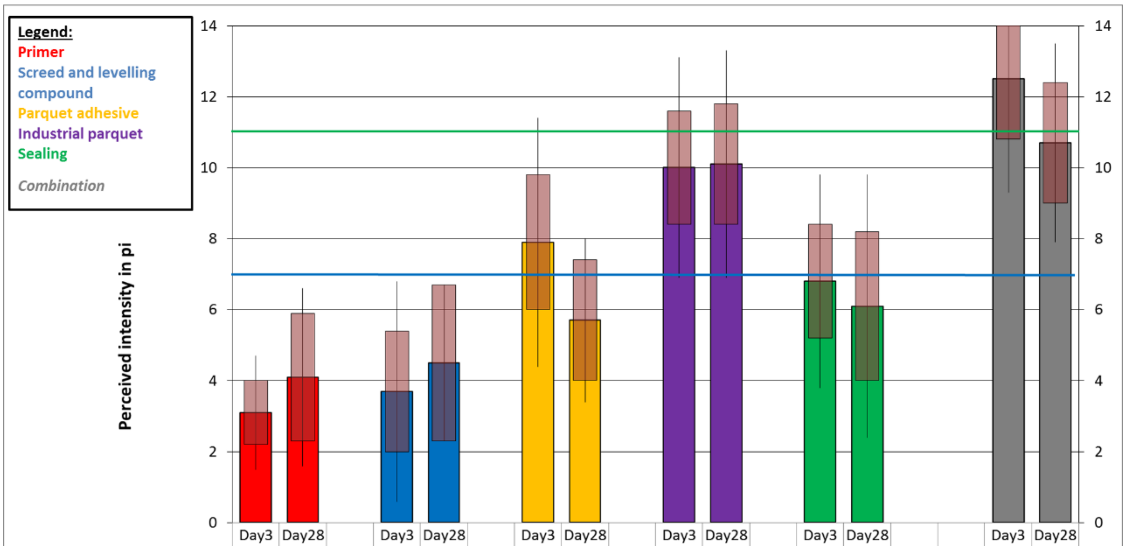
	Day3	Day28		Day3	Day28		Day3	Day28			Day3	Day28
Hedonics mean value	-1.0	-2.5		-0.8	-0.9		-0.8	-0.2			0.1	-0.7
Half confidence interval	0.7	0.7		0.5	0.7		0.5	0.7			0.6	0.5
Confidence interval min.	-1.7	-3.2		-1.3	-1.6		-1.3	-0.9			-0.5	-1.2
Standard deviation max.	0.2	-1.7		0.2	0.4		0.1	1.1			1.0	0.2
Standard deviation min	-2.2	-3.3		-1.8	-2.2		-1.7	-1.5			-0.8	-1.6
Confidence interval max.	-0.3	-1.8		-0.3	-0.2		-0.3	0.5			0.7	-0.2

The detailed results of VOC and aldehyde measurements are displayed in Annex 6.2 (Tables 42-46). The cement screed was not analysed analytically. The measured concentrations of the emitted substances from the footfall sound insulation, the screed insulation board and the combination were negligible and far below the respective LCI values.

6.3.3 Parquet

The parquet assembly consisted of 5 different components (see Table 17). The corresponding intensities are shown in Figure 78. The combination of the products had a very high intensity, which is why unfavourable interactions between the individual products were not excluded. Apart from this, all individual products except for the parquet (purple) had intensities below 7 pi on day 28.

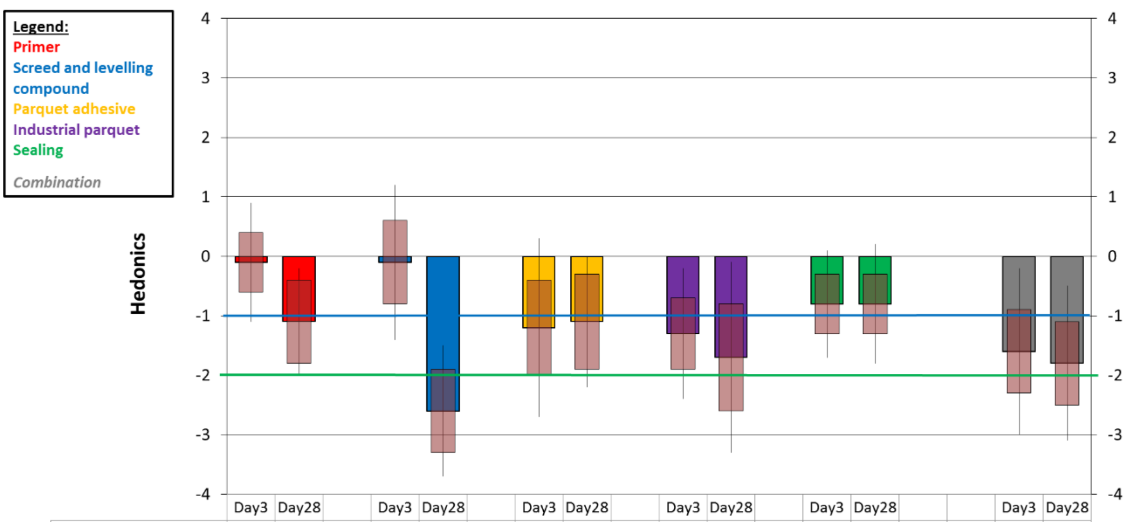
Figure 78: Intensity for parquet (UBA Haus 2019)



	Day3	Day28	Day3	Day28	Day3	Day28	Day3	Day28	Day3	Day28	Day3	Day28
Intensity mean value	3.1	4.1	3.7	4.5	7.9	5.7	10.0	10.1	6.8	6.1	12.5	10.7
Half confidence interval	0.9	1.8	1.7	2.2	1.9	1.7	1.6	1.7	1.6	2.1	1.7	1.7
Confidence interval min.	2.2	2.3	2.0	2.3	6.0	4.0	8.4	8.4	5.2	4.0	10.8	9.0
Standard deviation max.	4.7	6.6	6.8	6.4	11.4	8.0	13.1	13.3	9.8	9.8	15.7	13.5
Standard deviation min	1.5	1.6	0.6	2.6	4.4	3.4	6.9	6.9	3.8	2.4	9.3	7.9
Confidence interval max.	4.0	5.9	5.4	6.7	9.8	7.4	11.6	11.8	8.4	8.2	14.2	12.4

The hedonics assessment in Figure 79 paints a similar picture. Once again the combination received the worst assessments. There was a strong decline in the hedonics assessment of the levelling compound on day 28.

Figure 79: Hedonics for parquet (UBA Haus 2019)



	Day3	Day28	Day3	Day28	Day3	Day28	Day3	Day28	Day3	Day28	Day3	Day28
Hedonics mean value	-0.1	-1.1	-0.1	-2.6	-1.2	-1.1	-1.3	-1.7	-0.8	-0.8	-1.6	-1.8
Half confidence interval	0.5	0.7	0.7	0.7	0.8	0.8	0.6	0.9	0.5	0.5	0.7	0.7
Confidence interval min.	-0.6	-1.8	-0.8	-3.3	-2.0	-1.9	-1.9	-2.6	-1.3	-1.3	-2.3	-2.5
Standard deviation max.	0.9	-0.2	1.2	-1.5	0.3	0.0	-0.2	-0.1	0.1	0.2	-0.2	-0.5
Standard deviation min	-1.1	-2.0	-1.4	-3.7	-2.7	-2.2	-2.4	-3.3	-1.7	-1.8	-3.0	-3.1
Confidence interval max.	0.4	-0.4	0.6	-1.9	-0.4	-0.3	-0.7	-0.8	-0.3	-0.3	-0.9	-1.1

The detailed results of the VOC and aldehyde measurements are listed in Annexe 6.3 (Tables 47-58). The measured concentrations of the emitted substances for primer, screed, levelling compound and parquet adhesive were negligible and far below the respective LCI values. The main emitter for industrial parquet was acetic acid, but it provided low concentrations (day 7: 43 µg/m^3 and day 28: 11 µg/m^3). The sealing showed low emissions only on day 3, the highest concentration was 19 µg/m^3 triethylamine. Of the products used in “UBA Haus 2019”, most emissions were measured in the combination of materials (Table 18). The concentrations of the emitted substances decreased over time so that the combination would pass a test based on the AgBB scheme on day 28.

Table 18: Concentrations of selected compounds from the combination parquet

Substances	CAS No.	Day 7 (µg/m³)	Day 28 (µg/m³)
Acetic acid	64-19-7	71	30
Triethylamine	121-44-8	5	n.m.
4-Ethylmorpholine	100-74-3	14	n.m.
Ethylene glycol monobutyl ether	111-76-2	169	11
Unknown glycol compound		50	4
Unknown glycol compound		51	7
Unknown glycol compound		94	10
2-Butoxyethyl acetate	112-07-2	63	n.m.

6.4 Interim conclusions

The tests in “UBA Haus 2019” showed that the intensities detected during construction measures (CP 1-3) were in the medium quality range. The mechanical ventilation system was not in operation during this phase. With the exception of a few rooms, the intensity essentially decreased with time, i.e. after completing the construction. Irrespective of building products, use of the rooms brought in other odour and exposure (Immission) sources such as books, paper, perfume, tea etc. These influenced the perceived air quality assessments, as was seen in the hedonics assessment. In addition, the ventilation system was put into operation which had a positive effect on the intensities. This is a demand-oriented ventilation system which only delivers an increased volume flow when the rooms are being used. The air supply for the respective room is switched off when it is not being used. Due to non-use and therefore no additional ventilation, some rooms (e.g. the first-aid room) showed higher intensity assessments. Overall, the room air quality was in the medium range. The analytical tests showed good results for a new building; no guide values were exceeded in the analysed rooms on the last test day.

The product tests examined a large number of building products used and their combinations. The results were generally very good and the products largely met the proposed Blue Angel requirements. Increased intensities were caused by the industrial parquet used and the combination including this product. These high assessments were not found in the indoor air of the rooms.

Most of the materials used were low-emission.

7 Test object office renovation

7.1 Object description

This section monitored the renovation of new office rooms on the 7th floor of a large office building in Berlin. That floor did not have a ventilation system therefore ventilation occurred only manually by opening the windows. The preliminary stage of the odour assessment determined the air exchange in two rooms. The following figures show the results of the tests.

Figure 80: CO_2 drop in concentration in room 1 (office renovation)

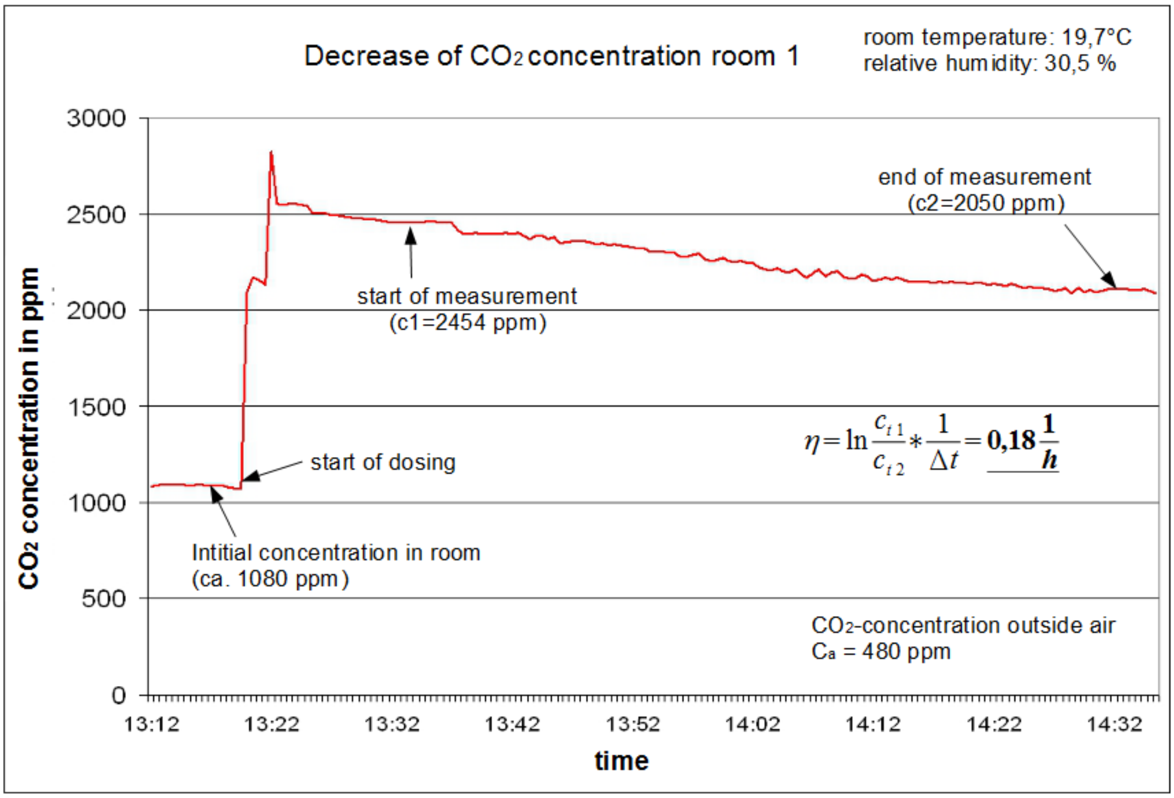
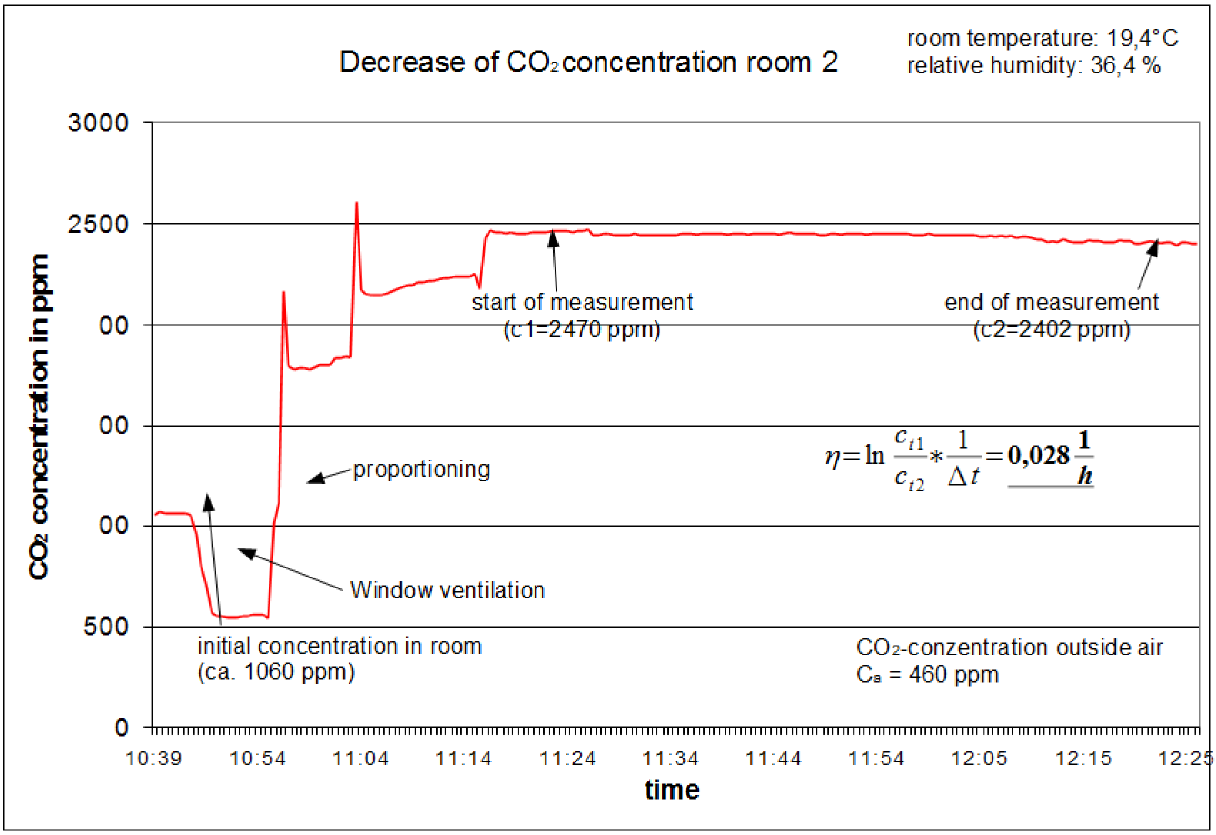


Figure 81: CO_2 drop in concentration in room 2 (office renovation)



The selected concentration of the indicator gas CO_2 to be spiked was approximately 2500 ppm. A comparison of the two figures reveals that room 1 had a larger drop in concentration. This may be due to the fact that the door of room 1 did not close as tightly as that of room 2. Nevertheless, both air exchange rates of 0.028 l/h and 0.18 l/h were very low and were below the recommended hygienic minimum air exchange rate of 0.5 l/h.

7.2 Indoor air measurements

Sensory-based and analytical assessments were carried out during certain construction phases or periods of use in the course of the office floor renovation. Since renovation prevented an on-site assessment, analyses were carried out via the room air sampling method using the AirProbe and a subsequent assessment in the HTW air quality laboratory.

The following table shows a timeline of the tests carried out:

Table 19: Timeline of office renovation

Construction phase	Date	Description
1	07.05.2013	Assessment of 10 indoor air samples after application of floor screed
2	31.05.2013 14.06.2013	Assessment of 10 indoor air samples after application of floor covering (carpet/linoleum)
3	10.07.2013	Assessment of 10 indoor air samples after moving into the office rooms (including furnishing)
4	12.09.2013	Assessment of 10 indoor air samples after approximately two months of use
5	16.10.2013	Assessment of 10 indoor air samples after approximately three months of use

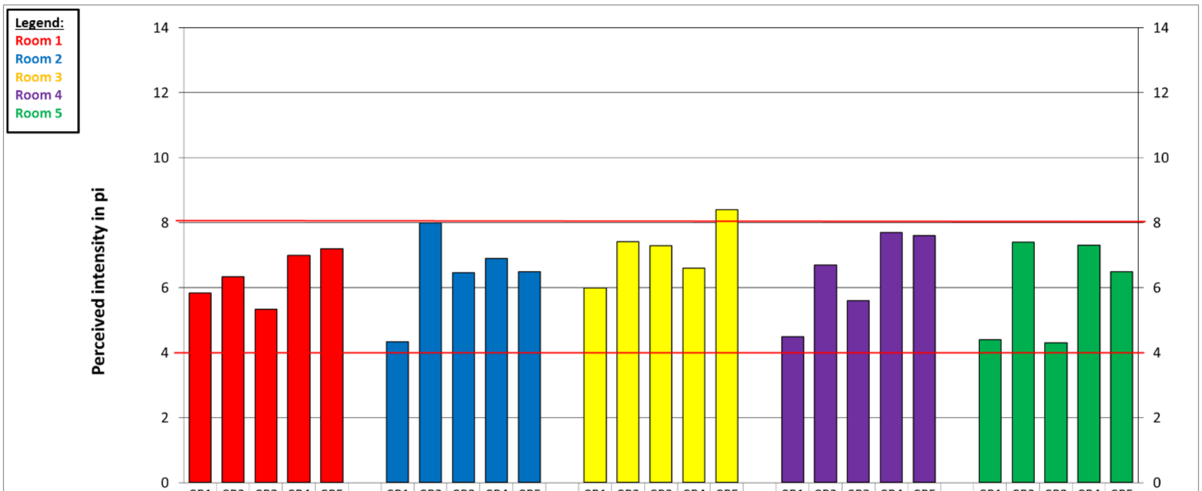
Table 20 lists the tested rooms and features on tests days (construction phases).

Table 20: Room overview (office renovation)

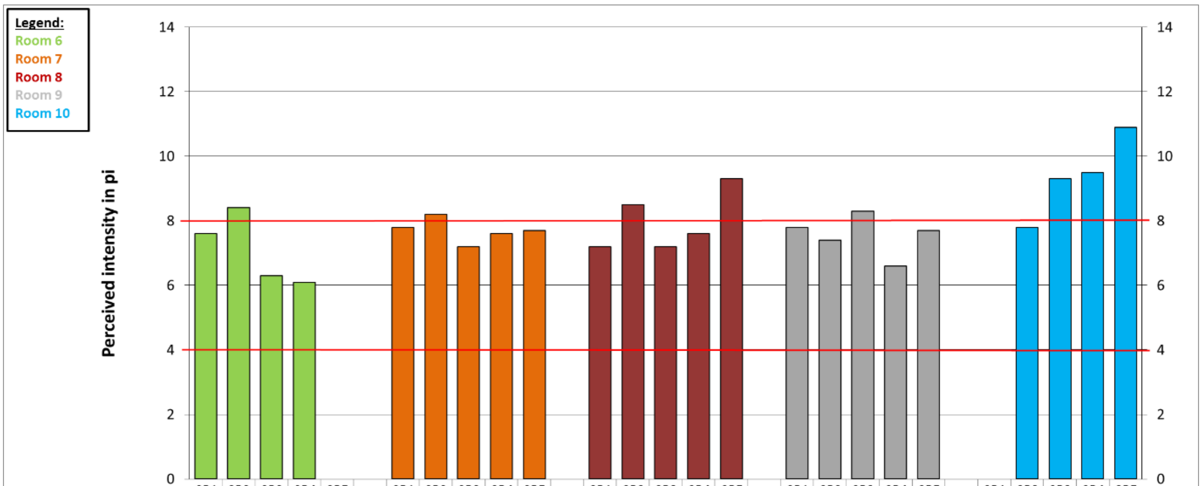
Room	Room description	CP 1	CP 2	CP 3	CP 4	CP 5
1	Office (14.5 m²)	Plastered walls, no door	Empty (carpet)	Unused (furniture)	Unused (furniture)	Unused (furniture)
2	Office (33 m²)	No door, furniture, cartons, gypsum plasterboards	Empty (carpet)	Unused (furniture)	Unused (furniture)	Unused (furniture)
3	Office (29.5 m²)	Empty, plastered walls	Empty (carpet)	Used (furniture)	Used (furniture)	Unused (furniture)
4	Office (14.5 m²)	Empty, plastered walls	Empty (carpet)	Used (furniture/ perfume)	Unused (furniture)	Used (furniture)
5	Office (13.5 m²)	Empty, plastered walls	Empty (carpet)	Used (furniture/ perfume)	Used, ventilated (furniture)	Used (furniture)
6	Meeting room (56 m²)	Empty, no door, ventilated	Empty (carpet)	Furniture deposit	Used (furniture)	Not assessed (inaccessible)
7	Office (29.5 m²)	No door, freshly painted	Empty (carpet)	Unused (furniture)	Used (furniture)	Used
8	Office (14.5 m²)	Empty, painted	Empty (carpet)	Unused (furniture)	Unused (furniture)	Unused
9	Office (14.5 m²)	Empty, painted	Empty (carpet)	Unused (furniture)	Unused (furniture)	Unused (carpet)
10	Gym	Not assessed, (strong plaster odour)	Empty (linoleum)	Unused, stuffy (linoleum)	Unused, stuffy (linoleum)	Unused, stuffy (linoleum)

CP 1 and CP 2 were assessments during renovation. In CP 1, the rooms were freshly painted, plastered or still without doors. In CP 2, the rooms were freshly equipped with floor coverings (carpet or linoleum). The rooms were partly used from CP 3 onwards and some foreign odours were detected. The table contains the descriptions "used" and "unused". "Used" means that someone was in the room on the day of the test. "Unused" means that no one was in the room before and during sampling on the day of the test. The descriptions in brackets describe the odour detected during sampling.

Figure 82: Intensity of indoor air (office renovation)



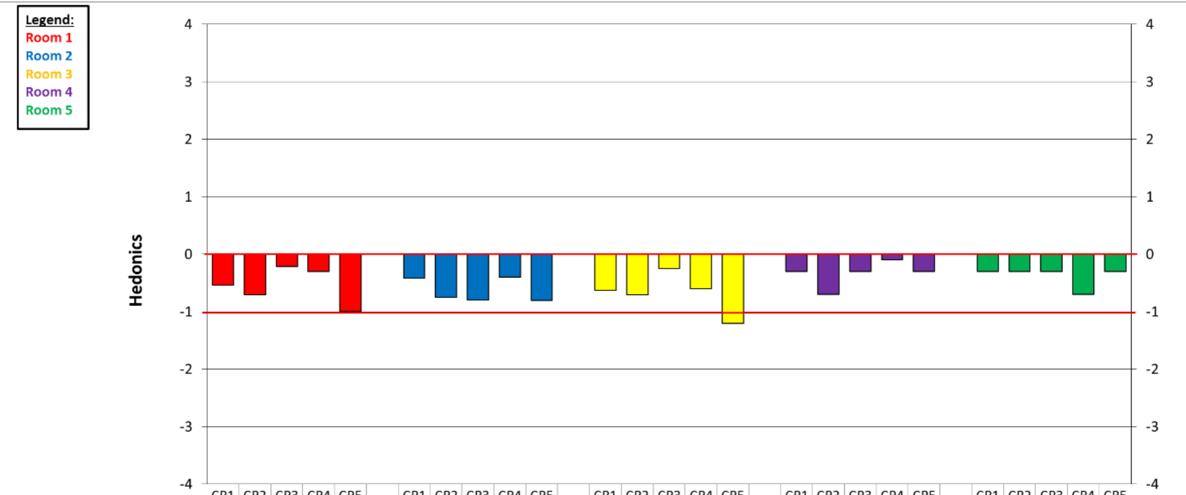
	CP1	CP2	CP3	CP4	CP5	CP1	CP2	CP3	CP4	CP5	CP1	CP2	CP3	CP4	CP5	CP1	CP2	CP3	CP4	CP5	CP1	CP2	CP3	CP4	CP5
Intensity mean value	5.8	6.3	5.3	7.0	7.2	4.3	8.0	6.5	6.9	6.5	6.0	7.4	7.3	6.6	8.4	4.5	6.7	5.6	7.7	7.6	4.4	7.4	4.3	7.3	6.5
Half confidence interval	1.5	1.1	1.1	1.7	1.9	1.6	1.3	1.3	1.7	2.0	1.1	1.0	1.5	1.7	1.8	1.3	1.3	1.3	2.1	2.0	0.8	1.4	1.3	1.8	1.9
Temperature in °C	22.0	24.4	24.8	23.5	22.2	22.0	23.3	24.8	21.2	22.1	21.0	23.7	25.5	21.4	21.5	21.8	23.8	24.7	22.8	20.6	22.1	21.9	24.0	23.6	20.1
Relative humidity in %	50.6	50.4	52.9	53.6	53.8	52.5	53.7	50.9	51.6	52.5	53.6	51.7	52.4	54.3	51.8	51.2	49.8	55.0	50.7	52.7	56.6	56.5	57.4	52.5	56.5



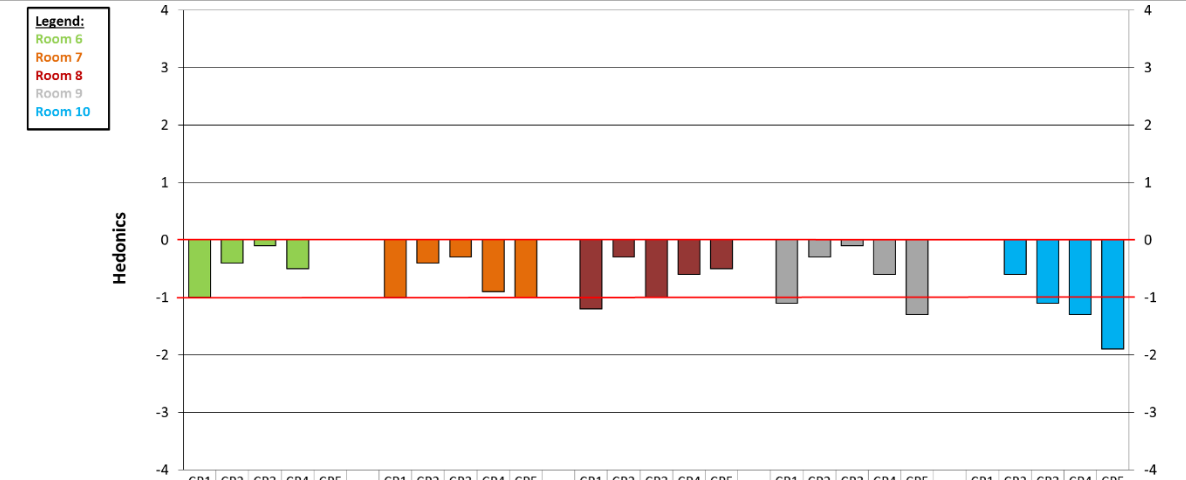
	CP1	CP2	CP3	CP4	CP5	CP1	CP2	CP3	CP4	CP5	CP1	CP2	CP3	CP4	CP5	CP1	CP2	CP3	CP4	CP5	CP1	CP2	CP3	CP4	CP5
Intensity mean value	7.6	8.4	6.3	6.1		7.8	8.2	7.2	7.6	7.7	7.2	8.5	7.2	7.6	9.3	7.8	7.4	8.3	6.6	7.7		7.8	9.3	9.5	10.9
Half confidence interval	1.8	1.9	1.5	1.8		1.6	1.7	1.8	1.9	1.4	1.8	1.4	1.6	1.7	2.0	1.3	1.4	1.6	1.1	1.8		1.2	1.6	2.0	1.7
Temperature in °C	21.7	20.7	24.7	21.5		22.3	21.2	23.5	23.7	22.4	22.0	21.6	23.5	23.0	21.3	21.9	21.6	23.8	23.1	20.5		24.6	24.9	24.5	22.9
Relative humidity in %	57.0	60.1	53.1	56.1		58.4	54.3	53.9	57.0	46.2	58.0	54.7	52.1	57.0	53.3	56.4	53.9	53.0	46.1	49.3		55.7	47.9	42.9	47.9

Figure 82 shows the perceived intensities of every room tested on various measurement days (CP 1-CP 5). For the sake of clarity, standard deviations and confidence intervals are not depicted here. Half of the confidence interval is listed in the data table and was adhered to in every test. The intensity increased slightly in most rooms after the second construction phase (CP 2), which indicated the application of floor covering. The intensities dropped somewhat in CP 3 (about one month after CP 2). Room 10 was an exception because it was equipped with linoleum and had the highest intensities compared to the other rooms during the test period. Otherwise, the intensities changed only slightly during the course of the test period and lie, with a few exceptions, in the medium room air quality range (between 6 and 8 pi).

Figure 83: Hedonics of indoor air (office renovation)



	CP1	CP2	CP3	CP4	CP5	CP1	CP2	CP3	CP4	CP5	CP1	CP2	CP3	CP4	CP5	CP1	CP2	CP3	CP4	CP5	CP1	CP2	CP3	CP4	CP5
Hedonics mean value	-0.5	-0.7	-0.2	-0.3	-1.0	-0.4	-0.8	-0.8	-0.4	-0.8	-0.6	-0.7	-0.3	-0.6	-1.2	-0.3	-0.7	-0.3	-0.1	-0.3	-0.3	-0.3	-0.3	-0.7	-0.3
Half confidence interval	0.4	0.5	0.5	0.6	0.6	0.3	0.5	0.7	0.5	0.6	0.3	0.4	0.6	0.5	0.8	0.3	0.5	0.7	0.4	0.6	0.3	0.7	0.6	0.6	0.6
Temperature in °C	22.0	24.4	24.8	23.5	22.2	22.0	23.3	24.8	21.2	22.1	21.0	23.7	25.5	21.4	21.5	21.8	23.8	24.7	22.8	20.6	22.1	21.9	24.0	23.6	20.1
Relative humidity in %	50.6	50.4	52.9	53.6	53.8	52.5	53.7	50.9	51.6	52.5	53.6	51.7	52.4	54.3	51.8	51.2	49.8	55.0	50.7	52.7	56.6	56.5	57.4	52.5	56.5



	CP1	CP2	CP3	CP4	CP5	CP1	CP2	CP3	CP4	CP5	CP1	CP2	CP3	CP4	CP5	CP1	CP2	CP3	CP4	CP5	CP1	CP2	CP3	CP4	CP5
Hedonics mean value	-1.0	-0.4	-0.1	-0.5		-1.0	-0.4	-0.3	-0.9	-1.0	-1.2	-0.3	-1.0	-0.6	-0.5	-1.1	-0.3	-0.1	-0.6	-1.3		-0.6	-1.1	-1.3	-1.9
Half confidence interval	0.4	0.5	0.7	0.7		0.4	0.5	0.7	0.4	0.5	0.5	0.5	0.6	0.9	0.7	0.4	0.5	0.7	0.7	0.7		0.6	0.8	0.7	1.0
Temperature in °C	21.7	20.7	24.7	21.5		22.3	21.2	23.5	23.7	22.4	22.0	21.6	23.5	23.0	21.3	21.9	21.6	23.8	23.1	20.5		24.6	24.9	24.5	22.9
Relative humidity in %	57.0	60.1	53.1	56.1		58.4	54.3	53.9	57.0	46.2	58.0	54.7	52.1	57.0	53.3	56.4	53.9	53.0	46.1	49.3		55.7	47.9	42.9	47.9

Figure 83 shows the hedonics assessment of the indoor air tests. These values also lie mainly in the medium quality range (between 0 and -1). The same as for intensity, room 10 (light blue) also received the worst assessment in this case.

In addition to the odour tests, VOC and aldehyde concentrations in the indoor air of rooms 1, 3, 5 and 8 were also measured. The detailed results can be found in Annex 7.2 (Tables 67 to 74).

Higher indoor air concentrations were measured during renovation, after applying the floor screed (CP 1) and floor covering (CP 2). Since the floor in the office building was being renovated at the time, VOC contents in the indoor air were not conspicuous. TVOC values of 475 µg/m^3 (via TE) and 575 µg/m^3 (the sum of individual values) were measured in room 5 in CP 1. The detected VOC constituents did not exceed the guide values at the time of the test. TVOC values of 530 µg/m^3 (via TE) and 610 µg/m^3 (the sum of individual values) were measured in room 8. The formaldehyde concentration in this room (147 µg/m^3) was above the guide value of 120 µg/m^3. Since renovations had recently been carried out in rooms 1 and 3, further sampling in these rooms did not appear to be appropriate.

The highest indoor air concentrations were detected in every tested room during CP 2. In room 1 TVOC values of 1360 µg/m³ (via TE) and 1520 µg/m³ (the sum of individual values) were measured. The GV I for certain glycol compounds was exceeded in this room. The formaldehyde concentration in room 1 was relatively high (100 µg/m³) but still below the guide value of 120 µg/m³. TVOC values in room 3 reached 1155 µg/m³ (via TE) and 1480 µg/m³ (the sum of individual values). The GV I for certain glycol compounds was also exceeded in this room. The formaldehyde concentration of 90 µg/m³ was below the guide value. TVOC values in rooms 5 and 8 were lower than in the first two offices (room 5: 660 µg/m³ (TE) and 850 µg/m³ (the sum of individual values), room 8: 700 µg/m³ (TE) and 800 µg/m³ (the sum of individual values)). The GV I for certain glycol compounds was also exceeded in these rooms.

The higher indoor air concentrations in CP 2 generally correlated with an increase of the intensity values. However, the hedonics in CP 1 received worse assessments for some rooms.

The indoor air concentrations decreased from CP 3 onwards. Room 5 measured very low TVOC values (40 µg/m³ (via TE) and 58 µg/m³ (the sum of individual values)). The room was furnished, had been in use for approximately two weeks and was thus also regularly ventilated. The window was tilted just before sampling. TVOC concentrations in room 8 were higher (570 µg/m³ (via TE) and 500 µg/m³ (the sum of individual values)), the room was furnished but was not yet in use, which means it was also not regularly ventilated. The TVOC values of the indoor air after a renovation were therefore not striking. In the case of the detected individual substances, an excess (143 µg/m³, DNPH method) of the GV I of 100 µg/m³ was detected in room 8 for the aldehydes substance group C4 to C11, saturated, acyclic, aliphatic. The hexanal concentration of 94 µg/m³ (DNPH method) was also noticeable, which may have contributed to the perceived unpleasant odour (see also Figure 82). The formaldehyde concentration in room 8 was still relatively high at 85 µg/m³.

TVOC concentrations decreased to below 300 µg/m³ by the end of the test period and corresponded to level 1 'hygienically harmless' of the reference value concept of the Committee on Indoor Guide Values. (Web page Umweltbundesamt)

Figure 84 and Figure 85 show the formaldehyde, acetaldehyde and hexanal concentrations (measured using the DNPH method) in rooms 5 and 8 over the test period. The high formaldehyde values already mentioned reached concentrations of approximately 40 µg/m³ by the last measuring day. An additional strong increase of these values was observed in room 8 from CP 2 to CP 4. Room 8 was not used until the last test day and therefore not regularly ventilated. High concentrations of hexanal were also detected in this room, which amounted to 44 µg/m³ in CP 5. Hexanal is an odour-active substance and may have contributed to the smell. The hexanal concentrations in room 5 were lower than in room 8, but the concentration increased continuously (up to 24 µg/m³ by the last test day). Both rooms experienced an increase of the acetaldehyde concentration from CP 4 to CP 5.

Figure 84: Aldehyde concentrations in room 5 (DNPH method)

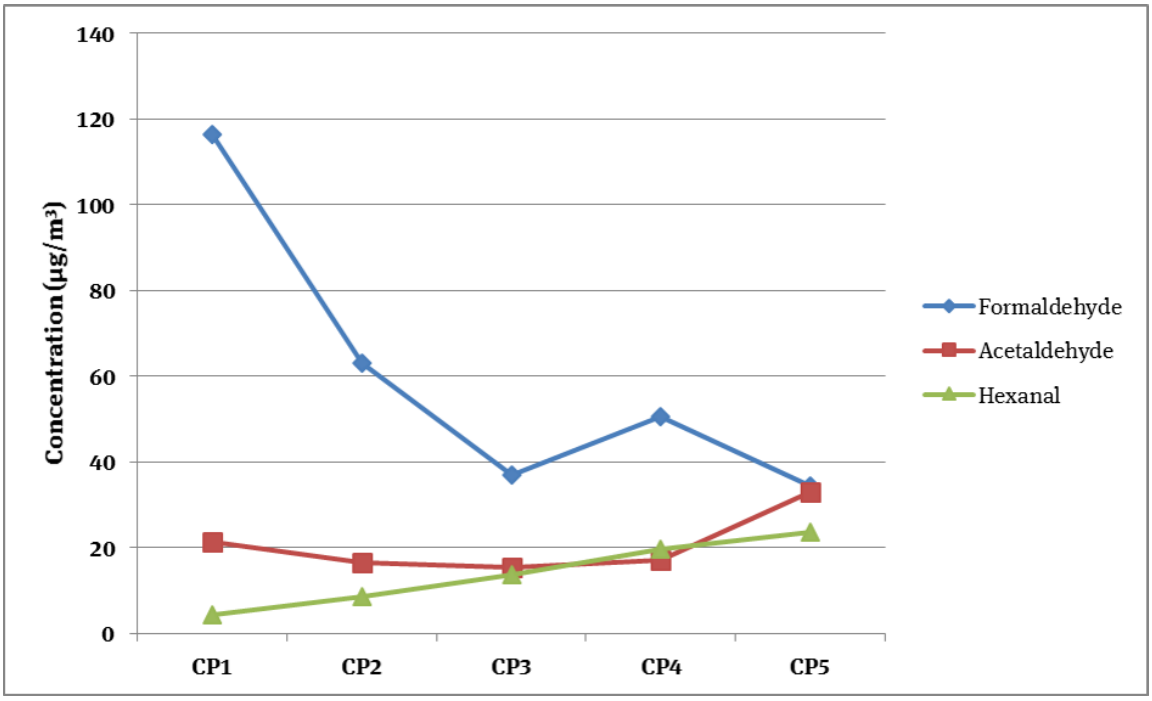
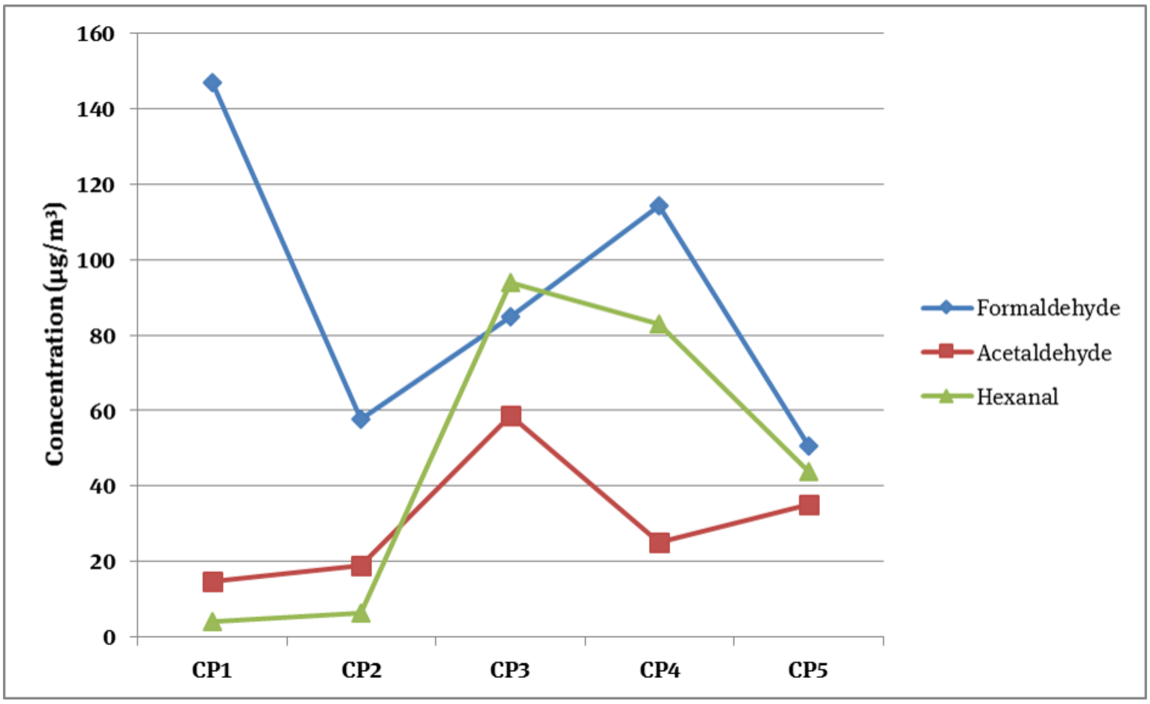


Figure 85: Aldehyde concentrations in room 8 (DNPH method)

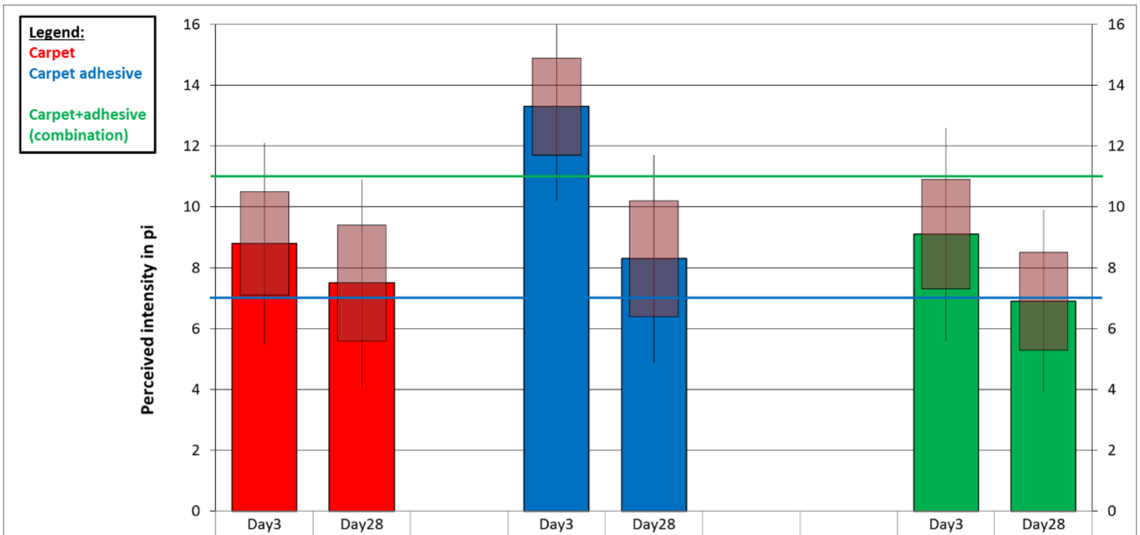


7.3 Product tests in the air quality laboratory

The objectives of this investigation also included assessing products in emission chambers (CLIMPAQ) in the air quality laboratory. The items tested were a carpet covering, a corresponding carpet adhesive and the combination of these two products.

Figure 86 shows the intensities determined on day 3 and day 28 after loading the products into the chambers. It is noticeable that the carpet adhesive (blue) exhibited about 13 pi on day 3 – a very high intensity. However, the same value was not shown by the combination (green) of the products: its intensity was around 9 pi i.e. within the range of the carpet covering (red). By day 28, the intensity of the adhesive had also decreased. The carpet covering had an intensity of about 7 pi and therefore lay in the range of the combination. This suggests that the intensity of the combination of the two products appears to be mainly influenced by the carpet.

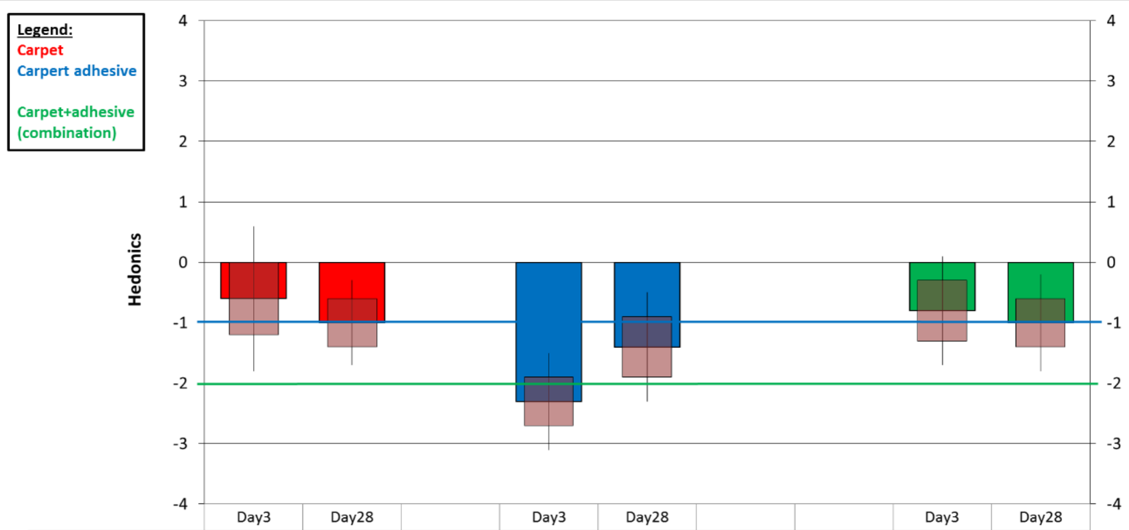
Figure 86: Product intensity (office renovation)



	Day3	Day28		Day3	Day28			Day3	Day28
Intensity mean value	8.8	7.5		13.3	8.3			9.1	6.9
Half confidence interval	1.7	1.9		1.6	1.9			1.8	1.6
Confidence interval min.	7.1	5.6		11.7	6.4			7.3	5.3
Standard deviation max.	12.1	10.9		16.4	11.7			12.6	9.9
Standard deviation min	5.5	4.1		10.2	4.9			5.6	3.9
Confidence interval max.	10.5	9.4		14.9	10.2			10.9	8.5

The hedonics assessment in Figure 87 underpins this finding. The somewhat unfavourable assessments of the adhesive do not affect the combination and their assessments match those of the carpet.

Figure 87: Product hedonics (office renovation)



	Day3	Day28		Day3	Day28			Day3	Day28
Hedonics mean value	-0.6	-1.0		-2.3	-1.4			-0.8	-1.0
Half confidence interval	0.6	0.4		0.4	0.5			0.5	0.4
Confidence interval min.	-1.2	-1.4		-2.7	-1.9			-1.3	-1.4
Standard deviation max.	0.6	-0.3		-1.5	-0.5			0.1	-0.2
Standard deviation min	-1.8	-1.7		-3.1	-2.3			-1.7	-1.8
Confidence interval max.	0.0	-0.6		-1.9	-0.9			-0.3	-0.6

VOC and aldehyde emissions from the materials used were also tested. The detailed results are presented in Annex 7.3 (Tables 75-80). The products generally showed low emissions on day 28 thus all would pass a test based on the AgBB scheme. In a similar way to odour assessments, some substances detected by the emission measurement of the combination (carpet + adhesive) were also found in the chamber test air of the carpet (for example, 4-phenylcyclohexene, alkane peak (Alkanberg)). The substance 4-phenylcyclohexene (typical for carpet emissions) was detected in the indoor air after placing the carpet into the rooms.

7.4 Interim conclusions

The indoor air tests showed that the rooms exhibited intensities in the medium room air quality range. The biggest problem was that only manual ventilation was available. Particularly high intensities occurred in unoccupied rooms that were not regularly aired (air exchange rates dependent on outside conditions were around 0.1 air exchanges per hour). Also, any odour nuisances emitted from furniture or building products hardly had any chance to dissipate.

Very low air exchange rates were found in the rooms. The consequence is that no matter which odour nuisance or other substances are introduced into the room, they cannot be vented away. These substances can only be removed by opening a window for ventilation. When using the rooms, a rapid increase in the CO_2 concentration can be expected in addition to the existing emissions. A human being emits about 20 l/h of CO_2 when sitting.

The intensity assessment of the building materials used provided values in a range of between 7 and 8 pi on day 28. The combination of the two products yielded 7 pi which was in the same range. These products are not particularly odorous. The results of the indoor air measurements in the selected offices showed inconspicuous TVOC values on the last test day.

All offices, except room 8, were used and thus aired during the presence of the users. However, there were odours in some unused rooms due to a long absence (e.g. business trips). As already mentioned, the removal of odour emissions from building products or equipment was rather difficult due to the low air exchange rate. Some odour-active aldehydes were measured in concentrations where odour perception cannot be excluded.

8 Summary/Outlook

In this research project the indoor air quality in energy-efficient buildings has been investigated with regard to odours and volatile organic compounds.

The original aim of the study was to investigate the indoor air quality of energy-efficient retrofitted buildings using the example of the German Environment Agency's (Umweltbundesamt, UBA) Bismarckplatz office building in Berlin. Due to the postponement of the remediation works for the Bismarckplatz office building, the project specification was changed in agreement with UBA and the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB). The new building "UBA Haus 2019" and one floor in an office building to be renovated were included in the new project specification. Both buildings are located in Berlin. In addition, further olfactory analyses of various wall and floor assemblies installed in test rooms of the eco-INSTITUT in Cologne were conducted. For the evaluation of the indoor air quality in the test rooms of UBA Bismarckplatz and eco-INSTITUT Cologne, direct and air sampling methods (AirProbe) were used. The two assessment methods provided comparable results.

Around 60 single products and combinations of materials have been tested in emission chambers. These products were also placed in the new or refurbished buildings or evaluated in real test rooms. Many of the single products examined achieved very good olfactory evaluations and, consequently, most of them fulfilled the proposed Blue Angel and AgBB criteria for odour assessment. Furthermore, the product evaluations from this project provide excellent information for an olfactory database which can be used in future projects. In this way various products can be compared and materials can be selected according to their odorous properties before placing them in buildings.

The results of this project show the influence of combinations of various single products on the perceived indoor air quality. The assessment of the perceived intensities for the single products can be found again in the results for the combinations. The corresponding emission measurements show a similar behaviour. The comparison of the indoor air and product testing in chambers reveals the fact that odour emissions from building products can be found in the indoor air.

By measurements in real test rooms one has to consider that the temperature and humidity of the room air cannot always be adjusted as in the laboratory. The laboratory tests take place under constant and defined ventilation; therefore different test conditions are possible. Further measurements of combinations of materials have to be conducted to achieve a larger database and to be able to draw appropriate conclusions.

The measurements of the VOC and aldehyde concentrations show good results in all tested objects on day 28. The selection of products has a big influence on the emissions. During the renovation work, higher concentrations of chemicals were measured in the indoor air of the tested rooms. These values declined over the investigation period. Due to a low air exchange rate in "unused" rooms the VOC and aldehyde concentrations show a slower decay over the measurement phases. In this case it has to be ensured that the hygienically recommended minimum air exchange rate of 0.5 1/h is achieved.

The materials used in the buildings show low or very low emissions.

The results show that the use of unobtrusive materials in terms of odour and VOC emissions can lead to a good indoor air quality.

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