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Passive flux sampling – a new method for measuring emissions from floor constructions

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Contents

1. Introduction
 2. Passive flux sampling – PFS
 3. Project design
 - 3.1 The CR-project
 - 3.2 The SP-project
 - 3.3 Materials
 - 3.4 Field studies
 4. Measurements
 - 4.1 Moisture measurements
 - 4.2 Emission measurements
 5. Results
 - 5.1 PFS-methodology
 - 5.1.1 Measuring under the flooring
 - 5.1.2 Measuring on top of flooring
 - 5.1.3 Measuring at different positions
 - 5.1.4 Influence of sampling times
 - 5.1.5 Influence of the environment
 - 5.1.6 Transport of PFS-cup
 - 5.1.7 Relation to FLEC-measurements
 - 5.2 Factors influencing emissions
 - 5.2.1 Various concretes
 - 5.2.2 Various levelling compounds
 - 5.2.3 Combinations concretes/levelling compounds
 - 5.2.4 Various adhesives and floorings
 - 5.3 Moisture barrier as primer
 - 5.3.1 Two-sided drying
 - 5.3.2 One-sided drying
 - 5.4 Field tests
 - 5.5 Costs
 6. Conclusions
 - 6.1 The PFS-method
 - 6.2 Factors influencing emissions
 7. Summary
 8. Acknowledgement
 9. References
-
- Appendix A. CR-project
 - Appendix B. SP-project
 - Appendix C. Measurements under the flooring with PFS at CR
 - Appendix D. Measurements on top of the flooring with PFS at CR
 - Appendix E. Measurements on top of the flooring with PFS at CR
 - Appendix F. Measurements on top of the flooring with PFS at CR
 - Appendix G. Measurements on top of the flooring with FLEC at SP
 - Appendix F. Weight results from SP-project
 - Appendix I. Moisture measurements, CR-project
 - Appendix J. Field measurements
 - Appendix K. Materials

Preface

This report gives the details from two parallel projects of measuring emissions from alkali attack on adhesives and floorings. Johan Alexanderson has published some of the results previously in Swedish, but he wrote this report to make all the details from the experiments available in English.

The report is published in our research report series since Johan Alexanderson's work is close to some of the research being done at the division of Building Materials at Lund Institute of Technology and we are continuously having discussions on these matters. Additionally, once he defended his PhD-thesis at the division.

Lars-Olof Nilsson

Head of the division of Building Materials at Lund Institute of Technology

1. Introduction

In the late 1980s, the existence of secondary emissions from floor constructions was discovered and believed to have an importance in relation to Sick Building Syndromes (SBS). In this case, “secondary” means that emissions from a floor construction could be different, both in magnitude and character, from the emissions of the separate parts of the floor construction (substrate, adhesive, flooring). The first “new” emission that was observed was 2-ethylhexanol, and it was believed to emanate from the DEHP plasticizer in PVC flooring. Later on it was discovered that 2-ethylhexanol also could come from adhesives based on hexyl acrylates. Further, also 1-butanol was observed as a secondary emission, and it could be traced back to adhesives based on butyl acrylates.

Parallel to these discoveries, a new method to measure emissions was developed, the FLEC (Field and Laboratory Emission Cell). This method is much simpler to use than the traditional chamber method, and can be used both for primary emissions from single materials, e.g. a flooring, and for combined constructions, such as a flooring adhered to a concrete substrate. Numerous laboratory studies have been made over the years with the FLEC-method, see e.g. the reference list in (Alexanderson 2004).

These studies have dealt with the influence of various factors, such as the moisture level in concrete, different concrete qualities, different levelling compounds, adhesives and floorings etc. The studies have convincingly shown that a low alkaline substrate, such as a levelling compound based on High Alumina Cement (HAC) as the main binder, is of utmost importance to decrease the risk for alkaline hydrolysis of adhesive and PVC flooring, and thereby minimizing the risk for secondary emissions of 2-ethylhexanol and 1-butanol from the floor construction.

2. Passive flux sampling – PFS

Although the FLEC-method can be used not only in the laboratory, but also in the field (as the name says), it is a rather awkward field method. It requires supply of clean air from gas tubes, and this air has to be flushed over the surface to be investigated for some time before the actual collection of the emissions is done. This limits the number of measuring points because the cost of testing is high.

In order to get quicker response, when measuring in the field, some consultants have applied a technique where the flooring is removed, e.g. a 25 mm circular hole, and then the emission is measured with FLEC after a very short time of flushing clean air, e.g. 10 minutes (Grantén 2004).

The idea of passive flux sampling, PFS, which comes from Japan (Kai et al. 2003), is to get a much simpler and cheaper field method compared to the FLEC. Thereby it should be possible to use it more routinely as a quality assurance method to verify that no problems with secondary emissions will occur. And it could also be a valuable tool in the case of SBS-problems, to identify if emissions from the floor construction are unusually high, and if so, to what extent in the building.

The passive flux sampler, PFS, is a cup with an inner diameter of 38 mm and an inner depth of 15 mm. The bottom of the cup is filled with Tenax that is covered with a mesh and a spring to hold the Tenax in place, see Figure 1.



Figure 1. The PFS cup with assembly parts to hold the Tenax in place.

When taking the sample from a surface, the cup is placed upside down for a certain time, and the emissions coming from the surface are absorbed by the Tenax and can then be analyzed in conventional manner by GC-FID or GC-MS. In the laboratory, where most of the tests in this project have been done, the application of the cup on the surface is done directly after the preparation of the cup.

In a field test, the prepared cup has to be transported to the site and back again after the sample has been taken. In order to avoid uptake of emissions during transport, a screw cap is put on the cup and then the cup is placed in an outer container, also with a screw cap. In this outer container Tenax is placed in the bottom to catch any emissions leaking in from the environment during transport, see Figure 2.



Figure 2. The bigger transport cup has Tenax in the bottom and can hold two PFS cups to avoid uptake of emissions during transport.

In the first part of the project, measurements were done after taking up a circular hole in the flooring, as this is the technique that has been used earlier with the FLEC method. The emissions under the flooring are much higher than those coming through the flooring, and it is of course of great importance how long the time delay is between opening the hole and taking the sample of emission (the so called conditioning time).

In the beginning of the project, different conditioning times were used. It was found out that the decay of emissions from the opened hole is very rapid directly after the opening and there is stabilization after some time. Therefore all emissions under the flooring that are given in this report have 24 hours conditioning time and 30 minutes sampling time (except where the decay of emissions is demonstrated in Table 1 and in Figure 5 in paragraph 5.1.1).

For various reasons, the method of measuring emissions under the flooring was abandoned in the project, and in the later part of the project all measurements are done on top of the flooring, see 5.1.1.

3. Project design

The project that is reported here has mainly been carried out at Cementa Research AB in Slite on the Swedish island of Gotland and it has been going on from 2005 to 2009 – *the CR-project*. It has mostly been laboratory measurements, but also some field tests. Some comparisons have been made with FLEC-measurements carried out at the Swedish Technical Research Institute in Borås (SP). A parallel project that was carried out at SP using the FLEC is also reported here – *the SP-project*.

3.1 The CR-project

The CR-project consists of four parts with details shown in Appendix A. All the test specimens in the CR-project were cast in circular plastic moulds with a diameter of 380 mm (series A and B) or 300 mm (series C and D). The bottom was made of wood, covered with a plastic sheet, so that there was one-sided drying in the climate 23°C and 50% RH. In most cases, when K30 concrete was used, an initial drying period of 28 days was followed by water curing for 7 days to simulate situations that often happen in practice. After a second drying period that could vary, a PVC flooring was applied with adhesive, and the edges were sealed with aluminium tape, see Figure 3.

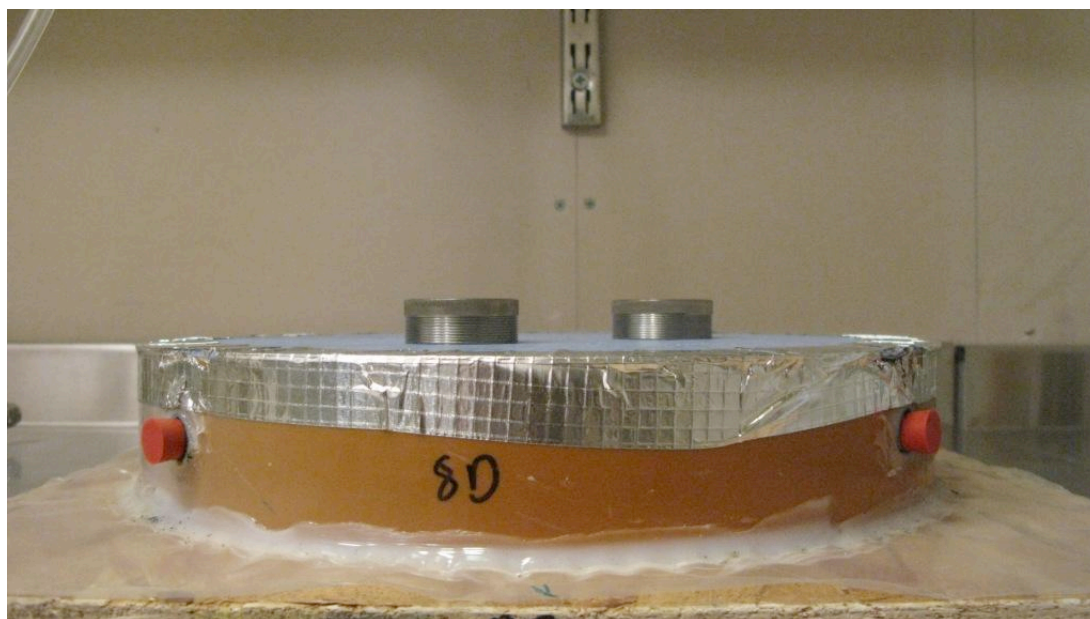


Figure 3. Concrete specimen with flooring and PFS cups in position. Rubber stoppers in holes for moisture measurement in the construction.

Moisture measurements were done either in the construction, on 40% of the height of the specimen, or under the flooring, using a special device. In some cases both these measurements were done.

The PFS-sampling for the emission measurements was done at various times after the application of the flooring. The analysis was done with GC-FID for quantification

of TVOC, 1-butanol and 2-ethylhexanol. In a few cases, GC-MS was done for identification of emissions.

The first part of the CR-project, **series A**, was used for studies of the methodology. In the beginning, only measurements under the flooring were made. Different conditioning times were applied. The *conditioning time* is the time that the hole in the floor is left open, before the PFS-cup is applied. The *sampling time* is the time that the cup is left over the hole, collecting emissions. In this series, two different levelling compounds were used, one so called self-drying (maxit 4160, sample no 1A) and one normal-drying (maxit 4150, sample no 2A). These were compared with two concrete specimens with long drying times (samples 3A and 4A)

Further in series A, four specimens consisted of concrete with different drying times and 5 mm maxit 4150 on top (samples 7A, 5A, 8A and 9A). And finally sample 6A was a reference concrete, as is used in the GBR industry protocol for the measurement of emissions from combined floor structures (GBR 2004).

In **series B**, the conditioning time was fixed to 24 hours, in order to avoid measuring at a time when the release of emissions from the open hole is changing rapidly, as it is in the beginning after removing the flooring (see 5.1.1). The sampling time was set at 30 minutes. Series B was divided in two parts, one with only levelling compounds, and the other one with only concrete.

The self-drying compound, maxit 4160, was varied with respect to water content and drying time, in order to see the influence of deviations from the nominal 21% water and 24 hours drying time, which are prescribed (Samples 1B -5B). Samples 6B-8B are also 4160, but using different adhesives. Samples 9B-12B have different levelling compounds, where 12B is a reference specimen, maxit 4150, with small thickness and long drying time.

The concrete samples 13B-16B are K30 concretes with the second drying time between 1 and 8 weeks and sample 17B is a low water/cement ratio concrete with 28 days drying time.

The results from series A and B led to the conclusion that measurements under the flooring are very unreliable – more about that later on in the report, 5.1.1 – and therefore in **series C**, measurements were only done on top of the flooring. This is of course a great simplification, especially for field measurements where you do not want to damage the flooring. The objective of series C was to validate measurements on top of the flooring. One aspect was to find out how soon the emissions appear on top of the flooring. Therefore the most aggressive substrate was used in samples 5C-7C, i.e. a reference concrete that only had one day drying time. And since the type of flooring was expected to have an influence in this respect, it was varied. These three floorings were also measured on a neutral substrate, plasterboard (samples 1C-3C). Sample 4C is a duplication of sample 2C tested in a different environment.

Samples 8C-12C are repetitions of samples with levelling compounds or concrete which were used in series A and B. For special reasons – which will be described

later on in 5.1.2 – sample 13C was a duplication of sample 6C and sample 14C was the same, but without adhesive.

Series C was designed to find out the following:

- How soon will alkaline degradation below the flooring show up as emissions on top of the flooring?
- What is the influence of sampling time?
- What is the influence of the type of flooring?
- What is the influence of the surrounding at the time of sampling?

Series D is really not a part of the evaluation of the PFS-method, but was made as a parallel to the SP-project – as described below. In all the samples of series D (except sample 4D), a moisture barrier was used as a primer before 5 mm maxit 4150 was applied on the substrate, which could be either concrete or a coarse levelling compound. The 4150 was allowed to dry 7 days before the gluing of the adhesive.

The main difference in series D, compared to the SP-project, was that there was no possibility for drying after the application of the flooring, while the related specimens in the SP-project were twice as thick (200 mm) and could dry out downwards. Another difference was that the emission measurements in the SP-project were done with FLEC, while series D used the PFS-method.

3.2 The SP-project

The layout for the SP-project is shown in Appendix B. It consists of two parts, samples 1SP -12SP, for the study of moisture barrier as a primer , and samples 13SP, 15SP,17SP and 19SP for the study of maxit 4150 as protection against alkali degradation (these samples are parallel to samples 7A, 5A, 8A and 9A in series A of the CR-project). Samples 21SP-23SP are reference samples according to the GBR industry protocol for emissions from combined constructions.

The specimens in the SP-project were measured with FLEC, but some samples were also tested with the PFS-method.

3.3 Materials

The composition of the materials used is shown in Appendix K.

The project has used three types of **concretes**. One has been called “K30” as a representative of a normal concrete used in housing projects. The K30 concrete in the CR-project had a somewhat lower cement content and higher water-cement ratio compared to the K30 concrete used in the SP-project. According to present European standardization, the K30 concretes can be considered as C25/30 or C28/35.

In the CR-project, also a higher quality concrete was used, which has been called “K60”. It can be considered as a C50/60. The third concrete was the GBR reference

concrete, which is the standard composition used when testing cement. It does not contain any coarse aggregate.

The **levelling compounds** used are all from maxit AB and are of the low alkali type, i.e. the binder contains more than 50% of high alumina cement and/or calcium sulphate. Both so called normal drying and self drying products have been used. The compositions are proprietary.

The **adhesives** and the **floorings** have mostly been GBR reference materials. But in some cases commercial adhesives and floorings have been used.

3.4 Field testing

One important objective of the PFS-project was to find out if the method is feasible for field studies. Therefore, in the CR-project, some samples were used to evaluate this question. One important aspect was to find out the variability with respect to *where* the sampling is done, compared to the variability when the sampling is *repeated* several times at the same position.

Another aspect is the question if the environment when sampling is influencing the results, e.g if there are volatile organic compounds (VOCs) in the room where the floor construction is tested. A similar question is whether the transport of the PFS-cup to and from the field site has an influence. This transport is meant to be done by ordinary postal mail, where the environment cannot be controlled.

4. Measurements

All the specimens in the projects were combined constructions, i.e. a flooring adhered to a substrate. Two types of measurements were performed –moisture and emission. The measurements were done at various times after the application of the flooring, ranging from one week up to four years.

4.1 Moisture measurements

The moisture measurements were done either in the construction or under the flooring –in many cases both measurements were performed. The measurements were done with a Vaisala equipment for relative humidity (RH). For measurement in the construction, a tube was located on 40 % of the height from the top of the specimen when the casting was done. The tube was plugged with a rubber stopper, which was removed before each measurement, see Figure 3 above.

The measurements under the flooring were performed using a special device, which was put over a 25 mm diameter hole that had been punched in the flooring, see Figure 4. The Vaisala sensor was put into the cylindrical hole of the device, and was first read after 48 hours and then every day until stable values were obtained. The Vaisala equipment was calibrated regularly.

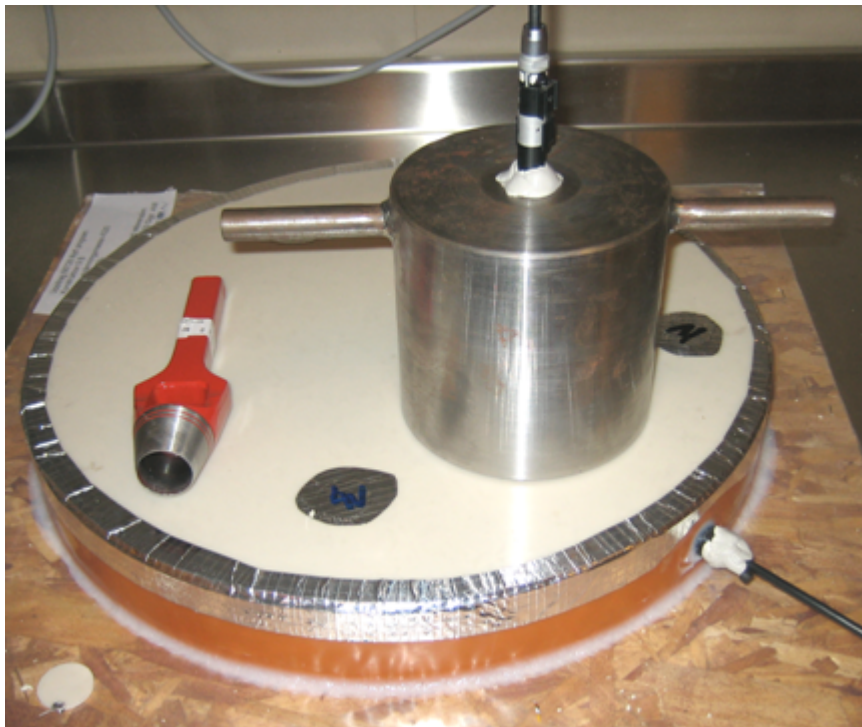


Figure 4. Special device for measuring relative humidity on the surface under the flooring. The punch is used to make the hole in the flooring.

4.2 Emission measurements

The operation of the PFS-cup has been described above in Chapter 2. After the exposure of the PFS-cup, the Tenax was put into a glass tube and analyzed in the

normal way with GC-FID. The emissions of 1-butanol, 2-ethylhexanol and TVOC are reported as emission rates, $\mu\text{g}/\text{m}^2\text{hour}$, and expressed as toluene equivalents.

The result of the GC-FID measurement at CR sometimes came outside the measuring range, (denoted **o.m.** in the following). This is because the instrument at CR has a maximum signal of the detector being 25mV. An increase of the measuring range can be done by changing the split, i.e. how much of the sample air that is allowed to pass the GC column, but a compromise had to be made, covering also other samples than from this project.

At SP, the measurements of emissions were done with FLEC according to the standard method and were reported in the same way as for PFS, i.e. as emission rates. Identification of emissions was done using MS.

5. Results

As the amount of data is quite considerable, it is put in Appendices. The results are found in the following:

Appendix C. Emission measurements under the flooring, CR-project.
 Appendix D. Emission measurements on top of the flooring, CR-project. Series A , B
 Appendix E. Emission measurements on top of the flooring, CR-project. Series C
 Appendix F. Emission measurements on top of the flooring, CR-project. Series D
 Appendix G. Emission measurements on top of the flooring, SP-project.
 Appendix H. Weight measurements, SP-project
 Appendix I. Moisture measurements, CR-project.
 Appendix J. Field tests

In order to facilitate the reading, the discussion of the results is structured as follows:

PFS-methodology

- Under flooring measurements
- Measurements on top of flooring
- Measuring at different positions
- Influence of sampling time
- Influence of the environment at sampling
- Transport of PFS-cups
- Relation to FLEC

Factors influencing emissions

- Various concretes
- Various levelling compounds
- Combination concrete/levelling compound
- Various adhesives and floorings

Field tests

Moisture barrier as primer

- Two-sided drying – SP-project,
- One-sided drying – CR-project

5.1 PFS-methodology

In the beginning of the project, quite some time was devoted to practical issues, such as the design of the cup and lid, how to apply Tenax, how to make it stay in position etc. The result of this work was described in Chapter 2. Although, the procedure seems quite straightforward, as it often is when you are ready, it took some effort to get there. Something similar can be said about measuring under the flooring.

5.1.1 Measuring under the flooring

As was mentioned above, the project started with measuring under the flooring, because we wanted to relate to measurements done by consultants in problem cases and in a laboratory study (Grantén 2004). We used the same diameter for the punched hole, 25 mm, as Grantén, and we also started with very short conditioning times. But we soon realized that the emission is decaying very rapidly after opening the hole. In **Table 1**, the emissions of 1-butanol and 2-ethylhexanol from sample 1B (maxit 4160) and 12B (maxit 4150) are shown after different conditioning times.

Table 1. Decay of emissions after opening of hole in the flooring, $\mu\text{g}/\text{m}^2 \cdot \text{hour}$

Conditioning	1-butanol		2-ethylhexanol	
	4160 (1B)	4150 (12B)	4160 (1B)	4150 (12B)
Hole 10 min	700	500	820	810
Hole 4 hours	600	300	170	400
Hole 8 hours	300	300	60	440
Hole 24 hours	200	200	20	90
On top of flooring	3	1	3	3

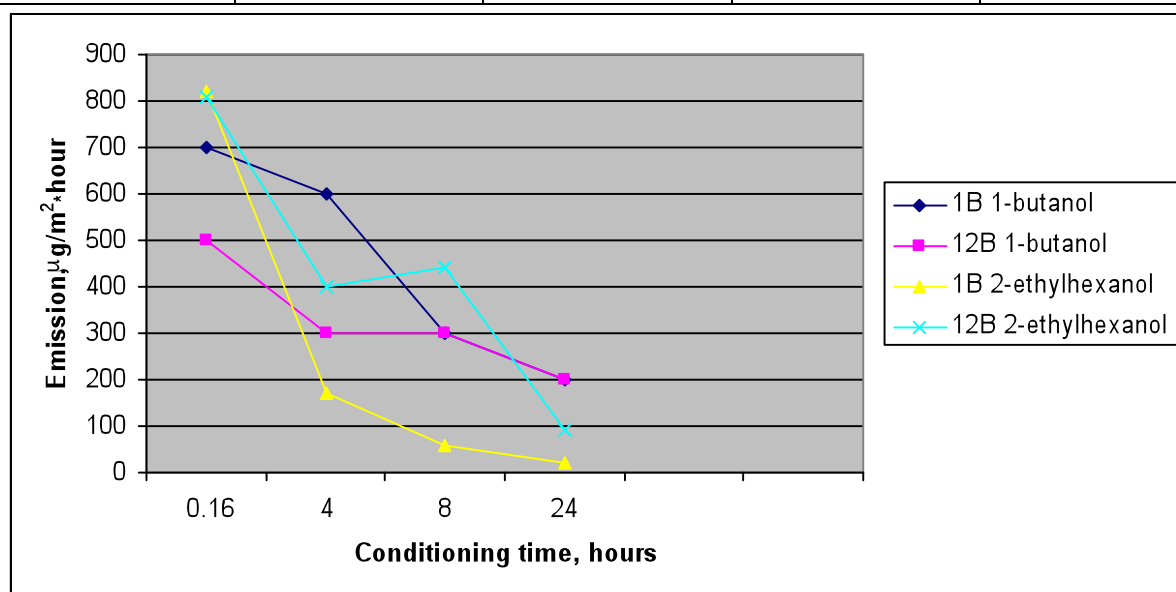


Figure 5. Decay of emissions after opening of hole in the flooring

As can be seen from the table and the figure, the decay of emissions during the conditioning time is quite variable. For 1-butanol, the decay between 10 minutes and 24 hours is 30-40%, while for the 2-ethylhexanol it is 2-11 %. But there is also a difference in decay between the two products, which is most obvious when looking at 2-ethylhexanol. The decay is much more rapid from 4160 than from 4150. Apart from that the two samples were from different products – 4160 is so called self-drying and 4150 is normal-drying – the specimens differed significantly in moisture level. The 4160 had about 80% RH, while the 4150 was the reference sample with the very low RH of about 50%. This could have had an influence on the decay of emissions.

The conclusion from these results is that since the decay after opening a hole in the flooring is so variable, it is very unreliable if you want to interpret the result in quantitative terms. Therefore, the decision was taken to carry on with measurements on top of the flooring, which of course is much more practical and more in line with what really is of interest, viz. those emissions that can influence the room climate. In Table 1, also the emissions on top of the flooring are shown. In this case they are very low.

Although measurements under the flooring cannot be interpreted quantitatively, they can give qualitative indications. Therefore all the measurements done under the flooring made with 24 hours conditioning time and 30 minutes sampling time are given in Appendix C. As an example it can be seen that sample 2A, which is a maltreated maxit 4150 (30 mm thickness, 1 day drying time) has an order of magnitude greater emission of 1-butanol under the flooring, as compared with sample 1A, which is a maxit 4160 (also 30 mm thickness and 1 day drying time).

Another example that really is exceptional is 6A, the GBR reference sample. The first measurement of 1-butanol on this sample after one year was so high that it came outside the measuring range, and the 2 year value was still extremely high. It is well known that the reference concrete is very aggressive. Also the K30 concrete with only one week of drying, sample 13B, stands out with rather high 1-butanol emissions, while the well dried concretes (3A, 4A, 16 B) show emissions in the same order of magnitude as 4160 (1A).

A qualitative interpretation of the under floor measurements can also be seen for the samples 7A, 5A, 8A and 9A, which are K30 concretes with varying drying times (7A being the wettest) with a topping of 5 mm 4150. It is clear from these results that the barrier effect of the low alkali levelling compound 4150 does not function for the wettest concrete. This is in accordance with earlier research (Alexanderson 2004).

The main arguments against measuring emissions under the flooring are:

- The emission from an opened hole is strongly dependent on the conditioning time with a very rapid decay at start. This makes it unsuitable to measure a short time after opening the hole.
- The decay of emissions after opening the hole is dependent on many factors, such as - *the nature of the substrate*, - *the moisture level*, -*what kind of emission that is measured*, -*how long the alkaline degradation has been going on* and probably other unknown factors.
- The effect of the flooring on the transmission of emissions to the room is not included

To summarize the findings from the under floor measurements, they can be used to identify very high emissions, but this can be done with measurements on top of the flooring as well. So there is definitely no point in doing measurements under the flooring, when more relevant information can be obtained on top of the flooring in a simpler way.

5.1.2 Measuring on top of flooring

For reasons stated above, the project proceeded with measurements on top of the flooring from series C and the later measurements in series A and B. Mostly the sampling time was 24 hours.

Samples 5C-7C were designed to find out how soon an emission under the flooring will appear on top of the flooring. Therefore, these specimens used the most aggressive substrate we could think of, viz. the GBR reference concrete that was allowed to dry only one day. The three specimens had different floorings as this was thought to have an influence on how soon the emission would penetrate up to the top of the flooring.

In Table 2 it can be seen that within four weeks, all the specimens showed high emissions on top of the flooring.

Table 2. Emissions on top of flooring on a very aggressive substrate when different floorings are used.

Sample	Emission, $\mu\text{g}/\text{m}^2 \cdot \text{hour}$	Time from floor application			
		1 week	2 weeks	4 weeks	8 weeks
5C Reference	1-butanol	<10	o.m.		
	2-ethylhexanol	24	16	<10	15
6C Tarkett Extra	1-butanol	o.m.			
	2-ethylhexanol	0	10	<10	<10
7C Tarkett Eminent	1-butanol	<10	<10	o.m.	
	2-ethylhexanol	<10	<10	<10	<10

o.m. = outside measuring range

For Tarkett Eminent, which is a 2 mm homogenous PVC, it took the longest time (4 weeks), while the simpler Tarkett Extra, a two layer flooring, was the quickest (one week). The GBR reference flooring was in between.

At these early ages, the emissions consist of 1-butanol coming from the adhesive. The 2-ethylhexanol in sample 5C is a primary emission from the reference flooring, which can be seen when looking at sample 1C, where the substrate is a plaster board. This primary emission of 2-ethylhexanol is decreasing with time, as is the TVOC, see Table 3.

Table 3. Primary emissions from **reference flooring** on a plaster board, $\mu\text{g}/\text{m}^2 \cdot \text{hour}$

Time	2-ethylhexanol	1-butanol	TVOC
1 week	26	1	87
3 weeks	11	1	49
11 weeks	5	1	36
51 weeks	1	0	16

The commercial floorings had negligible primary emissions of 2-ethylhexanol. The simpler two layer flooring, Tarkett Extra sample 2C, showed a small but measurable

emission of 1-butanol after one week even when the substrate was plaster board. This is probably a primary emission from the adhesive.

The **moisture measurements** of samples 5C-7C showed interesting results, as the moisture kept decreasing over time – after 13 weeks the moisture was down at about 80% RH. As it seems implausible that such a decrease in moisture could be a result of self-drying in the concrete, two more samples were cast. 13C is a duplication of 6C and 14C is the same, but without the adhesive. The moisture measurements of these samples, which are done in the middle of the 100 mm thick specimens, are shown in Figure 6.

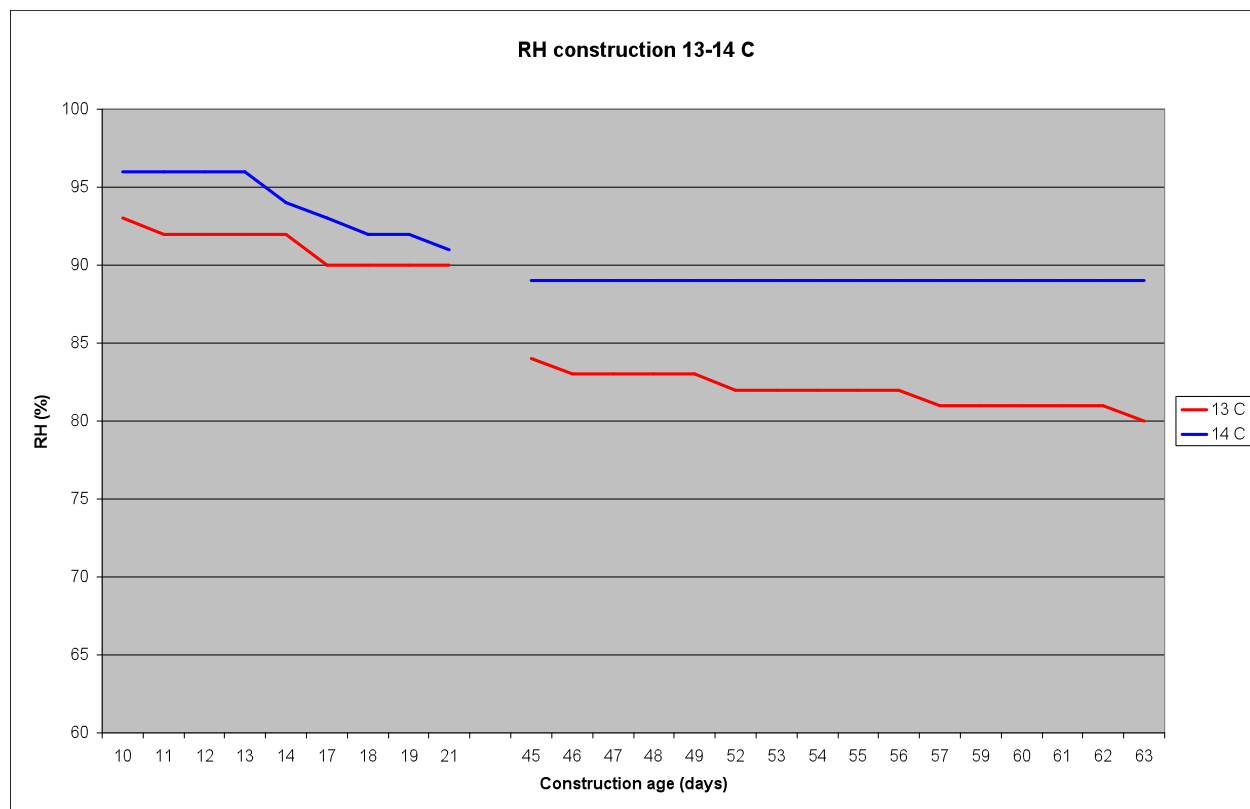


Figure 6. Decrease in moisture with time in samples with or without adhesive (13C and 14 C respectively) on a very aggressive substrate.

There is a small difference between the samples the first three weeks, but then sample 14C (without adhesive) stabilizes at about 90% RH, while 13C keeps on decreasing. The interpretation of this phenomenon is that the emission (in this case 1-butanol) caused by the alkaline hydrolysis influences the moisture measurement to a considerable extent. This phenomenon has been mentioned by others (Jutewik 2001).

Emission measurements after 8 weeks in 6C, 13C and 14C are shown in Table 4, where it is confirmed that no emissions appear without the adhesive (14C).

Table 4. No emissions without adhesive, sample 14C.

Sample	6C	13C	14C
1-butanol	o.m	o.m	<10
2-ethylhexanol	<10	<10	<10

The conclusion from the results with the very aggressive substrate, is that a low moisture reading is no guarantee that emissions from alkaline hydrolysis are low, since the moisture reading can be influenced by emissions in a way that not is negligible.

5.1.3 Measuring at different positions

In the PFS-method, the measurement is made on a very small surface area, but it is of course the idea to get information of much bigger areas, such as a whole floor or even a whole building. When validating the method, it is essential to know the variability of the measurement as such, as compared to the variability between measurements in different positions of the same surface. Therefore a test series was carried out where 4 measurements in different positions on the same concrete specimen (15B) on top of the flooring were done 4 days in a row, i.e. totally 16 measurements. The time after application of the flooring was about 15 months.

The results for the emission of 2-ethylhexanol are shown in Table 5. The emission of 1-butanol was so small ($< 5 \mu\text{g}/\text{m}^2 \cdot \text{hour}$) that it was not meaningful to study with respect to variation.

Table 5. Variability of emission of 2-ethylhexanol, $\mu\text{g}/\text{m}^2 \cdot \text{hour}$, depending on position and repeated measurement, **sample 15B**.

Different positions	Mean of 4	Stand dev	Different days	Mean of 4	Stand dev
Position A	45	5,4	Day 1	55	14,9
Position B	64	4,5	Day 2	59	9,3
Position C	47	6,5	Day 3	55	13,8
Position D	68	4,9	Day 4	56	11,7
Average	56	5,3	Average	56	12,4
Stand. dev	11,7		Stand. dev	1,9	

In Figure 7, the individual values are shown either as measurements in at the same position four days in a row (left part of the figure), or as measurements at four positions on the same day (right hand part of the figure). Thus the individual values in the two parts of the figure are the same, they are only grouped differently.

As can be seen from the results, the average standard deviation when measuring 4 times in the same position is less than half of what is obtained when measuring in different positions (**5.3 vs. 12.4**). Consequently the standard deviation of the over all average is much lower if you take the mean of 4 different positions each time as compared to when you take the mean of each position (**1.9 vs. 11.7**). The conclusion from these tests is that the reproducibility of the PFS method is very good, and that

the different emissions found in the different positions (A-D) on the same specimen are real, and not an indication of variations in the test method per se.

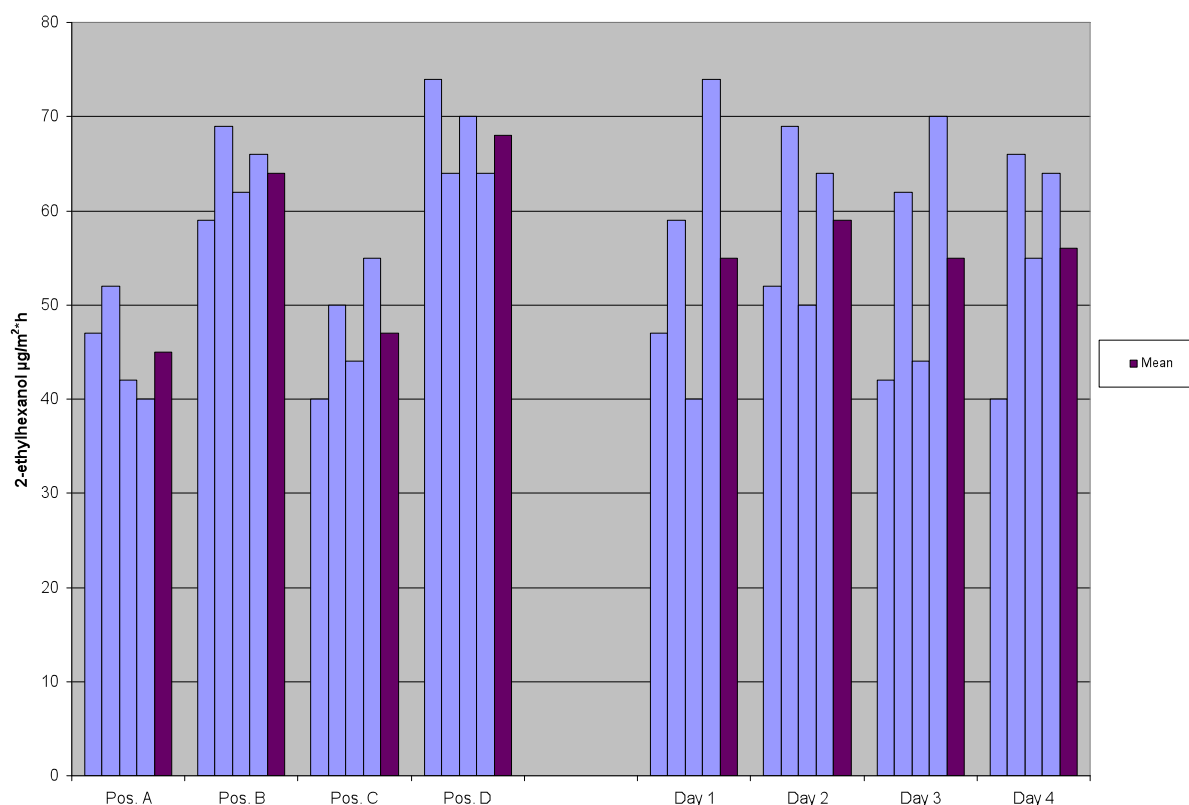


Figure 7. Variability of emission of 2-ethylhexanol depending on position and repeated measurement, **sample 15B**.

It is a striking finding that the secondary emission (in this case 2-ethylhexanol) from a combined floor construction can vary rather much, even within such a small surface area (380 mm diameter) of a laboratory sample. It is probably due to the fact that alkaline hydrolysis is a complex process, depending on many factors (e.g. humidity, alkalinity of the substrate, type and amount of adhesive, migration of plasticizer from PVC-flooring etc.)

Similar findings were done by GBR when developing the industry protocol for combined floor constructions (GBR 2004). The total emission of alcohols (sum of 2-ethylhexanol and 1-butanol) from the very aggressive reference construction after 26 weeks varied from about 200 $\mu\text{g}/\text{m}^2 \cdot \text{hour}$ up 1000 $\mu\text{g}/\text{m}^2 \cdot \text{hour}$.

In order to get a further affirmation of the variability between different positions in relation to the variability of the measurement as such, tests were performed at SP on samples 13SP and 15SP on three consecutive occasions. The time of testing was about 3,5 years after the application of the flooring. The samples are parallel to 7A and 5A of the CR-project. The results are shown in Tables 6 and 7.

Table 6. Variability of emission of 2-ethylhexanol, $\mu\text{g}/\text{m}^2 \cdot \text{hour}$, depending on position and repeated measurement, **sample 13SP**.

Different positions	Mean of 3	Stand dev	Different days	Mean of 3	Stand dev
Position a	180	16,3	Day 1	152	26,2
Position b	183	1,2	Day 2	161	33,1
Position c	131	5,5	Day 3	153	33,9
Position d	127	6,0			
Average	155	7,3	Average	155	31,0
Stand. Dev	30,4		Stand. dev	4,9	

Table 7. Variability of emission of 2-ethylhexanol, $\mu\text{g}/\text{m}^2 \cdot \text{hour}$, depending on position and repeated measurement, **sample 15SP**.

Different positions	Mean of 3	Stand dev	Different days	Mean of 3	Stand dev
Position a	95	0,6	Day 1	93	12,1
Position b	80	0	Day 2	92	11,0
Position c	87	1,5	Day 3	89	6,8
Position d	102	8,3			
Average	91	2,6	Average	91	10,0
Stand. dev	9,6		Stand. dev	2,1	

In tables 6 and 7, the results are shown in the same way as in Table 5 from the CR-project and the trend is the same. The standard deviation is much lower when you consider consecutive measurements in the same position, as compared with the standard deviation for measurements at four positions at the same occasion.

Altogether, it can be concluded that the PFS-method is quite reproducible, when measuring several times at the same position and the standard deviation can be estimated to be in the order of 5-10%, which is very encouraging.

The variability from place to place cannot be generalized – it depends on many factors. E.g. it can be seen that the variability of sample 15SP is considerably lower than for 13SP. Similar findings were done in the GBR-project.

The practical implication of these results is that it is absolutely essential to use a number of PFS-cups to evaluate a floor in practice. A minimum should be four cups, but the actual number needed is of course dependent on how big areas that are to be covered and how different the circumstances have been, e.g. with regard to drying of the construction.

5.1.4 Influence of sampling times

The sampling time has to be long enough so that the analyzing instruments can detect the emissions with reasonable accuracy. But if the sampling time is too long, there is a risk that the upper limit of the measuring range is exceeded

(as we already have seen examples of, noted as **o.m.**). If the emission rate is constant, the sampling time should not be important as long as you stay within the measuring range of the analyzing instrument. In the case of measuring under the flooring, this is not the case, as we have seen earlier (Table 1), and this was one of the reasons to abandon this type of measurements.

For measuring on top of the flooring, we have chosen 24 hours sampling time as a standard, but this has led to that the measuring range has been exceeded in some cases. Therefore it was of interest to find out the influence of the sampling time, if it is lower than 24 hours.

Sample 9C, which is a concrete with 7 days drying time, came outside the measuring range with regard to 1-butanol at the measurement 13 weeks after the flooring application. Therefore it was suitable to test lower sampling times on this specimen. Four positions and four measuring times were selected and the results are shown in Tables 8 and 9.

Table 8. Influence of sampling time on emission of **1-butanol** from sample 9C after 13 weeks, $\mu\text{g}/\text{m}^2 \cdot \text{hour}$

	Sampling time				Average
	2 hours	4 hours	8 hours	16 hours	
Position A	72	88		54	71
Position B	89	112	90		97
Position C	75	84	77	71	77
Position D	70	72	73	67	71
Average	77	89	80	64	78

Table 9. Influence of sampling time on emission of **2-ethylhexanol** from sample 9C after 13 weeks, $\mu\text{g}/\text{m}^2 \cdot \text{hour}$.

	Sampling time				Average
	2 hours	4 hours	8 hours	16 hours	
Position A	5	5		7	6
Position B	8	9	8	9	9
Position C	6	7	7	7	7
Position D	8	7	8	7	8
Average	7	7	8	8	8

As can be seen in Tables 8 and 9, **there is no systematic influence of the sampling time**, neither for 1-butanol nor for 2-ethylhexanol.

Varying sampling times were also studied at another specimen, sample 7C, which is the very aggressive reference concrete with only one day of drying time. Already four weeks after the application of the flooring, the emission results were outside the measuring range when the standard 24 hours sampling time was used. After 9 weeks, tests were made with very short sampling times, as shown in Table 10 for 1-butanol (the 2-ethylhexanol values were too low for this study).

Table 10. Emissions of **1-butanol** from sample 7C after 9 weeks using different sampling times, $\mu\text{g}/\text{m}^2 \cdot \text{hour}$.

Sampling time	1-butanol	Stand dev %
16 minutes	798	16
30 minutes	1033	6
60 minutes	961	7
120 minutes	o.m	

The values shown in the table are the average of 3 positions. Again, there is no systematic trend for sampling time, and the standard deviation is in same order of magnitude as before, averaging about 10 %.

To summarize the results from the measurements with different sampling times, we have not found any systematic influence, as long as the measurements are within the measuring range. But it cannot be ruled out that the sampling time could have an influence under other conditions than those tested here. Therefore, it seems wise (and practical) to stick to a standard sampling time of 24 hours, but if the measuring range is exceeded, shorter times can be used.

5.1.5 Influence of the environment

Most of our measurements have been done in a room with clean air, 23 °C and 50% RH. But as the PFS-method is meant to be used in the field, it is important to know if the environment around the PFS-cup, when sampling, has an influence on the result. One could think of a leakage under the edge of the cup from the surrounding air, and if that air is polluted, the emissions would be trapped on the Tenax and wrongly associated with the floor construction.

Sample 9C was used again for this purpose. This time it was 22 weeks after the application of the flooring. Four positions were measured in the so called **FLEC-room** (clean air, 23 °C and 50 % RH). The sampling time was 4 hours to avoid exceeding the measuring range. Then the specimen was moved to a **Climate room** with 20 °C and 65 % RH without control of the cleanliness of the air, and a new measurement of the four positions was made. This was repeated after one and seven days and then the specimen was moved back to the FLEC-room, where a final measurement was done 7 days after the relocation. The results are shown in Tables 11-13.

Table 11. Influence of the environment when sampling on the emission of **1-butanol** from sample 9C, $\mu\text{g}/\text{m}^2 \cdot \text{hour}$

Time at climate	Climate	Pos A	Pos B	Pos C	Pos D	Average	Stand dev %
154 days	23 °C and 50 % RH	190	190	214	150	186	14
0 days	20 °C and 65 % RH	177	188	188	195	187	4
1 day	20 °C and 65 % RH	153	192	329	209	221	34
7 days	20 °C and 65 % RH	143	143	109	167	140	17
7 days	23 °C and 50 % RH	207	208	173	219	202	10

Table 12. Influence of the environment when sampling on the emission of **2-ethylhexanol** from sample 9C, $\mu\text{g}/\text{m}^2 \cdot \text{hour}$

Time at climate	Climate	Pos A	Pos B	Pos C	Pos D	Average	Stand dev %
154 days	23 °C and 50 % RH	7	11	8	8	9	20
0 days	20 °C and 65 % RH	13	11	11	84	30	122
1 day	20 °C and 65 % RH	5	10	6	7	7	31
7 days	20 °C and 65 % RH	6	22	7	6	10	77
7 days	23 °C and 50 % RH	7	12	9	7	9	29

Table 13. Influence of the environment when sampling on the emission of **TVOC** from sample 9C, $\mu\text{g}/\text{m}^2 \cdot \text{hour}$

Time at climate	Climate	Pos A	Pos B	Pos C	Pos D	Average	Stand dev %
154 days	23 °C and 50 % RH	256	265	280	214	264	11
0 days	20 °C and 65 % RH	277	256	256	476	316	34
1 day	20 °C and 65 % RH	416	618	1456	897	847	53
7 days	20 °C and 65 % RH	230	447	204	243	278	41
7 days	23 °C and 50 % RH	266	265	235	275	261	7

Looking first at the 1-butanol, there does not seem to be any systematic influence when moving the specimen to a new climate and possibly unclean air. But the variation after one day in the new climate is bigger than what we have seen before (position C stands out). Also for 2-ethylhexanol, there does not seem to be any systematic influence of the environment, but the variation is bigger because two values stand out (positions B and D) at two different measuring times.

So, three measurements at three different occasions increase the variability for 1-butanol and 2-ethylhexanol. And when you look at the TVOC-results, it can be seen that also the values for TVOC at these three measurements stand out, being much higher than the other measurements done at the same time. The increase in the deviating TVOC-values is considerably higher than the increase in 1-butanol and 2-ethylhexanol. The most plausible explanation for this is there has been a leakage under the edge in the measurements with deviating results. But this leakage seems to be a bit haphazard, since it only has occurred at one position at each measurement, and what is more, at different positions. It must be observed that the expression of the emission as $\mu\text{g}/\text{m}^2 \cdot \text{hour}$ is “equivalent” in the case of leakage under the edge of the cup, as it is calculated using the area of the cup. For this reason, strongly deviating values should be disregarded, as being “outliers”.

The results related above stress two things. First, they emphasize the need to have a number of measuring positions, as we already have noticed when we earlier have studied the variability at different positions, paragraph 5.1.2. But the results also show the need for some reference testing in order to have a better justification to disregard outliers. Such reference tests ought to be done on an inert surface, and for practical reasons, the top of the lid to the PFS-cup was chosen for this purpose, since it will be available at field testing.

In tables 14 and 15, the results of reference testing on top of the PFS-lid in the FLEC-room (with clean air) and in the Climate room (unclean air) are shown with 4 hours sampling time and compared to sample 9C.

Table 14. Comparison of reference measurements and sample 9C in **FLEC-room**, $\mu\text{g}/\text{m}^2\cdot\text{hour}$

On lid of PFS-cup	Lid A	Lid B	Lid C	Lid D	Average	Stand dev %
TVOC	50	54	55	45	51	9
1-butanol	1	1	5	1	2	94
2-ethylhexanol	1	3	2	2	2	34
Sample 9C, 27 weeks	Pos A	Pos B	Pos C	Pos D	Average	Stand dev %
TVOC	289	285	302	227	276	12
1-butanol	223	226	247	164	215	17
2-ethylhexanol	6	14	8	9	9	40

Table 15. Comparison of reference measurements and sample 9C in **Climate-room**, $\mu\text{g}/\text{m}^2\cdot\text{hour}$

On lid of PFS-cup	Lid A	Lid B	Lid C	Lid D	Average	Stand dev %
TVOC	264	303	254	219	260	13
1-butanol	39	46	34	31	38	17
2-ethylhexanol	1	1	3	1	2	51
Sample 9C, 27 weeks	Pos A	Pos B	Pos C	Pos D	Average	Stand dev %
TVOC	447	941	1018	627	758	35
1-butanol	197	244	308	177	231	25
2-ethylhexanol	6	9	7	9	8	21

We can see that the emissions in the reference measurements are very low in the FLEC-room, while in the Climate-room, there is an increase in 1-butanol and TVOC (but not 2-ethylhexanol) for all four measurements. And consequently also the values for 1-butanol and TVOC (but not for 2-ethylhexanol) have increased in sample 9C when measuring in the Climate-room.

To summarize the measurements regarding the influence of the environment, there can be a leakage under the edge of the PFS-cup, and if the surrounding air is polluted, it can have an influence on the results. However, it seems to be a bit random, and therefore it is necessary in field measurements to have at least two reference samples (on the lid of the PFS-cup), in order to judge to which extent such a leakage could interfere with the measuring of the emissions from the floor construction.

Further reference tests were made on top of the PFS lid and inside the lid of the transport cup, and a comparison was made with an open PFS cup, i.e. where the surrounding air could have full access to the Tenax. These tests further confirmed the random behaviour of leakage under the PFS-cup. The conclusion is that when sampling in a room where the air is unclear, which of course is the case in the field, one has to consider the possibility of the results being influenced by the surrounding.

The primary interest in field measurements is to see if there are high emissions of alcohols, in the first place 1-butanol and 2-ethylhexanol, under the flooring. If there also are alcohols from the reference cups, it means that the values from the exposed cups may be too high, because of leaking from the surrounding. But in that case, it is

reasonable to assume that the alcohols in the surrounding emanate from the floor, and then it is not of primary concern to know exactly *how high* the emission is. It is enough to know that it is high.

When it comes to other emissions than 1-butanol and 2-ethylhexanol, it is important to identify the emissions in order to judge whether the emissions from the exposed cups could come from the floor or from the environment. Since we have seen that there can be a random leakage from the surroundings, the numerical value of TVOC is not relevant, in the case when sampling is done in a room with unclean air. But still comparisons of the identification of emissions from the exposed cups and the reference cups can be of interest. E.g. if you find emissions from the exposed cups that are not present in the reference cups, it can be concluded that these emissions most probably come from the floor.

5.1.6 Transport of PFS-cup

The idea of the PFS-project is primarily to develop a simple field test. Therefore it is necessary also to pay attention to how the PFS-cups are to be transported from the laboratory, where they are loaded with Tenax, to the field site and back again after the exposure. In the beginning of the project, different solutions were tried to make the lid tight enough, in order to prohibit emissions from the surroundings to enter the cup, but no good solution was found.

The problem was solved by making a bigger cup, large enough to hold two PFS-cups. This transport cup is loaded with Tenax in the bottom in the same way as the PFS-cups, and this Tenax traps the emissions leaking in through the lid of the transport cup. Tests were carried out on sample 21SP to check if this method was OK.

Four PFS-cups, B, C, E and F, were prepared by CR and were sent to SP in transport cups. At the same time, four empty cups, H, I, K and L, were sent to SP (also in transport cups), and at arrival, SP prepared these cups with Tenax. All eight cups were exposed for 24 hours on sample 21SP, and the cups B, C, K and L were sent back to CR in transport cups for analysis, while cups E, F, H and I were analyzed directly after exposure at SP. The age of sample 21SP was 2 years. The results for 2-ethylhexanol are shown in Table 16 (the 1-butanol emissions were outside the measuring range).

Table 16. Influence of PFS-preparation, transport and analysis at different laboratories, $\mu\text{g}/\text{m}^2 \cdot \text{hour}$.

Samples analyzed by SP		Samples analyzed by CR	
Sample	2-ethylhexanol	Sample	2-ethylhexanol
E	48	B	40
F	49	C	39
H	40	K	45
I	39	L	52
Average	44	Average	44
Stand dev	5,2	Stand dev	5,9

The agreement between the cups analyzed at SP (directly after exposure) and the ones analyzed by CR (after transport) is excellent. So in this case neither the preparation of the cup, the transport of exposed cups nor the analysis at different laboratories seems to have had an influence.

Some complementary tests were done, to study the influence of storing the exposed cups. The sample 13SP was exposed twice in four positions at SP at the age of 4,5 years. Half of the PFS-cups were analyzed directly after the exposure and the other four cups were stored in transport cups for a week before they were analyzed. The emission of 2-ethylhexanol was $123 \pm 12,3 \mu\text{g}/\text{m}^2 \cdot \text{hour}$ for the cups that were analyzed directly after the exposure and the ones that had been stored for a week in transport cups after the exposure had $142 \pm 17,8 \mu\text{g}/\text{m}^2 \cdot \text{hour}$. By mistake, the positions that were analyzed directly (a and c) were not the same as those analyzed after storage (b and d). Nevertheless, the results show that the fear that the Tenax in the transport cup should reabsorb emissions from the exposed PFS-cups is unfounded.

5.1.7 Relation to FLEC- measurements

A number of PFS-measurements have been done at some samples in the SP-project in order to compare PFS with FLEC. These measurements are shown in Table 17 and Figure 8..

Table 17. Comparison between PFS- and FLEC-measurements on samples from the SP-project. The time of measurement is about 3,5 years and the specimens are combinations of concrete and maxit 4150 at different moisture levels, $\mu\text{g}/\text{m}^2 \cdot \text{hour}$.

Sample no	1-butanol		2-ethylhexanol		TVOC	
	FLEC	PFS	FLEC	PFS	FLEC	PFS
13 SP	12	8	150	150	170	198
15SP	0	1	70	66	76	90
17SP	0	1	30	34	38	62
19SP	0	1	22	23	22	46

The results show that the agreement between the two methods is quite good, especially for the alcohols, which are of primary concern for floor constructions. The PFS gives about $20 \mu\text{g}/\text{m}^2 \cdot \text{hour}$ higher values for TVOC, compared to the FLEC. This could be explained by the handling of the Tenax in the PFS-method. Also leakage under the edge of the PFS-cup could give such an effect. But on the whole, there is no reason to believe that measurements with the PFS-method should give systematically different results, compared to the FLEC, taking consideration of the measurement uncertainty.

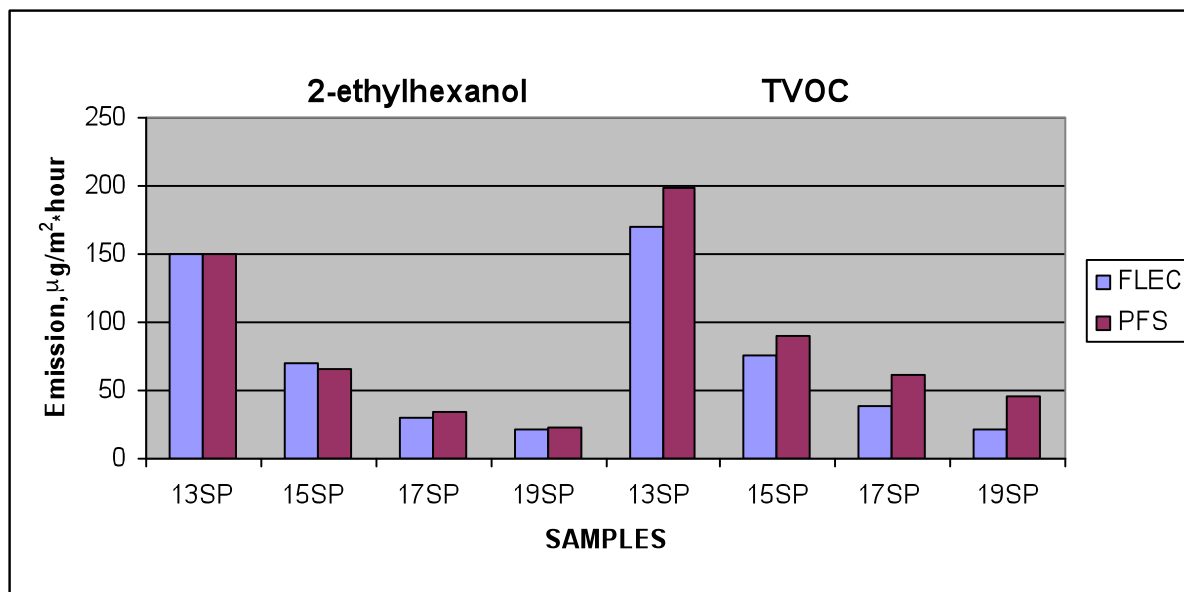


Figure 8. Comparison between PFS- and FLEC-measurements.

5.2 Factors influencing emissions

From the above it has been seen that the PFS-method is quite comparable to the FLEC-method, when studying emissions from floor constructions, especially 1-butanol and 2-ethylhexanol, which are the primary interesting emissions with regard to the room climate. In the appendices, all the results from the different test series are given (except the special studies regarding the PFS-methodology, which already have been reported in the running text).

In the following, the main focus will be on the alcohols 1-butanol and 2-ethylhexanol, while the TVOC only will be discussed when there is a special reason. An overview of the results shows that in many cases the emissions of 1-butanol and 2-ethylhexanol are low. It does not seem relevant to discuss differences within the low range, and the limit for what is considered “low” is set to $15 \mu\text{g}/\text{m}^2 \cdot \text{hour}$. A reason for this is that the limit for the sum of alcohols in the GBR industry protocol for combined floor constructions has been set to $30 \mu\text{g}/\text{m}^2 \cdot \text{hour}$ (for the best class AN 1).

Another group of results are those where the emissions have exceeded the measuring range of the analyzing instruments. These can be classified as “high”. And then of course there are those which are in between, and can be considered “middle”.

The primary objective of the project has been to develop the PFS-method, not to study the influence of different factors. Therefore this chapter will not go into great detail, but only give a general overview of influencing factors.

5.2.1 Various concretes

There are three types of concrete used in the project:

- Ordinary K30 concrete
- High quality concrete, K60
- GBR reference concrete

The K30 concrete has normally been dried for 28 days after the first day (when it was covered). Then it has been water cured for 7 days (to simulate rain on a building site) and after that, it has been dried for various times between 7 days and 1 year. The high performance concrete was dried for 28 days and the GBR reference concrete was dried for either 14 days or only one day.

The most aggressive concrete is the GBR reference concrete, when dried for only one day, as we already have seen (Table 2). But also when dried for 14 days (according to the GBR reference), the emissions are high. This is best illustrated by sample 21 in the SP-project (measured with FLEC) as shown in Table 18 and Figure 9.

Table 18. Emissions from reference concrete dried for 14 days measured with FLEC, $\mu\text{g}/\text{m}^2 \cdot \text{hour}$. Sample 21SP.

Time after flooring	1-butanol	2-ethylhexanol
26 weeks	232	33
1 year	270	51
2 years	205	64
3 years	145	59
4 years	120	50

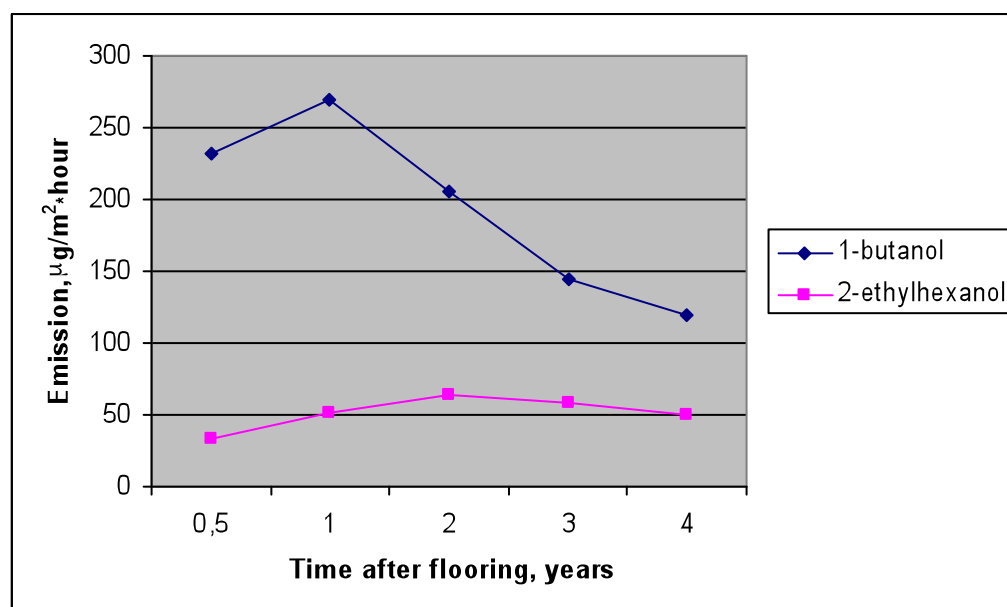


Figure 9. Emissions from reference concrete.

Sometime between one and two years, the emissions start to decrease. After 3 years a PFS-sampling was done at SP and the cups were sent to CR for analysis. The

1-butanol was outside the measuring range but the 2-ethylhexanol was quite similar to the FLEC-value (59 and 50 respectively).

The high performance concrete K60, sample 17B, had a moisture development in line with what can be expected from this type of concrete – going from 84% RH after 13 weeks and decreasing to 78% after one year. But in spite of that, the emission of 2-ethylhexanol is $35 \mu\text{g}/\text{m}^2 \cdot \text{hour}$ after one year and after 2,5 year it is outside the measuring range. But the 1-butanol emissions are low. The question of which emission will dominate when there is an alkali attack, seems to depend on the moisture level. At high moisture levels when applying the flooring, the 1-butanol from the adhesive will dominate (as in 5C-7C), but at lower levels of moisture, the 2-ethylhexanol will dominate, although it takes much longer time to appear. This is in line with earlier experience (Alexanderson 2004).

The emissions from the K30 concrete specimens are strongly dependent on the moisture level. The specimens that have dried for 5 months or more (3A, 4A and 8C) have low emissions, while those with the shortest drying time (1 week -13B, 9C) have high emissions. Samples 14B-16B that have drying times 2,4 and 8 weeks respectively, have low emissions of 1-butanol but not of 2-ethylhexanol. The difference in moisture for samples 13B -16B is surprisingly small, only a few %RH, thus hardly more than the measuring uncertainty in the RH-measurement. The moisture level for these samples is around 90% RH.

Obviously, more than 8 weeks drying time (less than 90 %RH) is needed for the K30 concrete to be safe to give low emissions. But as the results from the K60 concrete and the GBR reference concrete show, a low moisture level is not enough to safeguard against emissions. A high alkaline concrete can give emissions, even if the relative humidity is low. This is also in line with earlier experience (Alexanderson 2004, Wengholt-Johnson 1998)

5.2.2 Various levelling compounds

All the levelling compounds used in the project are from maxit AB and they are all of the low alkali type, i.e. the binder consists to more than 50% of high alumina cement and calcium sulphate. Or with other words, the binder has less than 50% of high alkali Portland cement. Both normal drying and self drying products have been used – maxit 4150 and 4160 respectively. Specimens with 4150 have been maltreated to be provocative with only one day of drying at 30 mm thickness, samples 2A and 12C. As a reference, the 4150 has also been used as it should, with 2 weeks of drying when the thickness was 10 mm, samples 12B and 10C.

The 4160 – the self drying product has been used with varying drying time and water content – samples 1A, 1B-8B, 11C. There were also some other levelling compounds tested, 9B-11B.

Of all the specimens with varying levelling compounds – altogether 17 specimens – none have shown an emission of 1-butanol over $15 \mu\text{g}/\text{m}^2 \cdot \text{hour}$ at any time (up to 4 years). And the same goes for 2-ethylhexanol up to one year. But after 2,5 years and more, there are some cases of increased emissions of 2-ethylhexanol (samples 1B, 2B, 8B -12B, the highest value being $65 \mu\text{g}/\text{m}^2 \cdot \text{hour}$. These values caused concern,

especially as the reference - well dried 4150, sample 12B - showed $39 \mu\text{g}/\text{m}^2 \cdot \text{hour}$ at this time. A closer look at this measurement shows that the variation of the four individual values was very high (4, 28, 119 and $4 \mu\text{g}/\text{m}^2 \cdot \text{hour}$ respectively). If the value 119 is considered as an outlier, the average will be $13 \mu\text{g}/\text{m}^2 \cdot \text{hour}$, which is more in line with what could be expected.

Because of this uncertainty of the values from later ages, an extra measurement was done after about three and a half year (samples 1B, 5B, 10B, 11B and 12B). At these measurements, all but 11B, had low emissions of 2-ethylhexanol, so the somewhat increased values at 2,5-3 years seems to have been an artefact.

The reason behind the increased emission of sample 11B is not clear. It is a rather thick specimen, 81 mm, with only 6 days drying time, which leads to high relative humidities. But this cannot be the only explanation, since sample 5B, which is a maltreated 4160, has just as high humidities, but does not show increased emissions.

On the whole, when comparing the results from samples with levelling compounds, (1 – 12B) with those with concretes (13-17B), the favourable effect on emissions from a low alkali substrate is confirmed.

5.2.3 Combinations concrete/levelling compounds

In series A and in the SP-project, combinations of K30-concretes with a topping of 5 mm maxit 4150 have been tested. The drying time was varied between 1 and 33 days, including the drying time of the levelling compound. The tests were designed to find the critical drying time below which the protective function of the low alkaline levelling compound does not work any more.

The results from the SP-project are shown in Table 19 and in Figure 10.

Table 19. Emissions from combined constructions with varying drying, $\mu\text{g}/\text{m}^2 \cdot \text{hour}$. Measurement with FLEC at SP.

		Sample no			
		13SP	15SP	17SP	19SP
1-butanol	0,5 years	15	-	-	-
	1 year	-	-	-	-
	2 years	-	-	-	-
	3 years	-	-	-	-
	4 years	-	-	-	-
2-ethylhexanol	0,5 years	10	10	8	8
	1 year	33	11	11	7
	2 years	110	38	17	15
	3 years	150	60	25	19
	4 years	150	81	34	25
TVOC	0,5 years	38	32	17	19
	1 year	60	20	20	20
	2 years	130	40	20	20
	3 years	170	62	35	19
	4 years	170	89	41	26

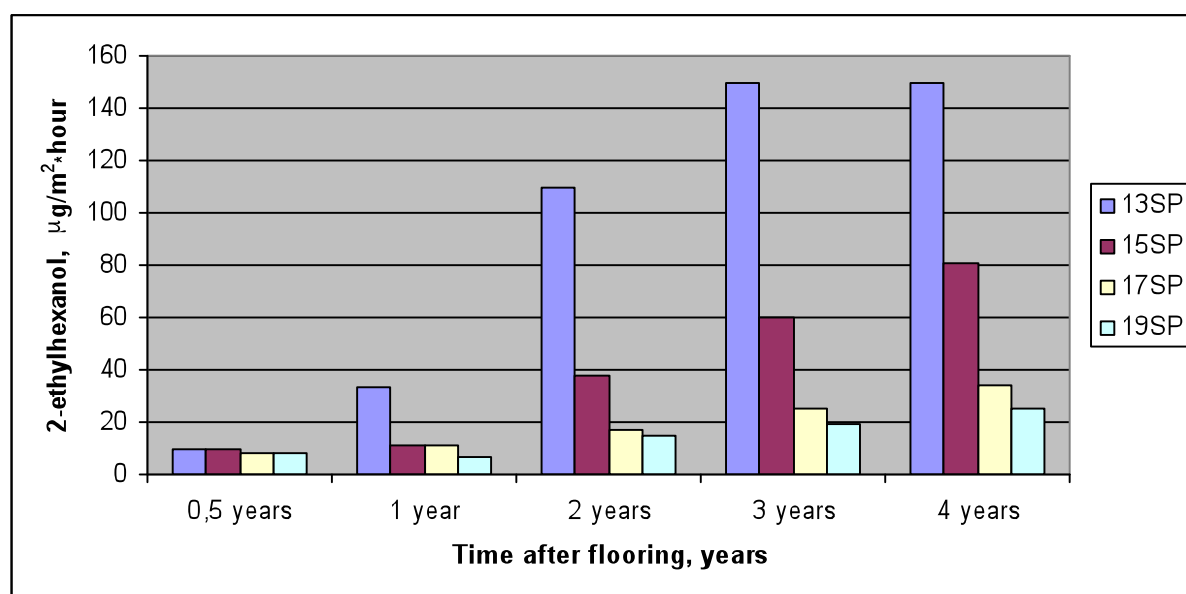


Figure 10. Emissions from combined constructions with varying drying

Here it can be seen that for sample 13SP, with only one day of drying, the emissions are low after half a year, but as time goes by, the emission of 2-ethylhexanol increases steadily. This is similar to earlier results with other levelling compounds (Alexanderson 2004), but in those cases, it was the 1-butanol rather than the 2-ethylhexanol that increased. For sample 15SP (7 days drying time), the increase in 2-ethylhexanol is less, but still quite noticeable. For the longer drying times, the increase in 2-ethylhexanol is rather low.

The results from series A in the CR-project are shown in table 20.

Table 20. Emissions from combined constructions with varying drying, $\mu\text{g}/\text{m}^2 \cdot \text{hour}$. Measurement with PFS at CR.

		Sample no			
		7A	5A	8A	9A
1-butanol	2 years	o.m.	25	3	3
	4 years	o.m.	3	3	2
2-ethylhexanol	2 years	7	7	9	6
	4 years	13	16	26	17
TVOC	2 years	o.m.	51	26	29
	4 years	o.m.	44	53	212

In principle, the results are similar to the SP-project, but in sample 7A with one day drying time, the emissions after longer time are 1-butanol rather than 2-ethylhexanol as was the case in the SP-project. The reason for this difference is not clear. It seems as if there is an alkali attack, *either* 1-butanol *or* 2-ethylhexanol will dominate over time.

The tests with combinations of concrete and levelling compounds confirm earlier findings that there is a critical moisture level, over which the protecting function of a low alkali levelling compound is lost. The critical moisture level is around 90% RH, when judged from the drying times and the moisture measurements done in series A. In the SP-project, there were no moisture measurements made.

5.2.4 Various adhesives and floorings

Mostly, in the project, the GBR reference adhesive and reference PVC-flooring have been used. But in series B, samples 6B-8B, different adhesives have been used. And in series C and in the SP-project different floorings have been used.

The three adhesives are all tested on a maxit 4160, parallel to sample 1B (21% water, 30 mm thickness and 24 hours drying time). Up to one year after application of the flooring, the three adhesives show low emissions of 1-butanol and 2-ethylhexanol just as the samples with reference adhesive. But the adhesive A (sample 8B) does show an increased TVOC-value of $180 \mu\text{g}/\text{m}^2 \cdot \text{hour}$ after one year. This can be compared with the average of samples 1B-7B, that was $29 \pm 3 \mu\text{g}/\text{m}^2 \cdot \text{hour}$.

After 2,5 years, the TVOC of sample 8B has increased further to $298 \mu\text{g}/\text{m}^2 \cdot \text{hour}$ and after a little more than 3 years, it is outside the measuring range. The corresponding values for the average of 1B-7B is 56 ± 31 and $49 \pm 14 \mu\text{g}/\text{m}^2 \cdot \text{hour}$ respectively. So there is no doubt that adhesive A behaves differently. The increased TVOC at later ages is accompanied by increased emissions of 2-ethylhexanol (but not of 1-butanol), but not at all to an extent that can explain the high TVOC-values.

In order to know more about the reason for the deviating behaviour of adhesive A, a GC-MS analysis was made, and a large peak representing 2-phenoxy ethanol was found. It has been confirmed that adhesive A contains this substance, contrary to Adhesives B and C, which are of the low emission type. The producer of the adhesives states that adhesive A would have about $2500 \mu\text{g}/\text{m}^3$ emission when tested according to EMICODE after 10 days, while the other two would give 100-300 $\mu\text{g}/\text{m}^3$.

It is a bit surprising that a primary emission from the adhesive shows up on top of a PVC-flooring after more than 3 years, and that it is still increasing after such a long time. To our knowledge, this is something that has not been reported before. The primary emissions from adhesives have mainly been thought of in terms of the work environment for the floor layer, but these results indicate that it also can be an issue for the indoor air in the dwellings.

The influence of the flooring was tested in series C, where the question was how soon the emissions can go through the flooring. This has already been discussed in paragraph 5.1.2.

In the SP-project, different floorings were tested, both in the moisture barrier part – which is dealt with further in the next chapter – and in three specimens with reference concrete, samples 21SP -23SP. Sample 21SP, which is the complete reference construction according to GBR, has already been presented in 5.1.3. Sample 22SP has linoleum flooring and it shows practically no emissions of alcohols, in spite of the

very aggressive reference concrete. This has been seen before, although the reason is not quite clear why the adhesive is not attacked by the highly alkaline substrate. It could be that the water absorption of the linoleum and the vapour transmission through the linoleum is big enough to keep the moisture level in the adhesive below the critical level.

Sample 23SP has a 2 mm homogeneous PVC flooring, Tarkett Eminent. It does nowadays (since 2001) not contain any DEHP plasticizer (often called DOP), and since the reference adhesive does not contain any ethylhexylacrylate, the emissions from sample 23SP do not show any 2-ethylhexanol. But there is 1-butanol as could be expected, coming from the adhesive..

It is interesting to compare samples 21SP and 23SP with sample 1SP, which has Eminent flooring glued with a commercial adhesive, Cascoproff 3448. Sample 1SP has a very moist K30 concrete, and shows emissions of both 1-butanol and 2-ethylhexanol over time, see Table 21.

Table 21. Comparison of emissions from different floorings and adhesives, $\mu\text{g}/\text{m}^2\cdot\text{hour}$

		Sample no		
		1SP	21SP	23SP
Adhesive		Cascoproff	Reference	Reference
Flooring		Eminent	Reference	Eminent
1-butanol	0,5 years	154	232	106
	1 year	112	270	118
	2 years	43	205	105
	3 years	19	145	66
	4 years	7	120	49
2-ethylhexanol	0,5 years	62	33	-
	1 year	87	51	-
	2 years	91	64	-
	3 years	75	59	-
	4 years	53	50	-
TVOC	0,5 years	252	307	118
	1 year	240	330	130
	2 years	220	270	140
	3 years	180	230	110
	4 years	140	170	92

From these results, it can be seen that the Eminent does not emit any 2-ethylhexanol when used together with the reference adhesive (sample 23SP), which is as expected since this PVC flooring does not contain DEHP plasticizer. Nor does the reference adhesive emit any 2-ethylhexanol, which also can be expected since this adhesive is based on butyl acrylate polymer. And as a consequence of these observations, it can be concluded that the 2-ethylhexanol in sample 1SP comes from

the commercial adhesive Cascoproff and the 2-ethylhexanol in sample 21SP comes from the reference flooring.

Table 21 shows higher 1-butanol from the reference adhesive when combined with the reference flooring compared to the Eminent. But it is an open question if this is significant or a random variation. Remember that emissions from the full reference construction can vary a lot. So, even if it from table 21 looks as the Eminent is very favourable from the emission point of view, it is not the full story. When looking closer at what is hidden in the TVOC-values, it can be found that new VOCs are emitted from the Eminent, as shown in Table 22.

Table 22. Identified VOCs, except 1-butanol and 2-ethylhexanol from different floorings glued with reference adhesive on reference concrete, $\mu\text{g}/\text{m}^2 \cdot \text{hour}$.

		Sample	
		21SP	23SP
Adhesive		Reference	Reference
Flooring		Reference	Eminent
Isooctanol CAS no 26952-21-6	0,5 years	-	-
	1 year	-	-
	2 years	-	12
	3 years	-	18
	4 years	-	18
6-metyl-1-oktanol CAS no 110453-78-6	0,5 years	-	-
	1 year	-	-
	2 years	-	6
	3 years	-	6
	4 years	-	10
1-nonanol CAS no 143-08-8	0,5 years	-	-
	1 year	-	-
	2 years	-	-
	3 years	-	5
	4 years	-	5

From these results it is apparent that the new emissions detected are coming from the flooring, and they are not primary emissions, since they do not appear the first year. According to the opinion of a representative from Tarkett, the emission of 1-nonanol is logical considering the composition of the PVC in Eminent, but he has no explanation to the other two substances. None of the specimens with reference flooring in the SP- project has shown these new emissions.

There were two more samples with Eminent directly on concrete in the SP-project, glued with Cascoproff. They are shown in Table 23.

Table 23. Identified VOCs, except 1-butanol and 2-ethylhexanol from Eminent flooring glued with Cascoproff adhesive on K30 concrete with different drying times, $\mu\text{g}/\text{m}^2 \cdot \text{hour}$.

		Sample	
		1SP	2SP
K30 concrete		Drying time	
		1 day	7 days
Isooctanol CAS no 26952-21-6	0,5 years	-	-
	1 year	-	-
	2 years	26	28
	3 years	37	28
	4 years	34	33
6-metyl-1-octanol CAS no 110453-78-6	0,5 years	-	-
	1 year	5	6
	2 years	14	13
	3 years	18	13
	4 years	17	16
1-nonanol CAS no 143-08-8	0,5 years	-	-
	1 year	8	12
	2 years	6	9
	3 years	8	6
	4 years	8	7
2-(2-butoxyetoxy)etanol CAS no 112-34-5	0,5 years	17	7
	1 year	15	6
	2 years	13	6
	3 years	10	<5
	4 years	5	-

We can see that the same emissions as for the reference concrete in 23SP appear here, and even with higher figures. And there is no tendency for the emissions to decrease with time. In addition to these new emissions, also another VOC is found, 2-(2-butoxyetoxy)etanol. This is appearing from start and decreasing, so it is certainly a primary emission from the Cascoproff adhesive.

It is beyond the scope of this report to discuss the importance of these new emissions from Eminent, but it is definitely noteworthy that absence of DEHP plasticizer does not necessarily mean absence of secondary emissions.

5.2 Moisture barrier as primer

We have seen above, and also from earlier experience, that a low alkali levelling compound cannot cope with the very moist concretes. Therefore, the SP-project was started to test the idea to use a moisture barrier as primer, instead of the normal one (which is rather water vapour permeable, especially as it normally is diluted).

Preliminary tests showed that the common moisture barriers from maxit were not as tight against water vapour as a homogeneous PVC-flooring. This led to the decision to start the project with specimens that could dry out in two directions. The idea was that the moisture barrier as primer below the levelling compound should be able to delay the moisture transport to the adhesive and the flooring long enough, so that the drying downwards (through the ceiling of the underlying floor) could ensure that the critical moisture level in the levelling compound never is exceeded.

The specimens 1SP-12SP were cast in order to test the idea. The concrete was K30 and it was treated the same way as before, i.e. initial drying, water curing and a second drying of 1 or 7 days. The specimens were cast in cylindrical moulds with the height of 200 mm. When drying, the specimens were laid on the side. The moisture barrier used was a PVDC-type, Serpo 550, which was applied in two layers. In some cases, a third layer of Serpo 554 (a rubber type barrier) was applied on top of the Serpo 550. On top of the moisture barrier, 5 mm of maxit 4150 was applied and it was allowed to dry for 7 days before the flooring was applied with Cascoproff adhesive. The flooring was either Tarkett Eminent or linoleum (from Forbo). Reference samples without levelling compounds, 1SP and 2SP, and with levelling compounds with a normal primer (MD16 diluted 1:3), 11SP and 12SP, were made.

Since the SP-project was started at the time when maxit launched a new generation of levelling compounds, it was decided to include the specimens 13SP, 15SP, 17SP and 19SP in order to study the critical moisture level, as was already discussed in paragraph 5.2.3. In these tests, the reference adhesive and the reference flooring were used.

Finally, in the SP-project, three specimens were made with reference concrete without levelling compounds and different floorings –reference flooring, linoleum and Tarkett Eminent respectively (samples 21SP-23SP). They have already been discussed at length in the previous chapter.

As the results from the samples with the moisture barrier in the SP-project were rather positive – as we shall see later on – a final test series D was started at CR, with similar design as the SP-project, but with one sided drying of 100 mm thick specimens. The idea was to see if the drop in moisture level that will occur over the moisture barrier, will be enough to leave the moisture in the levelling compound below the critical level over time.

5.3.1 Two-sided drying

The samples in the SP-project have been measured during four years and *all* samples with a moisture barrier had low emissions (only in a few cases $<5 \mu\text{g}/\text{m}^2 \cdot \text{hour}$ of 1-butanol or 2-ethylhexanol were detected). But in fact, also the samples with ordinary primer, MD 16, had low emissions as can be seen from Table 24, where those samples are compared to the case where the flooring is glued directly to K30 concrete.

Table 24. Emissions from specimens with or without levelling compound when **ordinary primer** is used, $\mu\text{g}/\text{m}^2 \cdot \text{hour}$.

		Sample no			
		1SP	2SP	11SP	12SP
K30 concrete drying time		1 day	7 days	0,2 days	1 day
5 mm maxit 4150 drying time		-	-	0,8 days	6 days
1-butanol	0,5 years	154	7	5	-
	1 year	112	7	6	-
	2 years	43	<5	6	-
	3 years	19	-	<5	-
	4 years	7	-	-	-
2-ethylhexanol	0,5 years	62	5	5	-
	1 year	87	6	7	-
	2 years	91	8	10	-
	3 years	75	6	10	-
	4 years	53	7	7	-
TVOC	0,5 years	252	40	30	25
	1 year	240	50	30	20
	2 years	220	80	50	20
	3 years	180	73	56	19
	4 years	140	89	61	18

From Table 24, it can be seen that not only the samples with levelling compounds have low emissions. Even the concrete without levelling compound and only one week of drying, sample 2SP, had low emissions. This is in great contrast to samples 13B and 9C that had the same short drying time. The difference is that sample 2SP was twice as thick, 200 mm, and had two-sided drying. Another difference is that sample 2SP had commercial flooring and adhesive (Eminent and Cascoproff) while the samples 13B and 9C had reference flooring and adhesive.

It seems obvious that the two-sided drying is the main cause for the low emissions of sample 2SP, in spite of a very short drying time of the concrete. It is the adhesive that has escaped emission of 1-butanol and 2-ethylhexanol, since in this case, with Eminent, we would not have expected any 2-ethylhexanol anyway. It is an open question if the more vulnerable reference flooring would have been saved by the two-sided drying. We have seen above that concrete with one-sided drying needs more than 8 weeks drying time (sample 16B) to safeguard low emissions, and in that case it was the reference flooring that caused the emission of 2-ethylhexanol, while 1-butanol was low.

Now, let us take a look at the new emissions that were found coming from Eminent. In Table 25, a comparison is made for the different alternatives – concrete, levelling compound and primer.

Table 25. Identified VOCs, except 1-butanol and 2-ethylhexanol from Eminent flooring glued with Cascoproff adhesive on K30 concrete with different drying times, $\mu\text{g}/\text{m}^2 \cdot \text{hour}$. Influence of levelling compound and primer.

		Sample					
		1SP	2SP	3SP	4SP	11SP	12SP
K30 concrete, drying time		1 day	7 days	1 day	1 day	0,2 days	1 day
Primer		-	-	2x550	2x550+554	MD16	MD16
5 mm maxit 4150 drying time		-	-	7 days	7 days	0,8 days	6 days
Isooctanol CAS no 26952-21-6	0,5 years	-	-	-	-	-	-
	1 year	-	-	-	-	-	-
	2 years	26	28	-	-	9	-
	3 years	37	28	5	-	18	-
	4 years	34	33	8	6	21	7
6-metyl-1-octanol CAS no 110453-78-6	0,5 years	-	-	-	-	-	-
	1 year	5	6	-	-	-	-
	2 years	14	13	-	-	5	-
	3 years	18	13	-	-	9	-
	4 years	17	16	-	-	10	-
1-nonanol CAS no 143-08-8	0,5 years	-	-	-	-	-	-
	1 year	8	12	-	-	-	-
	2 years	6	9	-	-	-	-
	3 years	8	6	-	-	8	-
	4 years	8	7	-	-	2	-
2-(2-butoxyetoxy)etanol CAS no 112-34-5	0,5 years	17	7	-	7	8	6
	1 year	15	6	13	9	7	5
	2 years	13	6	16	12	8	<5
	3 years	10	<5	-	-	-	-
	4 years	5	-	-	-	-	-

The presence of new secondary emissions from the flooring has already been shown in Table 23 (samples 1SP and 2SP), when the flooring is glued directly on the concrete. Now in Table 25, we can see what happens with those emissions when we introduce a levelling compound on the concrete, either with an ordinary primer (samples 11SP and 12SP) or with a moisture barrier (3SP and 4SP). It is clear from the results that the introduction of a levelling compound has a positive effect – the new emissions have almost vanished. But it can also be seen that the moisture barrier as primer is not any better than the ordinary primer, when the total drying time is about 7 days (samples 3SP and 4SP compared to 12SP). For the samples with only 1 day total drying time (1SP and 11SP), the new emissions are about cut to the half when introducing the levelling compound with ordinary primer. This is illustrated for isooctanol in Figure 11.

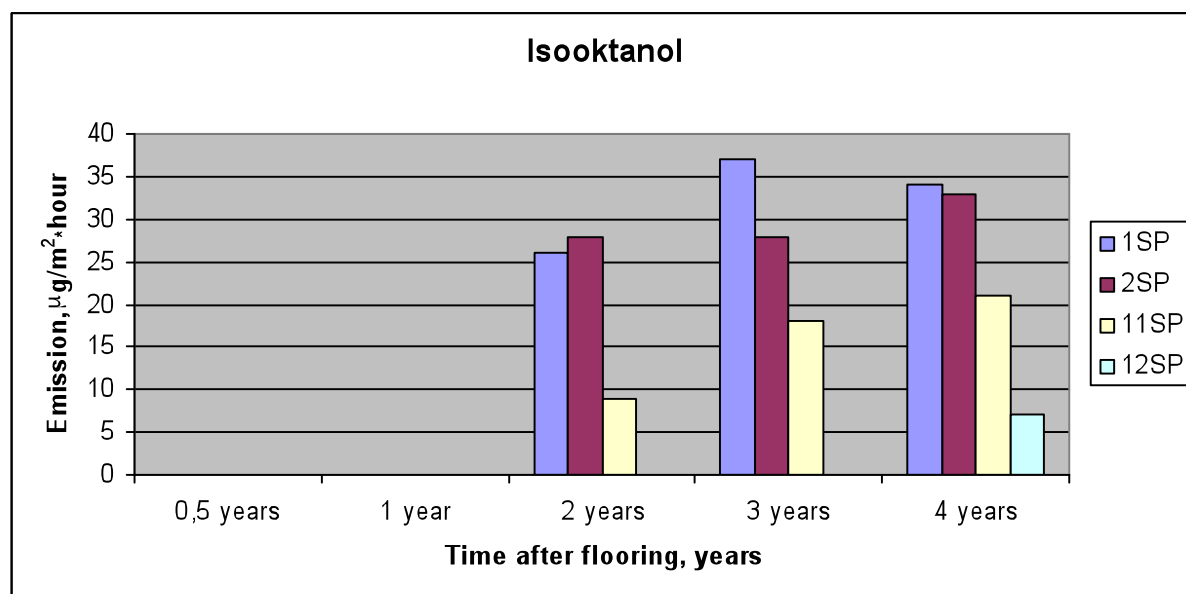


Figure 11. Emissions of isooctanol from samples without (1-2SP) and with levelling compound (11-12SP).

To summarize the above discussions, it is clear that two-sided drying of concrete reduces the risk of secondary emissions from the adhesive considerably, but the same does not necessarily go for the flooring. And the use of a low alkali levelling compound is again advantageous with regard to reducing the risk for secondary emissions. Even with the extremely moist conditions with only one day of drying, the levelling compound reduces the secondary emissions quite considerably. The moisture barrier as primer has not been shown to reduce the risk for secondary emissions. It is of course difficult to improve the already very positive results obtained with the normal primer.

5.3.2 One-sided drying

The specimens in the CR-project with moisture barrier and one sided drying, series D, are yet too young to be analyzed in detail. But there are already tendencies of increased TVOC and 2-ethylhexanol for some of the samples. So a preliminary conclusion is that the idea of a moisture barrier as primer does not seem to give any advantages compared to the normal primer, or in other words, the critical moisture

level when using a levelling compound does not seem to be raised by using a moisture barrier as primer.

5.4 Field tests

Field tests with the PFS-method were performed at five different locations, all of them with PVC flooring. Two of them were in different rooms at the laboratories of CR, and in this case there was no need for using the transport cups. Two field tests were carried out in Stockholm – one in an office and one in a bathroom. Both these locations were from the early 1990ies. The substrate of the office is unknown, while the substrate of the bathroom is a low alkaline levelling compound, Strå Rapid (no longer on the market).

The fifth location was at SP and was done on samples 13SP and 15SP. The idea here was to be sure to find emissions. In all the field tests there were two reference tests performed at the lid of the PFS-cup.

The results are shown in Appendix J. It can be seen that all the field tests have given low emissions of 1-butanol and 2-ethylhexanol except a slightly increased value of 2-ethylhexanol in one case. And of course the samples 13SP and 15SP had high values (outside the measuring range) as expected.

From the field tests, it can be seen that there is a varying uptake of emissions in the reference samples. Even though they are given as emission rates in $\mu\text{g}/\text{m}^2\cdot\text{hour}$, they should be considered as “equivalent” since the source of the emission is not the surface under the cup, but leaking air from the surrounding room. No identifications of the emissions from the reference cups were made, since the equipment at CR did not have the possibility of simultaneous analysis with FID and MS.

5.5 Costs

Since the main objective of developing the PFS-method was to find a simpler way for field tests, it is of course of interest to compare the costs for PFS and FLEC. The comparison is done for measurement in four positions in the field. In the case of PFS, two extra reference measurements are needed, as explained above. The cost for PFS has been obtained from SP and the cost for FLEC has been obtained from AK-Konsult, a consultant familiar with FLEC-measurements in the field. The cost for 4+2 PFS-measurements, including sending the cups by post, is estimated at € 1000, while the cost for 4 FLEC-measurements is about € 2300. So, the PFS-method is considerably cheaper than FLEC. And if the place of measurement is located far away from the consultant who is making the measurement, the difference will be even bigger. The PFS-measurement does not need any expert at the site.

6. Conclusions

From this rather extensive project, a number of conclusions can be drawn.

6.1 The PFS-method

The PFS-method has been found to be a quite simple and useful method, but with some limitations with regard to quantitative evaluations in field tests, if the surrounding air is polluted. In more detail, the following conclusions can be drawn regarding the PFS-method.

- Measurement under the floor (after opening a hole) is possible, but has no sense because the values obtained are influenced by many factors, some of which are not known. Even though measurement under the flooring can distinguish between “high” and “low” emissions, there is no point in doing so because this is done in a better, easier and more relevant way by measuring on top of the flooring, with the further advantage of not damaging the flooring.
- Measurements on top of the flooring should be done at the earliest one month after application of the flooring. At that time, emissions from alkali attack on the adhesive can be detected on top of the flooring. Alkali attacks on the flooring can take much longer time to appear – a year or more.
- When measuring with the PFS-method in an environment with clean air, the variation of measurements in the same position is around 10%. The variation between measurements at different positions can be much bigger. This stresses the need for at least four measurements at different positions of a surface to get a good estimate of the average emission.
- The sampling time ought to be kept constant at 24 hours, but with high emissions, shorter times can be used to avoid landing outside the measuring range. The sampling time does not seem to have a significant influence on the emission rate.
- When measuring in the field, where the cleanliness of the surrounding air is unknown, there is a risk for leakage under the PFS-cup, which has to be judged by comparing with reference samples taken on the lid of the PFS-cup. In this case, identification of emissions, apart from 1-butanol and 2-ethylhexanol, is important, in order to judge if they are coming from the floor or the surrounding.
- In case of leakage under the PFS-cup, TVOC-values are irrelevant, when calculated using the inner surface area of the PFS-cup. Also the values for 1-butanol and 2-ethylhexanol could be overestimated, because of leakage, but as the interest in field measurements is to find out if there are high emissions in the floor, not exactly *how* high, such an overestimation will be of little importance.
- The emissions measured according to PFS are quite comparable to those measured with FLEC.

- The PFS-method is very cost effective, compared to the FLEC-method.

6.2 Factors influencing emissions

Although the primary objective of the project has been to develop the PFS-method, a lot of information has been gathered regarding the influence of various factors on emissions from combined floor constructions.

- The type of concrete and the moisture level have a paramount influence on emissions. A highly alkaline concrete gives high emissions, even at low relative humidities. A normal K30 concrete gives high emissions when the relative humidity is about 90% and above, but at long drying times (more than two months), the emissions are low.
- Two-sided drying of concrete gives remarkably low emissions on concrete, even at very short drying times (one week on a 200 mm thick specimen)
- Low alkaline levelling compounds are favourable from the emission point of view, but they do not function as protection in the long run on the most humid concretes. This is in line with earlier research.
- One adhesive has surprisingly shown increasing emissions with time that has turned out to contain the primary emission of phenoxy ethanol.
- In the case of alkali attack, it seems as emissions will *either* be dominated by 1-butanol *or* 2-ethylhexanol. Mostly, the 1-butanol dominates at the highest moisture levels and it comes from the adhesive. This indicates that the critical RH for adhesives is not as low as the 85% that often is mentioned. At lower moisture levels – if there is an alkali attack – it is mostly the 2-ethylhexanol that dominates, and it often takes long time to appear.
- If the flooring does not contain DEHP plasticizer, it will not emit 2-ethylhexanol. However, it has been found that this is no guarantee that there will not be any secondary emissions from the flooring. From PVC containing the plasticizer diisononylftalate (DINP), we have found new secondary emissions two years after the application of the flooring. They were isooctanol, 6-metyl-1-octanol and 1-nonanol. There was no tendency for these emissions to decrease after four years. When using a low alkali levelling compound, there was a significant reduction of these emissions, which is further evidence that we are dealing with secondary emissions from alkali attack.
- Emissions from alkali attack can have a quite significant reduction of the readings, when measuring the relative humidity. Therefore a low RH measurement is no guarantee of low emissions.
- A moisture barrier as primer has so far not been found to have any great advantages compared to the normal primer under the levelling compound.

7. Summary

The PFS-method has turned out to be a simple and cost efficient method to evaluate emissions from combined floor constructions. When used in the laboratory, with clean air in the surrounding, the results are comparable to those with FLEC. The variability is quite low, only about 10%.

In field measurements, there can be disturbance from polluted air in the surroundings that has to be taken into account when evaluating the results.

The favourable qualities of a low alkali levelling compound with regard to reducing the risk of secondary emissions have been confirmed in line with earlier research.

An adhesive with a high primary emission has surprisingly been shown to emit this emission through a homogeneous PVC flooring after long time and with no tendency to decrease.

A PVC-flooring with DINP plasticizer has been shown to emit the new secondary emissions isooctanol, 6-methyl-1-octanol and 1-nonanol after long time and with no tendency to decrease.

8. Acknowledgement

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9. References

Alexanderson J. 2004. Secondary emissions from alkali attack on adhesives and PVC floorings. Report TVBM-3115. Building Materials, Lund University. Lund 2004.

GBR 2004. Measuring the emission characteristics of composite floor structures. Swedish Flooring Trade Association, Stockholm 2004.

Grantén, J 2004. Fuktsäkerhet vid limning på lågalkalisk avjämning (The risk of moisture when adhering flooring on low alkali levelling products). SBUF-project no 11427. Malmö 2004

Jutewik M. 2001. Påverkan av uppmätt relativ fuktighet i betong med emissionsskadad golvbeläggning (Influence of measured relative humidity in concrete with flooring damaged by emissions). Diploma work. YTH-BYGG. KTH 2001

Kai Y., Fujiib, M., Kumagaic, K., Shinoharac, N. & Yanagisawac, Y. 2003. A new method to measure emission rate of VOCs with passive flux sampler and evaluation of PFS with reference emission material. Healthy Buildings Singapore 2003.

Wengholt-Johnsson, H. 1998 Floorings on concrete substrates – field measurements of drying times and emissions in Gärdsrået, Umeå (in Swedish). Gothenburg 1998.

Appendix A. Project design - CR-project

Series A. The oldest measurements. Methodology. Different conditioning times and different sampling times. The first measurements only had measurements under the flooring. Later on also measurements on top of flooring.

Sample no	Concrete	Thickness	Drying time	Levelling	Thickness	Drying time	Adhesive	Flooring
1	-			4160	30 mm	1 d	Ref	Ref
2	-			4150	30 mm	1 d	Ref	Ref
3	K 30	100 mm	5 months	-			Ref	Ref
4	K 30	100 mm	1 year	-			Ref	Ref
5	K 30	100 mm	7 d	4150	5 mm	6 d	Ref	Ref
6	Ref	100 mm	14 d	-			Ref	Ref
7	K 30	100 mm	1 d	4150	5 mm	17 hours	Ref	Ref
8	K 30	100 mm	14 d	4150	5 mm	7 d	Ref	Ref
9	K 30	100 mm	28 d	4150	5 mm	7 d	Ref	Ref

Series B. *Different levelling compounds.* The first measurements only had measurements under the flooring with 24 hours conditioning time and 30 minutes sampling time. Later on also measurements on top of flooring with 24 hours sampling time.

Sample no	Levelling	Water content	Thickness	Drying time	Adhesive	Flooring
1	4160	21 %	30 mm	24 hours	Ref	Ref
2	4160	22 %	30 mm	24 hours	Ref	Ref
3	4160	23 %	30 mm	24 hours	Ref	Ref
4	4160	21 %	30 mm	4 hours	Ref	Ref
5	4160	23 %	30 mm	2 hours	Ref	Ref
6	4160	21 %	30 mm	24 hours	B	Ref
7	4160	21 %	30 mm	24 hours	C	Ref
8	4160	21 %	30 mm	24 hours	A	Ref
9	4320	19 %	50 mm	3 d	Ref	Ref
10	4320	21 %	50 mm	1 d	Ref	Ref
11	4360+4031	16 / 27 %	80+1 mm	5+1d	Ref	Ref
12 (ref)	4150	21 %	10 mm	14 d	Ref	Ref

Series B. Concrete. Thickness 100 mm. Initial drying 28 days, then 7 days moist curing followed by a varied drying time as shown below. Measurements as for levelling compounds in series B.

Sample no	Concrete	Second drying	Adhesive	Flooring
13	K 30	7 days	Ref	Ref
14	K 30	14 days	Ref	Ref
15	K 30	28 days	Ref	Ref
16	K 30	56 days	Ref	Ref
17	w/c 0,4	28 days	Ref	Ref

Series C. Validation tests. Only measurements on top of flooring.

Sample no	Substrate	Thickness	Drying time	Adhesive	Flooring
1	Plasterboard			Ref	Ref
2	Plasterboard			Ref	Tarkett Extra
3	Plasterboard			Ref	D:o Eminent
4*	Plasterboard			Ref	Tarkett Extra
5	Ref concrete	99 mm	1 d	Ref	Ref
6	Ref concrete	99 mm	1 d	Ref	Tarkett Extra
7	Ref concrete	99 mm	1 d	Ref	D:o Eminent
8	K 30	99 mm	5 months	Ref	Ref
9	K 30	99 mm	7 d	Ref	Ref
10	4150	10 mm	14 d	Ref	Ref
11	4160	30 mm	1 d	Ref	Ref
12	4150	30 mm	1 d	Ref	Ref
13**	Ref concrete	99 mm	1 d	Ref	Tarkett Extra
14**	Ref concrete	99 mm	1 d	None	Tarkett Extra

* emission measurement in cafeteria ** only moisture measurement

Series D. Moisture barrier as primer after varying drying time of the substrate.. One sided drying. Levelling with 5 mm 4150 with 7 days drying before gluing the flooring. Only measurements on top of flooring.

Sample no	Substrate	Thickness	Drying before moisture barrier	Moisture barrier	Adhesive	Flooring
1	K 30	94 mmm	7 days	2x Serpo 550	Cascoproff	Eminent
2	K 30	94 mmm	7 days	2x Ardal DT	Cascoproff	Eminent
3	K 30	94 mmm	7 days	2x Alcro Parketta	Cascoproff	Eminent
4	K 30	94 mmm	7 days	1x MD 16 (1:3)	Cascoproff	Eminent
5	K 30	94 mmm	1 day	2x Serpo 550	Cascoproff	Eminent
6	K 30	94 mmm	1 day	2x Ardal DT	Cascoproff	Eminent
7	4310	50 mm	5 days	2x Serpo 550	Cascoproff	Eminent
8	4310	50 mm	5 days	2x Ardal DT	Cascoproff	Eminent
9	4360	50 mm	5 days	2x Serpo 550	Cascoproff	Eminent
10	4360	50 mm	5 days	2x Ardal DT	Cascoproff	Eminent
11	Plan 416	95 mm	5 days	2x Serpo 550	Cascoproff	Eminent
12	Plan 416	95 mm	5 days	2x Ardal DT	Cascoproff	Eminent

Appendix B. Project design - SP-project

Series SP. Parallell with the CR-project about PFS, tests with FLEC have been done at SP. The tests have been done on two sided drying concrete with moisture barrier as primer (samples 1-12), *and* one sided drying concrete (samples 13-23). Samples are with or without levelling compound. Only measurements on top of flooring.

Sampl no	Concrete	Thick-ness	Drying time	One- or twosided drying	Moisture barrier/ primer	Levelling	Thick-ness	Drying time	Adhe-sive	Floor-ing
1	K 30	200	1 d	Twoside	-	-			C*	E*
2	K 30	200	7 d	Twoside	-	-			C*	E*
3	K 30	195	1 dygn	Twoside	2x 550	4150	5	6 d	C*	E*
4	K 30	195	1 d	Twoside	2x550 +554	4150	5	6 d	C*	E*
5	K 30	195	1 d	Twoside	2x 550	4150	5	6 d	C	L*
6	K 30	195	1 d	Twoside	2x550 +554	4150	5	6 d	C*	L*
7	K 30	195	7 d	Twoside	2x 550	4150	5	6 d	C*	E*
8	K 30	195	7 d	Twoside	2x550 +554	4150	5	6 d	C*	E*
9	K 30	195	7 d	Twoside	2x 550	4150	5	6 d	C*	L*
10	K 30	195	7 d	Twoside	2x550 +554	4150	5	6 d	C*	L*
11	K 30	195	0,2 d	Twoside	MD 16	4150	5	0,8 d	C*	E*
12	K 30	195	1 d	Twoside	MD 16	4150	5	6 d	C*	E*
13	K 30	95	0,2 d	Oneside	MD 16	4150	5	0,8 d	Ref	Ref
15	K 30	95	1 d	Oneside	MD 16	4150	5	6 d	Ref	Ref
17	K 30	95	7 d	Oneside	MD 16	4150	5	7 d	Ref	Ref
19	K 30	95	14 d	Oneside	MD 16	4150	5	19 d	Ref	Ref
21	Ref	100	14 d	Oneside	-	-			Ref	Ref
22	Ref	100	14 d	Oneside	-	-			Ref	L*
23	Ref	100	14 d	Oneside	-	-			Ref	E*

* C= Cascoproff 3448, E= Tarkett Eminent L= Forbo Linoleum

Appendix C, series A. Measurements under the flooring with PFS at CEMENTA Research.

The emissions are given in toluene equivalents in $\mu\text{g}/\text{m}^2 \cdot \text{hour}$ and are the average of two measurements. Conditioning time 24 hours, sampling time 30 minutes.

Sample no	Date for application of flooring	Age when measuring	TVOC	1-butanol	2-ethylhexanol
1A	2005-03-16	33 weeks	2550	430	
1A	2005-03-16	1 year	1360	190	50
1A	2005-03-16	2 years	880	160	30
2A	2005-03-16	33 weeks	8000	5630	
2A	2005-03-16	1 year	4130	2860	70
2A	2005-03-16	2 years	1390	590	110
3A	2005-09-08	28 weeks	2260	730	140
3A	2005-09-08	1 year	1400	600	210
3A	2005-09-08	1,5 years	1510	410	100
3A	2005-09-08	2 years	1410	270	150
4A	2006-02-27	26 weeks	1450	510	110
4A	2006-02-27	1 year	1170	480	80
4A	2006-02-27	1,5 years	1320	360	70
4A	2006-02-27	2 years	1370	310	220
5A	2005-04-27	1 year	2620	1820	130
5A	2005-04-27	2 years	6200	1940	250
6A	2005-04-28	1 year	o.m	o.m.	40
6A	2005-04-28	2 years	14220	13120	30
7A	2005-06-09	1 year	o.m.	o.m.	190
7A	2005-06-09	2 years	o.m	o.m	200
8A	2005-06-23	1 year	3040	1810	140
8A	2005-06-23	2 years	1780	680	180
9A	2005-07-06	1 year	1890	850	80
9A	2005-07-06	2 years	1740	460	100

o.m. = outside measuring range

Appendix C, series B1-B5, Measurements under the flooring with PFS at CEMENTA Research.

The emissions are given in toluene equivalents in $\mu\text{g}/\text{m}^2 \cdot \text{hour}$ and are the average of two measurements. Conditioning time 24 hours, sampling time 30 minutes.

Sample no	Date for application of flooring	Age when measuring	TVOC	1-butanol	2-ethylhexanol
1B	2006-05-05	1 week	3100	1170	70
1B	2006-05-05	2 weeks	2940	970	30
1B	2006-05-05	4 weeks	3120	1020	40
1B	2006-05-05	13 weeks	2950	920	60
1B	2006-05-05	26 weeks	2370	520	30
1B	2006-05-05	1 year	1570	370	50
1B	2006-05-05	78 weeks	750	160	20
1B	2006-05-05	2,5 years	960	60	120
2B	2006-05-05	1 week	3940	1970	40
2B	2006-05-05	2 weeks	3720	1060	50
2B	2006-05-05	4 weeks	3930	1400	70
2B	2006-05-05	13 weeks	3060	920	70
2B	2006-05-05	26 weeks	1580	280	20
2B	2006-05-05	1 year	1710	180	40
3B	2006-05-05	1 week	3300	1150	60
3B	2006-05-05	2 weeks	5340	1760	40
3B	2006-05-05	4 weeks	4020	1110	70
3B	2006-05-05	13 weeks	2940	790	60
3B	2006-05-05	26 weeks	1980	520	20
3B	2006-05-05	1 year	1190	260	30
4B	2006-05-15	1 week	3140	1160	40
4B	2006-05-15	2 weeks	2940	1200	40
4B	2006-05-15	4 weeks	3140	1030	60
4B	2006-05-15	13 weeks	3100	1120	60
4B	2006-05-15	26 weeks	2360	750	70
4B	2006-05-15	1 year	1640	390	40
5B	2006-05-15	1 week	5220	2160	60
5B	2006-05-15	2 weeks	4360	1500	100
5B	2006-05-15	4 weeks	4640	1690	50
5B	2006-05-15	13 weeks	5050	2060	170
5B	2006-05-15	26 weeks	3970	1070	70
5B	2006-05-15	35 weeks	3690	1130	50
5B	2006-05-15	35 weeks	2670	1160	30
5B	2006-05-15	1 year	2660	530	60

Appendix C, series B6-B11, Measurements under the flooring with PFS at CEMENTA Research.

The emissions are given in toluene equivalents in $\mu\text{g}/\text{m}^2 \cdot \text{hour}$ and are the average of two measurements. Conditioning time 24 hours, sampling time 30 minutes.

Sample no	Date for application of flooring	Age when measuring	TVOC	1-butanol	2-ethylhexanol
6B	2006-05-16	1 week	4200	1280	40
6B	2006-05-16	2 weeks	2200	700	20
6B	2006-05-16	4 weeks	3700	900	50
6B	2006-05-16	13 weeks	2500	690	60
6B	2006-05-16	26 weeks	1180	240	10
6B	2006-05-16	1 year	1310	140	30
7B	2006-05-24	1 week	2770	910	30
7B	2006-05-24	2 weeks	3080	1080	30
7B	2006-05-24	4 weeks	2800	830	30
7B	2006-05-24	13 weeks	1790	330	40
7B	2006-05-24	26 weeks	1560	470	60
7B	2006-05-24	1 year	1130	140	20
8B	2006-05-24	1 week	5380	1260	70
8B	2006-05-24	2 weeks	2620	500	30
8B	2006-05-24	4 weeks	2800	440	80
8B	2006-05-24	13 weeks	2450	440	40
8B	2006-05-24	26 weeks	2350	430	70
8B	2006-05-24	1 year	1400	140	50
9B	2009-06-01	1 week	2580	1110	40
9B	2009-06-01	2 weeks	2690	1260	30
9B	2009-06-01	4 weeks	2500	1090	40
9B	2009-06-01	13 weeks	2520	790	60
9B	2009-06-01	26 weeks	2570	1030	50
9B	2009-06-01	1 year	2340	630	50
9B	2009-06-01	2,5 years	7120	4710	1670
10B	2006-06-20	1 week	5520	2490	90
10B	2006-06-20	2 weeks	2990	1050	60
10B	2006-06-20	4 weeks	2870	1040	40
10B	2006-06-20	13 weeks	2050	740	
10B	2006-06-20	26 weeks	3700	1750	50
10B	2006-06-20	1 year	1910	320	40
11B	2009-06-13	1 week	2620	1390	40
11B	2009-06-13	2 weeks	1760	710	50
11B	2009-06-13	4 weeks	2080	1090	50
11B	2009-06-13	13 weeks	1390	940	30
11B	2009-06-13	26 weeks	2050	490	110
11B	2009-06-13	1 year	1140	310	260
11B	2009-06-13	2,5 years	950	80	400

Appendix C, series B12-B17. Measurements under the flooring with PFS at CEMENTA Research.

The emissions are given in toluene equivalents in $\mu\text{g}/\text{m}^2 \cdot \text{hour}$ and are the average of two measurements. Conditioning time 24 hours, sampling time 30 minutes.

Sample no	Date for application of flooring	Age when measuring	TVOC	1-butanol	2-ethylhexanol
12B	2006-06-13	1 week	2940	1010	40
12B	2006-06-13	2 weeks	2580	840	30
12B	2006-06-13	4 weeks	2690	1070	40
12B	2006-06-13	13 weeks	2080	800	10
12B	2006-06-13	26 weeks	1850	460	60
12B	2006-06-13	1 year	1370	300	370
12B	2006-06-13	65 weeks	1050	160	220
12B	2006-06-13	68 weeks	1310	250	220
12B	2006-06-13	72 weeks	780	150	90
12B	2006-06-13	2,5 years	1200	70	170
13B	2006-06-07	13 weeks	2060	1390	60
13B	2006-06-07	26 weeks	3330	1810	130
13B	2006-06-07	1 year	4270	2830	390
14B	2006-06-14	13 weeks	1930	1010	110
14B	2006-06-14	26 weeks	1620	610	230
14B	2006-06-14	1 year	1280	400	310
15B	2006-06-28	13 weeks	1450	540	
15B	2006-06-28	26 weeks	1310	380	180
15B	2006-06-28	1 year	2410	340	810
16B	2006-07-26	13 weeks	2150	570	110
16B	2006-07-26	26 weeks	2070	620	230
16B	2006-07-26	1 year	1560	270	260
17B	2006-06-28	13 weeks	1580	490	
17B	2006-06-28	26 weeks	1980	510	620
17B	2006-06-28	1 year	2980	350	1060

Appendix D, series A. Measurements on top of the flooring with PFS at CEMENTA Research.

The emissions are given in toluene equivalents in $\mu\text{g}/\text{m}^2 \cdot \text{hour}$ and are the average of four measurements. The coefficient of variation (Var %) is the standard deviation divided by the average in % (for four measurements).

Sample no	Age at measurement	TVOC		1-butanol		2-ethylhexanol	
		Average	Var, %	Average	Var, %	Average	Var, %
1A	2 years	20	7	3	19	2	10
2A	2 years	25	9	3	39	4	18
3A	1,5 years	20	19	3	109	5	32
3A	2 years	24	13	1	15	6	24
3A	3 Years	31	9	1	7	8	22
3A	4 years	26	4	1	14	8	20
4A	1 year	17	11	2	29	2	54
4A	1,5 years	21	7	1	89	2	68
4A	2 years	17	6	1	17	3	53
4A	3 Years	24	16	1	7	5	19
5A	2 years	51	47	25	120	7	57
5A	4 years	44	13	3	24	16	15
6A	4 years	70		39		7	
7A	2 years	o.m.		o.m.		7	36
7A	4 years	o.m.		o.m.		13	20
8A	2 years	26	11	3	40	9	18
8A	4 years	53	30	3	23	26	17
9A	2 years	29		3		6	
9A	4 years	212	148	2	18	17	11

o.m. = outside measuring range

Appendix D, series B1-B11, Measurements on top of the flooring with PFS at CEMENTA Research.

The emissions are given in toluene equivalents in $\mu\text{g}/\text{m}^2 \cdot \text{hour}$ and are the average of four measurements.

Sample no	Age at measurement	TVOC		1-butanol		2-ethylhexanol	
		Average	Var, %	Average	Var, %	Average	Var, %
1B	1 year	28	11	3	11	3	7
1B	2,5 years	111	15	3	57	20	17
1B	3 years 5 weeks	57	7	1	1	24	17
1B	3 years 27 weeks	145	154	0	18	12	9
2B	1 year	31	15	2	17	2	85
2B	2,5 years	83	18	2	33	18	23
2B	3 years 5 weeks	57	16	1	70	21	41
3B	1 year	28	12	4	48	3	4
3B	2,5 years	42	14	1	32	12	32
3B	3 years 5 weeks	30	16	1	70	13	34
4B	1 year	31	4	5	20	3	8
4B	2,5 years	30	2	2	33	3	20
4B	3 years 5 weeks	56		1	10	7	27
5B	1 year	31	11	4	34	4	5
5B	2,5 years	28	20	1	46	3	45
5B	3 years 5 weeks	37	25	1	102	5	48
5B	3 years 26 weeks	37	20	1	18	6	26
6B	1 year	23	48	2	37	2	63
6B	2,5 years	61	16	2	28	7	22
6B	3 years 5 weeks	68	28	2	7	12	34
7B	1 year	28	6	1	33	3	5
7B	2,5 years	40	46	1	21	9	68
7B	3 years 5 weeks	37	8	1	22	8	22
8B	1 year	180	8	1	13	4	7
8B	2,5 years	298	12	3	26	41	55
8B	3 years 5 weeks	o.m.		2	6	37	29
9B	1 year	29	39	3	25	2	24
9B	2,5 years	70	9	4	32	23	31
9B	3 years 5 weeks	86	14	2	21	32	21
10B	1 year	23	11	4	30	2	7
10B	2,5 years	203	55	7	8	58	74
10B	3 years 5 weeks	60	25	5	9	8	13
10B	3 years 21 weeks	197	125	1	49	5	10
11B	1 year	40	3	5	24	16	9
11B	1 year 6 weeks	43	36	4	68	12	16
11B	2,5 years	83		1	49	65	
11B	3 years 5 weeks	88	30	1	36	61	34
11B	3 years 20 weeks	120	11	1	82	76	3

Appendix D, series B12-B17, Measurements on top of the flooring with PFS at CEMENTA Research.

The emissions are given in toluene equivalents in $\mu\text{g}/\text{m}^2 \cdot \text{hour}$ and are the average of four measurements. The coefficient of variation (Var %) is the standard deviation divided by the average in % (for four measurements).

Sample no	Age at measurement	TVOC		1-butanol		2-ethylhexanol	
		Average	Var,%	Average	Var,%	Average	Var,%
12B	1 year	19	10	1	19	3	11
12B	2,5 years	121	110	1	101	39	138
12B	3 years 5 weeks	44	19	1	75	8	20
12B	3 years 20 weeks	25	33	0	87	5	34
13B	1 year	110	11	39	32	55	16
13B	2,5 years	o.m.		41		o.m.	
13B	3 years 6 weeks	o.m.		56	93	o.m.	
14B	1 year	55	17	5	45	33	17
14B	2,5 years	o.m.		5	50	o.m.	
14B	3 years 5 weeks	o.m.		6	40	o.m.	
15B	1 year	81	29	4	27	48	35
15B	2,5 years	o.m.		1	44	o.m.	
15B	3 years 5 weeks	o.m.		1	24	o.m.	
16B	1 year	49	23	2	22	29	35
16B	2,5 years	68	18	1	9	48	20
16B	3 years 5 weeks	75	23	1	5	55	31
17B	1 year	72	11	5	25	35	29
17B	2,5 years	o.m.		2		o.m.	
17B	3 years 5 weeks	o.m.		2	37	o.m.	

o.m. = outside measuring range

Appendix E, series C, Measurements on top of the flooring with PFS at Cementsa Research.

The emissions are given in toluene equivalents in $\mu\text{g}/\text{m}^2 \cdot \text{hour}$ and are the average of four measurements. The coefficient of variation (Var %) is the standard deviation divided by the average in % (for four measurements).

Sample no	Age at measurement	TVOC		1-butanol		2-ethylhexanol	
		Average	Var,%	Average	Var,%	Average	Var,%
1C	1 week	87	16	1	15	26	9
1C	3 weeks	49	10	1	44	11	8
1C	11 weeks	36	4	1	75	5	28
1C	51 weeks	16	12	0	17	1	5
2C	1 week	33	8	6	34		
2C	3 weeks	23	5	2	14	1	45
2C	11 weeks	16	6	1	53	1	18
3C	1 week	15	27	1	64	1	78
3C	3 weeks	17	17	0	20	1	35
3C	11 weeks	15	21	1	107	1	45
4C	1 week	15	6	2	80	1	12
4C	1 week	15	4	2	23	1	15
4C	3 weeks	19	28	2	85	1	3
5C	1 week	73	7	1	13	24	8
5C	2 weeks	o.m.		o.m.		16	10
6C	1 week	o.m.		o.m.		0	31
7C	1 week	21	12	2	31	1	27
7C	2 weeks	30	23	9	51	1	31
8C	4 weeks	57	32	3	22	14	25
8C	13 weeks	41	15	4	11	9	11
8C	26 weeks	40	7	3	6	15	9
8C	1 year	47	8	3	6	29	12
9C	13 weeks	90		53		8	7
9C	26 weeks	o.m.		o.m.		11	42
9C	1 year	o.m.		o.m.		24	16
10C	13 weeks	56	5	12	8	9	5
10C	26 weeks	32	4	4	20	4	12
10C	1 year	28	9	2	13	6	16
11C	13 weeks	60	7	9	8	8	13
11C	26 weeks	37	9	7	4	4	5
11C	1 year	52	29	5	8	3	11
12C	13 weeks	43	10	5	7	7	5
12C	26 weeks	47	8	11	6	5	2
12C	1 year	28	8	6	8	4	6
13C	8 weeks	o.m.		o.m.		1	6
14C	8 weeks	78	6	2	70	0	62

Appendix F, series D, Measurements on top of the flooring with PFS at CEMENTA Research.

The emissions are given in toluene equivalents in $\mu\text{g}/\text{m}^2 \cdot \text{hour}$ and are the average of four measurements. The coefficient of variation (Var %) is the standard deviation divided by the average in % (for four measurements).

Sample no	Age at measurement	TVOC		1-butanol		2-ethylhexanol	
		Average	Var,%	Average	Var,%	Average	Var,%
1D	26 weeks	41	19	4	28	3	45
1D	1 year	40	23	4	15	2	13
2D	26 weeks	43	22	2	10	2	16
2D	1 year	42	13	2	9	2	40
3D	26 weeks	39	4	3	33	2	12
3D	1 year	64	29	2	10	3	23
4D	26 weeks	27	46	2	23	1	51
4D	1 year	45	18	2	26	1	17
5D	26 weeks	135		6	20	7	6
5D	1 year	131	13	9	0	10	15
6D	26 weeks	77		4	23	6	10
6D	1 year	109	1	4	18	8	6
7D	26 weeks	103	32	3	23	6	16
7D	1 year	85	24	2	9	7	22
8D	26 weeks	154	32	4	10	31	80
8D	1 year	103	3	2	9	4	40
9D	26 weeks	167	9	5	11	10	53
9D	1 year	162	15	4	15	9	8
10D	26 weeks	104	7	4	3	4	3
10D	1 year	81	10	3	7	7	98
11D	26 weeks	101	23	8	11	15	11
11D	1 year	122		8		16	
12D	26 weeks	105	25	16	5	17	21
12D	1 year	o.m.		12	7	36	23

o.m. = outside measuring range

Appendix G , series SP1-SP9. Measurements on top of the flooring with FLEC at Swedish Technical Research Institute.

The emissions are given in toluene equivalents in $\mu\text{g}/\text{m}^2 \cdot \text{hour}$.

Sample no	Date for application of flooring	Age when measuring	TVOC	1-butanol	2-ethylhexanol
1SP	2005-05-11	0,5 years	252	154	62
1SP	2005-05-11	1 year	240	112	87
1SP	2005-05-11	2 years	220	43	75
1SP	2005-05-11	3 years	180	19	53
1SP	2005-05-11	4 years	140	7	
2SP	2005-05-17	0,5 years	40	7	5
2SP	2005-05-17	1 year	50	7	6
2SP	2005-05-17	2 years	80	<5	6
2SP	2005-05-17	3 years	73		7
2SP	2005-05-17	4 years	89		
3SP	2005-05-18	0,5 years	<10		
3SP	2005-05-18	1 year	30		
3SP	2005-05-18	2 years	40		
3SP	2005-05-18	3 years	38		
3SP	2005-05-18	4 years	28		
4SP	2005-05-18	0,5 years	30		
4SP	2005-05-18	1 year	20		
4SP	2005-05-18	2 years	20		
4SP	2005-05-18	3 years	29		
4SP	2005-05-18	4 years	26		
5SP	2005-05-18	0,5 years	155	6	
5SP	2005-05-18	1 year	110	5	
5SP	2005-05-18	2 years	80	<5	
6SP	2005-05-18	0,5 years	147	6	
6SP	2005-05-18	1 year	110	5	
6SP	2005-05-18	2 years	80	<5	
7SP	2005-05-24	0,5 years	20		
7SP	2005-05-24	1 year	20		
7SP	2005-05-24	2 years	30		
8SP	2005-05-24	0,5 years	27		
8SP	2005-05-24	1 year	30		
8SP	2005-05-24	2 years	40		
9SP	2005-05-24	0,5 years	134	5	
9SP	2005-05-24	1 year	110	<5	
9SP	2005-05-24	2 years	90	<5	

Appendix G , series SP10-SP19. Measurements on top of the flooring with FLEC at Swedish Technical Research Institute.

The emissions are given in toluene equivalents in $\mu\text{g}/\text{m}^2 \cdot \text{hour}$.

Sample no	Date for application of flooring	Age when measuring	TVOC	1-butanol	2-ethylhexanol
10 SP	2005-05-24	0,5 years	128	5	
10 SP	2005-05-24	1 year	110	<5	
10 SP	2005-05-24	2 years	80	<5	
11SP	2005-05-11	0,5 years	30	5	5
11SP	2005-05-11	1 year	30	6	7
11SP	2005-05-11	2 years	50	6	10
11SP	2005-05-11	3 years	56	<5	10
11SP	2005-05-11	4 years	61		7
12SP	2005-05-17	0,5 years	25		
12SP	2005-05-17	1 year	20		
12SP	2005-05-17	2 years	20		
12SP	2005-05-17	3 years	19		
12SP	2005-05-17	4 years	18		
13SP	2005-05-11	0,5 years	38	15	10
13SP	2005-05-11	1 year	60	14	33
13SP	2005-05-11	2 years	130	14	110
13SP	2005-05-11	3 years	170	14	150
13SP	2005-05-11	4 years	170	10	150
15SP	2005-05-17	0,5 years	32		10
15SP	2005-05-17	1 year	20		11
15SP	2005-05-17	2 years	40		38
15SP	2005-05-17	3 years	62		60
15SP	2005-05-17	4 years	89		81
17SP	2005-05-24	0,5 years	17		8
17SP	2005-05-24	1 year	20		7
17SP	2005-05-24	2 years	20		17
17SP	2005-05-24	3 years	35		25
17SP	2005-05-24	4 years			34
19SP	2005-06-13	0,5 years	19		8
19SP	2005-06-13	1 year	20		7
19SP	2005-06-13	2 years	20		15
19SP	2005-06-13	3 years	19		19
19SP	2005-06-13	4 years			25

Appendix G , series SP21-SP23. Measurements on top of the flooring with FLEC at Swedish Technical Research Institute.

The emissions are given in toluene equivalents in $\mu\text{g}/\text{m}^2 \cdot \text{hour}$.

Sample no	Date for application of flooring	Age when measuring	TVOC	1-butanol	2-ethylhexanol
21SP	2005-04-28	0,5 year	307	232	33
21SP	2005-04-28	1 year	330	270	51
21SP	2005-04-28	2 years	270	205	64
21SP	2005-04-28	3 years	230	145	59
21SP	2005-04-28	4 years	170	120	50
22SP	2005-04-28	0,5 year	134	5	
22SP	2005-04-28	1 year	70	5	
22SP	2005-04-28	2 years	50	<5	
23SP	2005-04-28	0,5 year	118	106	
23SP	2005-04-28	1 year	130	118	
23SP	2005-04-28	2 years	140	105	
23SP	2005-04-28	3 years	110	66	
23SP	2005-04-28	4 years	92	49	

Appendix F. Weight results from the SP-project, gram.

Sample no	Weight after application of flooring	0,5 year	1 year	2 years	3 years	4 years
1SP	21941	21860	21810	21750	21690	21665
2SP	22374	22290	22260	22190	22150	22131
3SP	21874	21790	21750	21670	21630	21608
4SP	21532	21450	21420	21350	21310	21287
5SP	21787	21700	21660	21600		
6SP	22139	22060	22020	21950		
7SP	21979	21910	21870	21810		
8SP	21931	21860	21820	21760		
9SP	21518	21440	21400	21330		
10SP	21553	21480	21430	21370		
11SP	22343	22260	22210	22140	22090	22062
12SP	21811	21730	21690	21620	21580	21561
13SP	11399	11387	11370	11359	11344	11329
15SP	11321	11316	11300	11298	11288	11278
17SP	10900	10899	10890	10889	10884	10878
19SP	10880	10880	10877	10872	10867	10862
21SP	10780	10778	10770	10764	10755	10748
22SP	10624	10614	10600	10585		
23SP	10745	10741	10730	10724	10712	10703

Appendix I. Moisture measurements, CR-project.

The values are in RH. C= in construction 40% from top. S=at the surface.

Sample no	Flooring	4weeks		13weeks		26weeks		1year		2years		2,5 years	3years
	C	C	S	C	S	C	S	C	S	C	S	C	
1A							83		87		81		
2A							95		97		90		
3A	84					90	83	87	84	83	83		80
4A	82					81	79	80	79	77	78		75
5A							95		90		89		
6A							82		86		72		
7A							97		93		84		
8A							92		96		87		
9A							91		92		88		
1B		94	93	91	93	89	88	85	84			75	73
2B		97	96	93	94	91	89	86	84			81	73
3B		94	96	93	96	91	90	87	85			82	77
4B		96	96	94	96	92	92	89	89			86	80
5B		96	96	96	96	95	95	92	93			87	85
6B		94	92	91	92	89	88	86	84			77	77
7B		93	91	90	90	87	88	84	85			80	
8B		93	90	90	91	88	86	85	85			78	
9B		96	96	95	95	93	91	91	91			87	
10B		94	95	96	95	93	93	94	94			97	
11B		97	94	95	93	93	89	91	89			87	
12B			72		66		59		50				
13B				95	93	94	90	89	84				
14B				95	93	93	91	91	94				
15B				93	91	92	89	90	89				
16B				92	88	92	89	91	88				
17B				84	83	80	80	78	78				
5C		86		80									
6C		85		78									
7C		86		80									
8C		90		88		89		87					
9C				95		96		88					
11C				90		89		86					
12C				94		95		93					
13C		86		77									
14C		90		88									
1D						96		91					
2D						95		92					
3D						95		92					
4D						92		92					
5D						100		93					
6D						98		93					
12D						94		90					

Appendix J. Field measurements.

The emissions are given as averages in toluene equivalents in $\mu\text{g}/\text{m}^2 \cdot \text{hour}$.

Location	PFS on PVC flooring			Reference PFS on lid		
	TVOC	1-butanol	2-ethylhexanol	TVOC	1-butanol	2-ethylhexanol
Bathroom, Stockholm 1993	75	9	5	55	5	2
Apparatus room CR 1979	35	0	18	32	0	0
Chemistry room CR 1979	27	0	0	11	0	0
Office Stockholm About 1995	316	2	2	227	2	2
Sample 13SP	o.m.	9	o.m.	70	2	0
Sample 15SP	o.m.	3	o.m.			

o.m. = outside measuring range

Appendix K. Materials

K30 concrete used in the CR-project, kg/m³

Cement	270
8 -16	779
4-8	263
2 – 4	253
Sand 90	370
Sand 1	253
Limus 40/limestone filler	29
Water	181

K30 concrete used in the SP-project, kg/m³

Cement	320
0 -8	1158
8 – 16	638
Water	184
Plasticizer Cementsa 92	4,3

K60 concrete used in the CR-project, kg/m³

Cement	440
8 -16	724
4-8	270
2 – 4	234
Sand 90	380
Sand 1	198
Water	176

GBR reference concrete, kg

Cement	100
Standard sand	300
Water	50

GBR reference adhesive, %

Water	30,0
Hydroxyethyl cellulose	0,4
Butylacrylate polymer	30,0
Sodium polyacrylate	0,5
Paraffin mineral oil	0,1
Conservatives	0,1
• 2-brom-2-nitro-1,3-propanol	
• Methyl-klor-isotiazolinon	
• Methyl- isotiazolinon	
Calcium-magnesium carbonate	30,4
Triethylene glykolester from pine resin	8,5
Total	100,0

GBR reference flooring, %

S-PVC	48
Di-ethylhexylphthalate	20
CaZn-stabilizor	1
Epoxidated soybeanoil	1
Calciumcarbonate (filler)	30
Total	100

Cascoproff 3448 adhesive,%

Calciumcarbonate	25-30
Water	10-25
Resin	10-25
Styrene acrylate copolymer	10-25
Acrylate copolymer	10-25

Tarkett Eminent homogeneous 2 mm PVC flooring, %

PVC	45
Diisononylphthalate	17
CaZn-stabilizor	<1
Epoxidated soybeanoil	<1
Mineral filler	33
Titaniumoxid	2
Polyurethane strengthening	<1

Tarkett Extra heterogeneous PVC flooring, %

PVC	40
Diisononylphthalate	20
Diisoheptylphthalate	5
Benzoate	3
CaZn-stabilizor	2
Mineral filler	24
Titaniumoxid	3
Glassfiber fabric	3
Polyurethane strengthening	<1

Adhesives A, B and C

The only specific ingredient mentioned on the website of the producer is phenoxyethanol which is found in adhesive A..