Measurement of air pollution in indoor artificial turf halls

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Norwegian Pollution Control Authority/
Norwegian Institute for Air Research
State Programme for Pollution Monitoring

Foreword

In October 2005, the Norwegian Institute for Air Pollution (NILU) was commissioned by the Norwegian Pollution Control Authority (SFT) to measure the concentration of airborne dust and gas phase compounds in indoor air in indoor artificial turf pitches.

The measurements were taken in a hall with recently laid rubber granulate (SBR rubber or Styrene Butadiene Rubber), a hall with rubber granulate (SBR rubber) which had been in use for one year and a hall with granulate made from thermoplastic elastomer.

The study will be used as a basis for exposure calculations and the assessment of heath effects.

Many thanks to everyone who has contributed to this project:
Norwegian Football Association; Ole Myhrvold
Manglerudhallen; Rune Molberg
Valhall; Rune Brattfoss
Østfoldhallen; Leif Andersen

The report was prepared by NILU.

Kjeller, 30 November 2005

Christian Dye
Project Manager

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Summary

This report describes measurements of air quality for three indoor artificial turf pitches. The measurements were taken in a hall with recently laid rubber granulate (SBR rubber or Styrene Butadiene Rubber), a hall with rubber granulate (SBR rubber) which had been in use for one year and a hall which used granulate made from thermoplastic elastomer. The parameters which were covered are the concentration and chemical composition of airborne dust and the concentration in indoor air of volatile organic compounds (VOC) and polycyclic aromatic hydrocarbons (PAH).

The study will be used as a basis for exposure calculations and the assessment of health effects. There is little data in the literature from corresponding air studies. There are also no specific criteria or guidelines concerning air quality in indoor sports facilities. NILU's own experience of indoor environments over many years, together with guidelines and recommendations that NILU considers to be relevant references, was therefore used in the assessment of the results.

The study is characterised as a random sample study based on a limited number of pitches. The measurement programme was pre-determined.

The results indicate that the use of rubber granulate from ground car tyres (SBR rubber) causes a considerable burden on the indoor environment. Manglerudhallen and Valhall use this type of rubber granulate. Rubbers granulate produced from thermoplastic elastomer generate less pollution from the parameters that were measured compared with rubber granulates made from thermoplastic elastomer. For all three halls, the study shows the presence of organic chemicals which have not been identified or reported.

The report contains a method description, measurement results and some results from laboratory studies of the rubber granulate. The results are discussed and summarised.

The report has been prepared by the Norwegian Institute for Air Research (NILU) on behalf of the Norwegian Pollution Control Authority (SFT). NILU is responsible for the results, assessments and conclusions.

1. Introduction

In October 2005, the Norwegian Institute for Air Research (NILU) was commissioned by the Norwegian Pollution Control Authority (SFT) to measure the concentration of airborne dust and gas phase compounds in indoor artificial turf pitches. The measurement programme is described in Table 1.

Table 1: Measurement programme for indoor artificial turf facilities on behalf of SFT.

Fraction	Parameter
Airborne dust (PM_{10})	Concentration Proportion of rubber Vulcanisation compounds, preservative compounds Phthalates Tar compounds (PAH)
Airborne dust ($PM_{2.5}$)	Concentration Proportion of rubber Vulcanisation compounds, preservative compounds Phthalates
Gas phase	Volatile organic compounds (VOC) Tar compounds (PAH)

The measurements were to be taken in a hall with recently laid rubber granulate (SBR rubber), a hall with rubber granulate (SBR rubber) which had been in use for one year, and a hall with granulate made from thermoplastic elastomer.

There is little data from corresponding air studies in the literature. There are also no criteria or guidelines for air quality in indoor sports facilities. NILU’s own experience of indoor environments over many years, together with guidelines and recommendations that NILU considers to be relevant references, was therefore used in the assessment of the results.

2. Materials and methods

2.1 Sampling

Airborne dust was collected on a 47 mm quartz fibre filter with a flow rate of 2.3 m^3/hour. Separate filters were used for the PM_{10} fraction (particulate material with an equivalent aerodynamic diameter < 10 µm) and the $PM_{2.5}$ fraction (particulate material with an equivalent aerodynamic diameter < 2.5 µm). The sampling system was of the Kleinfiltergerät type, with an intake which complies with prEN12341.

The airborne dust (PM_{10}) which was to be analysed for PAH was collected on a 150 mm glass fibre filter with a flow rate of 30 m^3/hours, while the gas phase compounds were collected on polyurethane plugs. The sampling system was a Digital Automatic High Volume Aerosol Sampler (DHA-80) with an intake which complies with prEN12341.

Volatile organic compounds (VOCs) were collected on a Tenax-adsorbent using active sampling in accordance with prEN ISO 16017. The carbonyl compounds with one to three carbon atoms were collected on a silica-adsorbent impregnated with 2,4-dinitrophenylhydrazine, using active sampling (Brombacher et al., 2002).

2.2 Chemical analysis

The chemical analysis of the airborne dust involved extracting part of the filter in a solvent in an ultrasound bath for 30 minutes. This was done twice to optimise the extraction yield, and the extracts were then combined and analysed jointly. No isotope-marked standards are commercially available for many of the analytes which were analysed. The sample preparation was therefore based on careful handling, while calculations were based on an external standard. Validation studies which were carried out at the laboratory show that recovery rates in excess of 90% were achieved for most of the analytes.

The carbon analysis was carried out by heating the filter in accordance with the EGA (evolved gas analysis) principle. All the carbon was converted to CO_2 and then methane. The methane was quantified using a FID (flame ionisation detector) (Birch et al., 1996)

The methodology which was used for PAH in airborne dust and gas phase was based on Thrane et al. (1985). The results were corrected for any loss during extraction and preparation through the setting of an internal standard. The most relevant analytical parameters are shown in Table 2.

Determination of all types of volatile organic compounds was carried out in accordance with prEN ISO 16017.

Table 2: The most relevant analytical parameters.

Parameter	Extraction	Preparation	Quantification	Ionisation technique	Column	Measurement uncertainty
Carbon EC/OC	None	Thermo-optical transmission	Methane - Internal state	None	None	± 10%
Proportion of rubber	Liquid	SPE	LC/MS-TOF	ESI(+)	Atlantis dC18, 3 µm 15 cm * 2.1 mm	± 20%
Vulc. and preservative compounds	Liquid	Centrifuging	LC/MS-TOF	ESI(+), ESI (-)	ACE C18 3 µm 15 cm * 2.1 mm, Atlantis dC18, 3 µm 15 cm*2.1 mm	± 25%
Phthalates	Liquid	Centrifuging	LC/MS-TOF	ESI(+)	Atlantis dC18, 3 µm 15 cm*2.1 mm	± 20%
Tar compounds (PAH)	Soxhlet	Liquid/Liquid, LC	GC/MS	EI	Cp Sil8 25m*0.25 mm	± 30%
Volatile organic compounds (VOC)		Thermodesorption	GC/MS	EI	DB 1701, 1 µm, 30 m,0.5 mm	± 25%
Carbonyl compounds	Liquid	SPE	HPLC/UV		NovaPakC18, 15 cm * 3.9 mm	± 14%

EC means elementary carbon, OC means organic carbon.
EI: Electron impact ionisation.
ESI (-/+): negative/positive electrospray.
GC/MS: Gas chromatography linked to mass spectrometer
LC/MS-TOF: Liquid chromatography linked to a "time-of-flight" mass spectrometer. This gives high resolution mass spectrometry in contrast to an ordinary LC/MS. (Instrument: Waters LCT).
SPE: Solid phase extraction. (OASIS MCX, Waters DNPH-silica).
Thermo-optical transmission: See www.sunlab.com

2.3 Measuring points

Table 3 describes the artificial turf pitches from which samples were taken. We have also enclosed photographs of the halls and the rubber granulate in Appendix 2. Table 4 describes the sample types which were taken.

Table 3: Description of measuring points.

	Manglerudhallen (Oslo)	Manglerudhallen (Oslo)	Valhall (Oslo)	Østfoldhallen (Østfold)
Date	17.10.05	19.10.05	19.10.05	18.10.05
Time	16.20 - 22.35	17.33 - 18.17	16.45 - 21.55	17.05 - 22.40
Temperature start (°C)	18	15	15	17
Temperature stop (°C)	10	15	15	17
Relative air humidity (%)	53	Not measured	42	34
Air pressure (hPa)	Not measured	Not measured	1009	1028
Pitch dimensions (metres)			68X105	68X105
Rubber granulate (type)	Ground car tyres (black and an unknown type (green)	Ground car tyres (black and an unknown type (green)	SBR rubber	Thermoplastic elastomer

Weight/volume of rubber granulate (kg/m^3)	489	489	395	790
Weight per granule with standard deviation (mg)	10 (±2.2) black 15 (±4.1) green	10 (±2.2) black 15 (±4.1) green	13 (±2.8)	7 (±0.7)
Age (number of months at time of sampling)			2	10

Table 4: The samples which were taken.*

Fraction	Location	Typical volume in litres
Airborne dust (PM_{10})	Manglerudhallen, Valhall, Østfoldhallen	12
Airborne dust ($PM_{2.5}$)	Manglerudhallen, Valhall, Østfoldhallen	12
Volatile organic compounds (VOC)	Manglerudhallen, Valhall, Østfoldhallen	5-25
Tar compounds (PAH) in airborne dust and gas phase	Manglerudhallen, Valhall, Østfoldhallen	120 000-170 000
Highly volatile carbonyl compounds	Manglerudhallen, Valhall, Østfoldhallen	600

* Samples of granulate and rubber mats in the body of the pitch were also taken.

3. Results

The results from the measurements are presented in Tables 5 to 7.

Table 5: Concentration of polycyclic aromatic hydrocarbons (PAH) in the gas phase and airborne dust (PM_{10}).

Location **Sample type** **Measurement period** **Unit** **Parameter**	**Manglerudh.** **Gas phase** **16.26-22.31** **ng/m³**	**Manglerudh.** **PM10** **16.26-22.31** **ng/m³**	**Valhall** **Gas phase** **16.47-21.55** **ng/m³**	**Valhall** **PM10** **16.47-21.55** **ng/m³**	**Østfoldh.** **Gas phase** **17.07-22.37** **ng/m³**	**Østfoldh.** **PM10** **17.07-22.37** **ng/m³**
Naphthalene	20.9	0.13	56.4	0.17	11.1	0.04
2-Methylnaphthalene	22.3	0.13	57.7	0.13	24.7	0.06
1-Methylnaphthalene	16.1	0.16	42.5	0.07	16.5	0.10
Biphenyl	16.6	0.08	32.7	0.05	13.4	0.03
Acenaphthylene	32.4	0.19	78.1	0.04	6.24	0.07
Acenaphthene	5.82	0.06	14.2	0.02	4.77	0.02
Dibenzofurane	10.8	0.10	17.0	0.04	10.2	0.05
Fluorene	10.2	0.10	19.2	0.04	7.86	0.06
Dibenzothiophene	1.76	0.03	2.74	0.01	0.88	0.03
Phenanthrene	19.7	0.52	25.0	0.33	14.0	0.44
Anthracene	1.86	0.05	1.33	0.04	0.77	0.04
3-Methylphenanthrene	2.02	0.09	2.82	0.08	1.54	0.09
2-Methylphenanthrene	2.12	0.12	3.03	0.12	1.78	0.12
2-Methylanthracene	0.39	0.02	0.22	0.02	0.12	0.01
9-Methylphenanthrene	1.89	0.10	2.75	0.09	1.37	0.12
1-Methylphenanthrene	1.52	0.09	2.11	0.08	1.08	0.09
Fluoranthene	2.81	0.67	2.20	0.48	1.66	0.62

Pyrene	3.54	0.81	3.09	0.64	1.80	1.17
Benzo(a)fluorene	0.05	0.06	0.12	0.02	0.05	0.05
Rethene	0.67	0.36	0.42	0.12	0.49	0.20
Benzo(b)fluorene	0.11	0.10	0.03	0.08	0.07	0.06
Benzo(ghi)fluoranthene	0.17	0.29	0.11	0.23	0.08	0.28
Cyclopenta(cd)pyrene	0.15	0.58	0.07	0.35	0.07	0.23
Benzo(a)anthracene	0.15	0.56	0.07	0.36	0.05	0.14
Crysene /Triphenylene	0.19	0.76	0.11	0.53	0.10	0.38
Benzo(bjk)fluoranthene	0.04	2.24	0.01	1.23	0.04	0.72
Benzo(a)fluoranthene	0.02	0.44	0.01	0.23	0.03	0.35
Benzo(e)pyrene	0.03	0.78	< 0.01	0.48	0.02	0.39
Benzo(a)pyrene	0.02	1.15	< 0.01	0.56	0.01	0.38
Perylene	0.02	0.20	< 0.01	0.09	0.01	0.08
Indeno(123-cd)pyrene	< 0.02	1.11	< 0.01	0.73	< 0.01	0.42
Dibenzo(ac/ah)anthracene	< 0.02	0.13	< 0.01	0.07	< 0.01	0.06
Benzo(ghi)perylene	< 0.02	1.11	< 0.01	0.84	< 0.01	0.69
Anthanthrene	< 0.02	0.39	< 0.01	0.22	< 0.01	0.21
Coronene	< 0.01	0.61	< 0.01	0.51	< 0.01	0.38
Dibenzo(ae)pyrene	< 0.01	0.06	< 0.01	< 0.01	< 0.01	< 0.01
Dibenzo(ai)pyrene	< 0.01	0.04	< 0.01	< 0.01	< 0.01	< 0.01
Dibenzo(ah)pyrene	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Total	174.17	10.84	363.74	6.46	120.64	4.89

Table 6a: Simplified presentation of the concentration of volatile organic compounds (VOC). Typical rubber components are shown. A more detailed list from each sample is presented in Appendix 1.

Measuring location	Measurement period	Benzothiazole µg/m³	Toluene µg/m³	4-methyl-2-pentanone µg/m³	Total VOC µg/m³
Manglerudh. A	16.31-18.50	15.7	85.0	12.7	715.5
Manglerudh B	18.55-22.00	8.9	51.2	3.4	233.8
Manglerudh C	20.26-22.06	4.5	30.0	2.0	150.5
Manglerudh D (19.10.05)	17.33-18.17	20.4	39.4	11.5	255.3
Valhall A	16.53-22.00	29.1	15.0	11.3	233.9
Valhall B	19.35-22.00	31.7	15.3	12.7	289.8
Østfoldhallen A	17.15-20.10	3.4	17.2	< 0.9	136.3
Østfoldhallen B	20.13-22.35	3.9	19.4	< 1.2	161.3

Table 6b: Concentration of phthalates in the gas phase. The concentrations are included in TVOC.*

Measuring location	Measuring period	Diethylphthalate (DEP) µg/m³	Diisobutylphthalate (DiBP) µg/m³	Dibutylphthalate (DBP) µg/m³
Manglerudh. A	16.31-18.50	0.04	0.07	0.20
Manglerudh. B	18.55-22.00	0.06	0.10	0.20
Manglerudh. C	20.26-22.06	0.03	0.13	0.38
Valhall A	16.53-22.00	0.01	0.02	0.07
Valhall B	19.35-22.00	0.02	0.01	0.07

Østfoldhallen A	17.15-20.10	0.06	0.03	0.06
Østfoldhallen B	20.13-22.35	0.09	0.05	0.18

*Phthalates which are not referred to in the table have gas phase concentrations of < 0.005 µg/m3

Table 7: Results from the physical and chemical analysis of airborne dust.

Location **Sample type**		**Mangl.** **PM_{10}**	**Mangl.** **$PM_{2.5}$**	**Valh.** **PM_{10}**	**Valh.** **$PM_{2,5}$**	**Østf.** **PM_{10}**	**Østf.** **$PM_{2.5}$**
Measuring period		**16.26-22.31**	**16.26-22.31**	**16.47-21.55**	**16.47-21.55**	**17.07-22.37**	**17.07-22.37**
Parameter	**Unit**						
Weight	µg/m^3	40.10	17.32	31.72	18.83	31.26	10.31
Organic carbon (OC)	µg/m^3	14.72	8.24	10.95	9.70	11.41	7.70
Elementary carbon (EC)	µg/m^3	2.73	1.86	3.51	3.40	0.93	0.83
Total carbon (EC+OC)	µg/m^3	17.45	10.10	14.47	13.10	12.33	8.53
Dimethylphthalate (DMP)	ng/m^3	39.1	11.6	50.3	7.6	17.9	5.4
Diethylphthalate (DEP)	ng/m^3	24.4	2.8	10.4	5.7	27.9	19.8
Dibutylphthalate (DBP)	ng/m^3	31.4	15.1	51.7	53.7	45.4	44.0
Diamylphthalate	ng/m^3	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Diethylhexylphthalate (DEHP)	ng/m^3	31.3	5.5	17.7	11.6	22.1	13.2
Dioctylphthalate (DOP)	ng/m^3	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
bis (2-n-ethoxethyl) phthalate	ng/m^3	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Benzylbutylphthalate (BBP)	ng/m^3	5.2	2.3	4.3	2.5	3.9	2.6
bis (2-n-butoxyethyl) phthalate	ng/m^3	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Total phthalates	ng/m^3	131.4	37.3	134.4	81.2	117.1	84.9
Rubber dust*	µg/m^3	9.3	8.8	8.8	6.6	1.0	0.5
Proportion of rubber dust of total PM	%	23.2	50.1	27.7	35.1	3.2	4.9
2-aminobenzothiazole***	pg/m^3	54	51	28	21	< 0.4	< 0.2
2-methylthiobenzothiazole***	pg/m^3	153	145	137	102	< 5	< 3
N-isopropyl-N'-phenyl-p-phenylendiamine***	pg/m^3	887	839	267	201	< 0.08	< 0.04
N-cyclohexyl-2-benzothiazole sulphenamide***	pg/m^3	23	21	3	2	< 0.03	< 0.02
2-(4-morpholinyl)benzothiazole***	pg/m^3	48	45	38	28	< 0.2	< 0.1
2-morpholinothiobenzothiazole***	pg/m^3	171	162	63	47	< 0.3	< 0.2
N-phenyl-1,4-phenylenediamine***	pg/m^3	158	149	150	112	< 0.1	< 0.05
2-mercapto benzothiazyl disulphide***	pg/m^3	22	21	27	20	< 0.2	< 0.1
N-cyclohexyl-2-benzothiazolamine (NCBA)***	pg/m^3	36	35	60	45	< 0.003	< 0.002
2-mercaptobenzothiazole***	pg/m^3	287	272	352	264	< 0.03	< 0.02
2-hydroxybenzothiazole***	pg/m^3	346	328	566	425	< 0.05	< 0.03
Total selected vulcanisation and preservative compounds	pg/m^3	2185	2068	1691	1268		

*: In Manglerudhallen and Valhall, the rubber quantity was determined using NCBA as a trace material (Kumata et al. 2000). In Østfoldhallen, a trace material with a molecular weight of 312 ionised with APCI (Atmospheric Pressure Chemical Ionisation) was used.

***: Calculated using measurements carried out on ground granulate and measured concentrations of rubber in the airborne dust.

4. Assessment

4.1 Limits

The norms prEN12457 and DIN 18035-7 are often used in connection with environmental aspects linked to rubber granulate. These norms were originally designed to study the leaching of chemicals into water and did not concern air. The norms are therefore considered to be of little relevance to this study.

Today, there are no limits which specifically regulate indoor environments in sports facilities. The national recommended norm for indoor climate is the norm which covers this type of indoor environment. Table 8 summarises the norms and limits together with the norms for outdoor air for information purposes.

Table 8: Norms, limits and national targets for relevant parameters.

Parameter	Measurement period	24 hours	Calendar year	Non-specific
PM_{10}	Binding limits for outdoor air	50 µg/m^3 , can be exceeded 35 times a year	40 µg/m^3	
PM_{10}	National target for outdoor air	50 µg/m^3 **A)** can be exceeded 7 times a year		
PM_{10}	National recommended norm for outdoor air	35 µg/m^3		
$PM_{2.5}$	National recommended norm for indoor climate **B)**/outdoor air	20 µg/m^3		
Benzene	National target		2 µg/m^3 **A,C)**	
Benzene	Binding limit for outdoor air		5 µg/m^3	
Benzo(a)pyrene	EU target value for outdoor air[4)]	1 ng/m3 **D)**		
Volatile organic compounds (VOC)	National recommended norm for indoor climate	**B)**		Based on a practical hygienic assessment, unnecessary exposure should be avoided. The presence of particularly irritating/reactive

	substances must be assessed separately.

A): Must be met by 1.1.2010
B): Report from the National Institute for Public Health (1998) Recommended technical norms for indoor climate, ISBN:82-7364133-3
C): Applies to urban background
D): Directive 2004/107/EC of the European Parliament and of the Council, 15 December 2004, Brussels

4.1.1 Experience

NILU's experience of the determination of volatile organic compounds (VOC) in indoor environments shows that in well ventilated domestic environments, individual components with a concentration of over 10 µg/m^3 are rarely encountered. The total concentration of volatile organic compounds (TVOC) in commonly occurring indoor environments is normally below 100 µg/m^3. However, in poorly ventilated single family houses during the winter, levels of 100-150 µg/m^3 will typically be found. Complaints about air quality can be made at concentrations as low as 100 µg/m^3. However, experts no longer focus solely on concentration because no clear link has been demonstrated between concentration and health effects. In poor indoor environments, NILU's experience is that the occurrence of problematic components often has a greater impact than the total level of pollution, and pollutants in the gas phase must be considered together with airborne dust. This is because the airborne dust in itself can cause illness and increased mortality and because fine particulate airborne dust acts as a transporter of semi-volatile organic compounds (SVOC) down into the lungs.

The occurrence of airborne dust in indoor environments is influenced by factors such as level of activity and the characteristics, ventilation and construction materials of the room. It is therefore difficult to present a simple picture of what concentrations of airborne dust should be expected. There are no limits for homes, sports halls or other comparable buildings. In the discussion of the results, reference is therefore made to examples of corresponding measurements (parameters) which have been taken in indoor environments in the Oslo region. A summary of these studies is presented in Table 9.

Table 9: Summary of studies of airborne dust in 14 different indoor environments in Oslo. The study covers schools, nurseries and private homes.

	OC µg C/m^3	EC µg C/m^3	TC µg C/m^3	Weight µg/m^3
PM_{10}				
Arithmetic mean	6.3	0.8	7.1	21.1
Min	1.3	0.3	1.7	3.8
Max	17.6	1.3	18.6	83.5
$PM_{2.5}$				
Arithmetic mean	2.9	0.7	3.5	7.2
Min	1.1	0.2	1.4	0.9
Max	5.8	1.5	7.3	14.9

4.2 Volatile organic compounds (VOC)

The results give an average over the measuring period. The occurrence of volatile organic compounds is created by dynamic processes which are influenced by temperature, air pressure, air humidity, air turnover, concentrations of airborne dust and source strength. For example, the use of scents, spray-painting, washing, miscellaneous use of machinery, etc. could alter the composition from one minute to the next.

4.2.1 Manglerud artificial turf hall, Oslo

Sampling was commenced at 16.31 and concluded at 22.06. The sampling location was chosen as the halfway line off the pitch itself, so as not to hinder planned football activities (see the photograph in Appendix II). After 30 minutes' sampling, 8 roof hatches and 16 windows were opened for ventilation. The outdoor temperature was around 0°C while the temperature inside the hall was 18°C. This created a considerable air flow and by 20.00 the indoor temperature had fallen to 10°C. The sampling was therefore carried out sequentially in order to demonstrate any concentration gradient during the ventilation period. The ventilation was stopped when the sampling equipment was packed away at about 22.15.

The first sample taken at the halfway line (16.31-18.50) shows a TVOC concentration of 716 $\mu g/m^3$ (Table 6a, Appendix I). This is considered to be an extremely high concentration given that there was full ventilation during 80% of the sampling period. Other samples at the halfway line (18.55-22.00) show a TVOC concentration of 234 $\mu g/m^3$. This is also a high concentration, but considerably lower than the first sample. Assessed on the basis of the effectiveness of the ventilation, i.e. the difference between the first and the second sample, it is reasonable to assume that the TVOC was closer to 1000 $\mu g/m^3$ at the start of sampling and down towards 100 $\mu g/m^3$ at the end. Sample 3 with a TVOC of 151 $\mu g/m^3$ was taken at the entrance to the hall (20.26-22.06) and can be characterised as a slightly but not uncommonly high value.

The analyses of the air show a very large number of compounds which experience has shown could contribute to an unpleasant atmosphere. The chemical spectrum shows a good correspondence with NILU's degassing analyses of the rubber granulate from the pitch substrate and the rubber mats (Dye et al., 2005) which are lowermost in the pitch substrate with typical rubber components such as benzothiazole, 4-methyl-2-pentanone, miscellaneous alkylbenzenes (such as styrene) and formaldehyde. The correspondence is so clear that it must be concluded that the rubber granulate is the most important source of the TVOC values measured. The results show that even with good ventilation and low temperatures, values would not fall much below 100 $\mu g/m^3$ with the clear dominance of chemicals from the rubber granulate. This indicates a considerable source strength in the rubber granulate, something which requires a high turnover of air.

The total concentration of PAH in the gas phase was 174 ng/m^3 (Table 5). This corresponds to an outdoor sample from Oslo during the summer (Larssen, 1988)

Inside the halls during the period, we measured a benzene concentration of 2 ug/m^3 (Appendix I). Based on regular outdoor measurements of BTEX (Benzene, Toluene, Ethylbenzene and Xylene) adjacent to the E6 European road at Manglerud, the rolling 12-month average benzene concentration was measured at 1.3 ug/m^3 in October 2005. In the case of Manglerudhallen, there was a significant wind from the background area when the last VOC sample was taken (east, southeast). There was also a period when the road traffic normally decreased significantly. We therefore estimate the outdoor concentration of benzene to have been 0.7 ug/m^3. The net contribution of benzene from indoor sources in Manglerudhallen is therefore estimated to be 1.3 ug/m^{3s}.

Due to the ventilation, a further sample was taken on 19.10.05 during the period 17.33-18.18, two days after the first round. Roof hatches and windows were closed and the temperature in the hall was 15°C. The TVOC concentration measured during this period was 255 µg/m^3 (Table 6a, Appendix I).

4.2.2 Østfoldhallen artificial turf pitch, Fredrikstad

Sampling was carried out during the periods 17.15-20.10 and 20.13-22.35. The samples were taken from the centre of the pitch (see the photograph in Appendix II). Activity levels and operating conditions on the pitch were normal throughout the sampling period. The first sample showed a TVOC concentration of 136 µg/m^3, whilst the second sample showed 161 µg/m^3 (Table 6a, Appendix I). This level indicates that the environment is affected by one or more sources, but the level itself is not unusual in indoor environments. The TVOC level rises slightly with use. This rise can be explained through the mechanical working of the granulate which causes degassing to increase. It is unclear whether the concentrations of benzothiazole largely originate from the rubber mat beneath the artificial turf or whether the rubber granulate is the source. Analyses of the rubber granulate (NILU report) indicate the absence of traditional vulcanisation chemicals which are found in SBR and the presence of benzothiazole. The chemical spectrum in the air also shows the signature of the timber in the hall (α-pinene) and the road traffic from outside the hall (BTEX).

4.2.3 Valhall artificial turf pitch, Oslo

Sampling was carried out during the periods 16.53-22.00 and 19.35-22.00. Activity levels and operating conditions on the pitch were normal throughout the sampling period. A large hall door was opened on two occasions early in the sampling period in order to let two vehicles out. This could have reduced the concentrations slightly. A sampling location was chosen off the pitch so as not to hinder planned football activities (see the photograph in Appendix II). The average TVOC concentration for the entire period was 234 µg/m^3, whilst the corresponding value for the second half of the sampling period was 290 µg/m^3 (Table 6a, Appendix I). This increase can be explained by mechanical working of the granulate, causing an increase in degassing. The TVOC concentrations are relatively high and the air analyses show good correspondence with NILU's degassing analyses of the rubber granulate from the pitch substrate and the rubber mats (glued rubber granulate) lowermost in the pitch substrate (NILU report), with typical rubber components such as benzothiazole, 4-methyl-2-pentanone, miscellaneous alkylbenzenes (such as styrene) and formaldehyde. The correspondence is so clear that it must be concluded that the rubber granulate is the most important source of the TVOC values measured.

The total concentration of PAH in the gas phase was 363 ng/m^3 (Table 5). This is more than twice the figure for Manglerudhallen. The level could correspond to outdoor air in Oslo on days with severe pollution during the warmer months (Larssen, 1988).

Inside the hall, during this period we measured a benzene concentration of 2.4 ug/m^3 (Appendix I). The dominant outdoor wind direction during the sampling was east-north-east, i.e. parallel to the E6. The sampling was carried out during a period when road traffic is normally quiet. Based on regular outdoor measurements of BTEX in Oslo, we estimate the background level of benzene to have been 1 μg/m^3. The net contribution of benzene from indoor sources is therefore estimated to have been 1.4 μg/m^3.

4.2.4 Laboratory tests

4.2.4.1 Relative source strength

A degassing test was carried out to compare the source strength for the rubber granulates. Rubber granulate samples (2g) from each of the pitches were stored in a 100 ml Pyrex glass bottle for equal periods of time at 23°C. An adsorption tube was placed in each of the bottles to take samples of the degassed compounds. In such a test, each individual volatile compound will act according to its own physical and chemical properties. To obtain a simple overview, benzothiazole was chosen as an indicator component because it is a typical rubber component. The results are shown in Figure 1. The values have been normed in relation to Valhall, which gave the highest values. Manglerudhallen gives off 82% compared with Valhall, while the granulate in Østfoldhallen gives off 27%. The results correspond well with the actual measurements shown in Table 6a.

Relative source strength

%

Østfoldhallen Valhall Manglerudhallen

Figure 1: Relative source strength for benzothiazole in the artificial turf granulate.

4.2.4.2 Surface coating on the granulate

The granulate in Valhall was glossier and shinier than that from Manglerudhallen. Examination under a stereo microscope (visual magnification) confirmed that the granulate from Valhall appeared to have a coating or a film on the surface to which particulate material was attached. The granulate from Manglerudhallen appeared to have a drier surface which was also significantly more covered with particles. Against the background of these observations, both the granulates were washed with cyclohexane. The cyclohexane dissolved the coating slightly, indicating lipid (fat- or oil-like) properties. After washing, the surfaces of both granulates were visually identical, and for both granulate types the washing process resulted in considerable quantities of black fine-grained particulate material being left behind in the solvent after decanting. After drying, a further degassing test was carried out.

Relative source strength after washing

%

Valhall Manglerudhallen

Figure 2: Relative source strength for benzothiazole in the artificial turf granulate after washing with cyclohexane.

The results are shown in Figure 2. These results indicate that the difference in source strength with regard to benzothiazole increased considerably compared with the results in Figure 1 (before washing). A reasonable explanation (hypothesis) of this phenomenon could be that the observed film is saturated with benzothiazole and therefore acts as a diffusion barrier. As the diffusion barrier dries out or is removed mechanically by wear, the source strength will increase. The magnitude of the increase over time (years) is difficult to estimate because the granulate will also be ‘emptied’ of chemicals. On the basis of this test, there is reason to assume that the TVOC level in Valhall will increase to a maximum after a period of time (years) and then decrease as the granulate is “emptied”.

4.2.4.3 Source strength and temperature influence

The ventilation in Manglerudhallen generated a need to know how the temperature affects the source strength. This was tested in headspace studies at 6°C, 20°C, 27°C and 36°C. The results are presented for benzothiazole and 4-methyl-2-pentanone in Figure 3. The figure shows that the source strength for the two components during a temperature reduction from 18°C to 10°C decreased by 50% and 22% for benzothiazole and 4-methyl-2-pentanone respectively. The effect of the source strength reduction is therefore in addition to the replacement of the air in Manglerudhallen. The temperature test in Figure 3 will in principle be of relevance to both Valhall and Østfoldhallen; the values and the increase coefficients of the curves may however be slightly different.

Source strength vs. temperature

Intensity

Benzothiazole
4-Methyl-2-pentanone

°C

Figure 3: Change in source strength with change in temperature for rubber granulate in Manglerudhallen.

It is assumed that temperatures over 25°C in the granulate are rare indoors, but in no way unrealistic outdoors in direct sunlight.

4.3 Airborne dust

The EC/OC ratio (the ratio between elementary carbon (EC)/carbon black and organic carbon (OC) was determined for the particle samples. The aim in doing this was to determine what proportion of the particles is inorganic and what proportion is organic. The relevance for artificial turf pitches is that rubber from car tyres contains between 26% (Edeskär, 2004) and 33% (Dye et al., 2005) carbon black. Together with trace material measurements, the method can therefore give an indication of the sources of the airborne dust. This makes it easier for example to assess any measures in relation to the sources of the airborne dust.

A general characteristic of airborne dust is that the concentrations of individual organic components can often seem modest compared to what is present in the gas phase. This does not mean that the chemical composition of the airborne dust is of no importance, but the mechanisms of action are complex and will not be considered in this report.

4.3.1 Manglerud artificial turf hall, Oslo

The values measured in the hall represent an average over the measurement period. Due to the ventilation described in section 4.2.1, it must be assumed that the results represent some of the lowest values that can be achieved in the hall. The PM_{10} level was 40 $\mu g/m^3$, while the $PM_{2.5}$ level was 17 $\mu g/m^3$ (Table 7). Based on the discussion in 4.2.1, it is reasonable to assume that the airborne dust values may have been more than twice as high because the source strength of the airborne dust could hardly have been as strong as it is for volatile organic compounds. It follows from this that the airborne dust levels were probably of the order of twice that of norms and national targets for 24-hour mean values.

The concentrations measured are higher than the arithmetic mean in the Oslo study (Table 9), which showed values of 21 $\mu g/m^3$ and 7 $\mu g/m^3$. The proportion of carbon is also higher than in the Oslo study, with an EC/PM_{10} ratio of 0.07. In the Oslo study, the arithmetic mean for the EC/PM_{10} ratio was 0.04. The proportion of rubber dust was 23.2% in the PM_{10} fraction and 50.1% in the $PM_{2.5}$ fraction. This indicates a strong contribution from the granulate. The presence of selected vulcanisation and preservative compounds is given in Table 7 and indicates that the granulate contains the same compounds that are found in car tyres. The air concentration of PAH in the airborne dust is comparable to an outdoor air sample from Oslo during the warm months (Larssen, 1988). Based on chemical analyses of the granulate (Dye et al., 2005) and the measured concentration of rubber in the airborne dust, the granulate is an insignificant source of benzo(a)pyrene in the airborne dust.

4.3.2 Østfoldhallen artificial turf pitch, Fredrikstad

The values measured in the hall represent an average over the measurement period. The PM_{10} level was 31 μg/m^3, while the $PM_{2.5}$ level was 10 μg/m^3 (Table 7). This is higher than the arithmetic mean in the Oslo study, which showed values of 21 μg/m^3 and 7 μg/m^3 respectively (Table 9). The proportion of carbon is also higher in Østfoldhallen with an EC/PM_{10} ratio of 0.03. In the Oslo study, the arithmetic mean of the EC/PM_{10} ratio was 0.04. This indicates a slightly weaker EC source than that indicated by the Oslo study. The rubber granulate in Østfoldhallen does not contain any carbon black. The proportions of rubber in the PM_{10} and $PM_{2.5}$ fractions are 3.2% and 4.9% respectively. These values are not abnormally high, but the rubber which was found originates from the granulate. The granulate does not contain any vulcanisation or preservative compounds which are normally found in car tyres. The air concentration of PAH in the airborne dust is comparable to an outdoor air sample close to a busy road.

4.3.3 Valhall artificial turf pitch, Oslo

The values measured in the hall represent an average over the measurement period. The PM_{10} level was 32 μg/m^3, while the $PM_{2.5}$ level was 19 μg/m^3 (Table 7). The levels are lower than in Manglerudhallen and can be explained by the film on the surface of the granulate acting as a particle trap. This effect is assumed to decrease over time as the film dries out, and the concentration of particulate matter in the air can therefore be expected to increase.

The concentrations of PM_{10} and $PM_{2.5}$ are higher than the arithmetic mean in the Oslo study, which showed values of 21 μg/m^3 and 7 μg/m^3 respectively (Table 9). The proportion of carbon is also higher in Valhall with an EC/PM_{10} ratio of 0.11. In the Oslo study, the EC/PM_{10} ratio was 0.04. This indicates a considerably stronger EC source than that indicated by the Oslo study. The proportion of rubber dust was 27.8% in the PM_{10} fraction and 35.1% in the $PM_{2.5}$ fraction. This indicates a strong contribution from the granulate. The presence of selected vulcanisation and preservative compounds is given in Table 7 and indicates that the granulate contains the same compounds as those found in car tyres. The air concentration of PAH in the airborne dust was 6.5 ng/m^3 and is half of what was found in Manglerudhallen. Based on chemical analyses of the granulate (Dye et al., 2005) and the measured concentration of rubber in the airborne dust, the granulate is an insignificant source of benzo(a)pyrene in the airborne dust.

4.3.4 Occurrence of rubber particles in the airborne dust

In Manglerudhallen, the proportion of rubber dust in the PM_{10} fraction was 23.2%, while the corresponding figure for the $PM_{2.5}$ fraction was 50.1% (Table 7). In Valhall, the proportion of rubber dust was 27.8% in the PM_{10} fraction and 35.1% in the $PM_{2.5}$ fraction. No good references were found in the literature concerning the occurrence of rubber particles in indoor airborne dust. The formation of airborne dust from car tyre wear is however a well known phenomenon outdoors. Concentrations of airborne dust from car tyres and the size distribution of the particles vary with the location of the sampling site relative to the source (road traffic). A general characteristic is that at locations with a high rate of wear (sharp bends), large rubber particles are formed which are not converted into airborne dust, whilst on high speed roads smaller rubber particles are formed which can be found in the airborne dust. A number of studies show a proportion of car rubber particles in the PM_{10} fraction of around 1% (Cadle et al. (1979), Rogge et al (1993) and Fishman et al. (1996)). Along busy roads and urban background areas, Hüglin (2000) found 7.5% and 2% rubber in the PM_{10} fraction respectively. Kumata et al. (1996) found an extremely low contribution of car rubber (0.001 $\mu g/m^3$) in TSP (total quantity of airborne dust) 500 metres from a road in a suburb of Tokyo. Compared with existing literature, both Manglerudhallen and Valhall have unusually high concentrations ($\mu g/m^3$) of particles from car rubber (granulate). The proportion of car rubber (granulate) in the airborne dust is also unusually high in both the PM_{10} and the $PM_{2.5}$ fraction.

Rubber particles have the property that they give off chemicals to the surroundings. This will take place directly to air and liquids with which the particles come into contact. A selection of such chemicals is shown in Table 7. The smaller the particles, the larger the surface area of the particles per unit weight. Smaller particles will have a more effective separation of chemicals per unit weight of rubber than larger particles. In total, larger particles will give off more chemicals, but over a longer period of time and at a slower rate per unit weight.

An average European car tyre consists of 42% rubber. The rubber used consists of 58.3% synthetic rubber and 41.7% natural rubber, Blic (2001). The natural rubber is produced from latex (sap) from the rubber tree, Hevea Brasiliensis. Williams et al. (1995) demonstrated the occurrence of latex allergen from car tyres in airborne dust from Denver in Colorado. Williams concluded that this finding should be taken into account when calculating changes in illness rates and mortality as a result of exposure to particles from car tyres. Latex allergen has also been demonstrated in airborne dust (PM_{10}) along roads in Oslo (Namork (2004)). In the literature, no unambiguous answer is given to the question of whether the latex allergen from car tyre particles airborne dust causes an increase in the occurrence of asthma. It is assumed that variations in the choice of methodology and experimental set-up could contribute to the ambiguity. The concentrations of rubber particles in the indoor air in Manglerudhallen and Valhall are however considerably higher than those reported in these studies. It is therefore recommended that possible problem areas linked to exposure to latex allergens via the air passages be assessed by specialists in the discipline.

It is not uncommon to observe football players sitting on the pitch with their hands in contact with the granulate. Following skin contact with the granulate in Manglerudhallen and Valhall, soot-like remains can be seen on the skin which among other things consists of very small rubber particles. This means that the skin is a possible exposure path for chemicals in the airborne dust, assuming that there is direct skin contact with the rubber granulate. It is recommended that possible problem areas linked to exposure to latex allergens via the air passages be assessed by specialists in the discipline.

4.4 Other factors

4.4.1 Swallowing of granulate

Many users have verbally stated that from time to time they can swallow rubber granulate accidentally. Table 10 presents the weight of each individual rubber ball or granule for the halls in this study. By cross-mirroring the findings in Table 9 with the results in Table 7, one can find answers to potential chemical exposure.

Example calculation:
N-isopropyl-N'-phenyl-p-phenylendiamine occurs in a concentration 887 pg/m^3 in the PM_{10} fraction in Manglerudhallen. This comes from 9.3 µg rubber/m^3. 887 divided by 9.3 gives 95.4 pg chemical/µg rubber. This gives a potential exposure of 954 ng for the black granulate.

Table 10: Weight of the rubber granulates.

	Østfoldhallen	Valhall	Manglerudhallen black	Manglerudhallen green
Average weight of 10 granules (mg)	7	13	10	15
Standard deviation (mg)	0.7	2.8	2.2	4.1
Relative standard deviation (%)	10.6	22.2	21.5	27.3

In general, people who swallow granulates will be exposed in the range 0.1-1000 ng for each chemical depending on the chemical and granulate type. Based on laboratory tests which show that the chemicals are released over a long period of time (until no further chemicals remain), it is reasonable to assume that chemicals will be released throughout the entire digestion period.

The Norwegian Building Research Institute (Plesser et al., 2004) has recently published a report which describes a study of the chemical composition of the rubber granulate. This study largely corresponds with the findings made by NILU in the granulate from Manglerudhallen, Valhall and Østfoldhallen. By comparing the results in Table 10 with the results in the Building Research Institute's report, it will be possible to obtain more answers with regard to potential exposure caused by swallowing.

5. Conclusions

Based on measurements and observations in this study, there are grounds to reach the following conclusions:

Quantity of airborne dust: Østfoldhallen has airborne dust concentrations that one would expect in an indoor environment for both PM_{10} and $PM_{2.5}$ fractions. Manglerudhallen (with full ventilation) and Valhall have elevated levels of the $PM_{2.5}$ fraction and are close to the national recommended norm of 20 μg/m^3. Manglerudhallen (with full ventilation) and Valhall fall within what one normally finds in an indoor environment for the PM_{10} fraction. Without full ventilation (and with a low outdoor temperature), Manglerudhallen will probably have high values of airborne dust and exceed norms, recommendations and limits for the PM_{10} and $PM_{2.5}$ fractions. Laboratory tests which were carried out indicate that the concentration of airborne dust in Valhall will rise over time (years).

Composition of airborne dust: the airborne dusts in Manglerudhallen and Valhall contain large quantities of rubber from the granulate, whilst in Østfoldhallen the proportion of rubber from the granulate is considerably less. In all three halls, the proportion of organic material is considerable. The airborne dust contains polycyclic aromatic hydrocarbons (PAH), phthalates, semi-volatile organic compounds, benzothiazoles and aromatic amines. It also contains organic and inorganic pollutants which are not specified in this study. Possible problem areas linked to latex exposure via the skin and air passages should be assessed by specialists.

Volatile organic compounds (VOC): The total concentration of volatile organic compounds in Manglerudhallen could, without ventilation, reach very high levels. Even with ventilation over a long period of time, the concentration of TVOC could be characterised as higher than normal. The component spectrum has a clear signature from the rubber granulate and contains a considerable number of components which are associated with adverse effects on health. However, the importance in this particular case must be assessed by specialists in other disciplines.

In Valhall, the concentration of TVOC can be characterised as high, and the level rises slightly over the evening. Laboratory tests indicate that the TVOC level will rise over time (years). The component spectrum has a clear signature from the rubber granulate and contains a large number of components which are associated with adverse effects on health. However, the importance in this particular case must be assessed by specialists in other disciplines.

In Østfoldhallen, the data indicates that the hall has sources which contribute to slightly elevated TVOC concentrations. The level comes in the upper range of normal levels and rises slightly during use over an evening. The component spectrum has a signature from the pitch substrate together with a number of components which are associated with adverse effects on health. However, the importance in this particular case must be assessed by specialists in other disciplines.

The measurements taken in this study show that the TVOC concentrations in Manglerudhallen and Valhall are higher than in Østfoldhallen. This means that there are alternative rubber granulates which give lower TVOC levels than SBR rubber. It can therefore be concluded that the national recommended norm for TVOC in indoor climates is not being met in Manglerudhallen and Valhall. In this conclusion, there is however no general recommendation of the granulate which is used in Østfoldhallen as the study was not broad enough to give such a recommendation.

Unclarified factors: The chemical analyses in this study were carried out with regard to chemicals which are known in the literature to be commonly occurring in SBR rubber (car tyres). The chemical composition of the thermoplastic elastomer which is used in Østfoldhallen is very unlike SBR rubber, and there is little information available on this elastomer in the literature. Further studies of thermoplastic elastomers should therefore be carried out to map the occurrence of other components. In all three halls, it can be seen from the chemical analyses of the airborne dust that organic chemicals are present which have not been identified in this study. The levels will probably be of the order of ng/m^3 (for each individual compound) or lower. The identity of these compounds has not been determined. The presence of inorganic compounds was not covered by this study.

Due to the dimensions of a football pitch, inadequate product research before launching a product will lead to a risk of undesirable exposure to chemicals with adverse health effects. An active approach is therefore recommended with respect to future suppliers and manufacturers combined with independent product testing before new pitches are constructed.

6. References

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Appendix I

customer	Manglerudhallen
sample id	pipe 142 16.31-18.50
	17 October 2005

Compound	Concentration (µg/m3)
toluene	85.0
butenylbenzene (isomers)	82.5
benzoic acid	81.0
diethenylbenzene (isomers)	41.0
butenylbenzene (isomers)	39.3
p-and m-Xylene (1,4 and 1,3 dimethylbenzene)	25.5
diethenylbenzene (isomers)	24.7
ethylbenzaldehyde (isomers)	19.7
benzothiazoles	15.7
1,1'-biphenyl	15.6
acetone	15.3
o-xylene (1,2-dimethylbenzene)	13.1
4-methyl-2-pentanone	12.7
3-phenyl-2-propenal	10.2
ethylbenzaldehyde (isomers)	8.0
pentenyl benzene (isomers)	7.3
pentanedioic acid dimethylester	6.8
ethylbenzaldehyde (isomers)	6.7
ethylbenzene	6.7
styrene (ethenylbenzene)	6.1
hexenylbenzene (isomers)	6.1
ethylcyclohexane	5.6
formaldehyde	5.5
2-butoxyethanol	5.3
unidentified naphthalene derivative	5.0
hexenylbenzene (isomers)	4.8
hexenylbenzene (isomers)	4.6
octane	4.6
undecane	4.6
acetaldehyde	4.3
unidentified naphthalene derivative	4.3
nitromethane	4.1
1-propynylbenzene	4.0
Total concentration of identified compounds	585.6
number of identified compounds	33.0
Total concentration of volatile organic compounds (TVOC)	**715.5**
number of compounds included in TVOC (conc.> 0.1µg/m3)	218.0

customer	Manglerudhallen
sample id	pipe 4 18.55-22.00
	17 October 2005

Compound	Concentration (µg/m3)
toluene	51.2
benzoic acid	20.9
p-and m-Xylene (1,4 and 1,3 dimethylbenzene)	17.4
acetone	9.3
benzothiazole	8.9
acetonitrile	8.3
o-xylene (1,2-dimethylbenzene)	7.7
ethylbenzene	4.1
formaldehyde	3.4
4-methyl-2-pentanone	3.4
acetaldehyde	3.2
2-butoxyethanol	3.2
dodecane	3.0
ethylcyclohexane	2.9
octane	2.7
pentanedioic acid dimethylester	2.2
2-methylnaphthalene	2.2
nonane	2.1
decane	2.1
tetrahydrofurane	2.0
cis 1,3-dimethyl cyclohexane	1.9
2-methyloctane	1.9
undecane	1.8
benzene	1.7
benzoic acid ethylester	1.6
heptadecane	1.6
1-ethyl-4-methylbenzene	1.5
3-methyloctane	1.4
TXIB	1.4
junipene (longifolene)	1.4
5-methyltetradecane	1.3
hexanedioic acid dimethylester	1.3
1,2,4-trimethylbenzene	1.2
Total concentration of identified compounds	180.3
number of identified compounds	33.0
Total concentration of volatile organic compounds (TVOC)	**233.8**
number of compounds included in TVOC (conc.> 0.1µg/m3)	219.0

customer	Manglerudhallen
sample id	pipe 420 20.26-22.06
	17 October 2005

Compound	Concentration (µg/m3)
toluene	30.1
acetonitrile	16.8
p-and m-Xylene (1,4 and 1,3 dimethylbenzene)	10.1
acetone	6.5
o-xylene (1,2-dimethylbenzene)	4.7
benzothiazole	4.5
tetrahydrofurane	3.6
formaldehyde	3.5
ethylbenzene	2.6
benzene	2.2
acetaldehyde	2.0
4-methyl-2-pentanone	2.0
dodecane	1.9
acetic acid ethylester (ethylacetate)	1.7
undecane	1.6
decane	1.5
ethylcyclohexane	1.5
benzoic acid	1.4
octane	1.3
1-ethyl-4-methylbenzene	1.3
1,2,4-trimethylbenzene	1.2
1-methylnaphthalene	1.2
nonane	1.1
hexandioic acid dimethylester	1.0
cis 1,3-dimethyl cyclohexane	0.9
4-(1-methylethyl)-phenol	0.9
tridecane	0.9
pentanediacid dimethylester	0.9
2-methyloctane	0.9
2-methylnaphthalene	0.8
heptane	0.8
2-butoxyethanol	0.8
Total concentration of identified compounds	113.4
number of identified compounds	33.0
Total concentration of volatile organic compounds (TVOC)	**150.5**
number of compounds included in TVOC (conc.> 0.1µg/m3)	222.0

customer	Manglerudhallen
sample id	pipe 728
	19.10.2005, 17.33-18.17
Compound	Concentration (µg/m3)
toluene	39.4
benzothiazole	20.4
p-and m-Xylene (1,4 and 1,3 dimethylbenzene)	17.4
4-methyl-2-pentanone	11.5
o-xylene (1,2-dimethylbenzene)	11.2
dodecane	6.0
pentanedioic acid dimethylester	5.1
ethylbenzene	4.2
undecane	3.7
ethylcyclohexane	3.3
benzoic acid	3.3
octane	3.3
decane	3.1
cyclohexanone	2.9
tridecane	2.8
nonanal	2.7
benzene	2.3
limonene	2.2
2-butanone	2.1
hexanal	2.0
nonane	2.0
2-butoxyethanol	1.9
hexanedioic acid dimethylester	1.8
pentadecane	1.8
decamethyl cyclopentasiloxane	1.8
tetradecane	1.8
junipene (longifolene)	1.7
Texanol B	1.7
butanedioic acid dimethylester	1.6
heptadecane	1.6
Total concentration of identified compounds	166.6
number of identified compounds	30.0
Total concentration of volatile organic compounds (TVOC)	**255.3**
number of compounds included in TVOC (conc.> 0.1µg/m3)	216.0

customer	Valhall
sample id	pipe 722 16.53-22.00
	19 October 2005

Compound	Concentration (µg/m3)
benzothiazole	29.1
toluene	15.0
4-methyl-2-pentanone	11.3
acetone	9.5
o-xylene (1,2-dimethylbenzene)	9.5
p-and m-Xylene (1,4 and 1,3 dimethylbenzene)	9.2
cyclohexanone	8.4
benzoic acid	8.2
formaldehyde	6.5
junipene (longifolene)	5.8
decane	4.8
dodecane	3.4
1,2,4-trimethylbenzene	3.1
styrene (ethenylbenzene)	3.0
acetaldehyde	2.9
undecane	2.9
ethylbenzene	2.9
naphthalene	2.7
hexanedioic acid dimethylester	2.6
1,2-propanediol	2.6
pentadecane	2.5
acetic acid	2.5
limonene	2.5
2-(2-butoxyethoxy)ethanol	2.4
2-methylnaphthalene	2.1
tridecane	2.1
benzene	2.1
1-methoxy-2-propanol	2.1
2,6-bis-(1,1-dimethylethyl)-4-methylphenol (butylated hydroxytoluene)	1.9
butanoic acid butylester	1.9
3-carene	1.8
tetradecane	1.8
1-ethyl-2-methylbenzene	1.7
Total concentration of identified compounds	170.9
number of identified compounds	33.0
Total concentration of volatile organic compounds (TVOC)	**233.9**
number of compounds included in TVOC (conc.> 0.1µg/m3)	209.0

customer	Valhall
sample id	pipe 700 19.35-22.00
	19 October 2005

Compound	Concentration (µg/m3)
benzothiazole	31.7
benzoic acid	19.3
toluene	15.3
4-methyl-2-pentanone	12.7
alpha pinene	10.5
cyclohexanone	9.8
p-and m-Xylene (1,4 and 1,3 dimethylbenzene)	9.6
acetone	9.5
junipene (longifolene)	7.2
formaldehyde	6.5
decane	5.0
acetic acid	4.3
dodecane	3.7
ethylbenzene	3.3
1,2,4-trimethylbenzene	3.2
styrene (ethenylbenzene)	3.2
undecane	3.1
acetaldehyde	2.9
limonene	2.6
2-methylnaphthalene	2.5
benzene	2.4
3-carene	2.2
pentadecane	2.2
2,3-dihydro-1,1,3-trimethyl-3-phenyl-1H-indene	2.1
naphthalene	2.1
hexanal	2.0
1,2-propanediol	2.0
1-methoxy-2-propanol	2.0
butanoic acid butylester	1.8
tridecane	1.8
nonanal	1.8
tetradecane	1.8
cyclohexane	1.7
Total concentration of identified compounds	191.7
number of identified compounds	33.0
Total concentration of volatile organic compounds (TVOC)	**289.8**
number of compounds included in TVOC (conc.> 0.1µg/m3)	245.0

customer	Østfoldhallen
sample id	pipe 704 17.15-20.10
	18 October 2005
Compound	Concentration (µg/m3)
toluene	17.2
acetone	8.9
p-and m-Xylene (1,4 and 1,3 dimethylbenzene)	6.8
alpha pinene	6.3
formaldehyde	5.1
benzothiazole	3.4
actealdehyde	3.0
decane	2.5
nonanal	2.3
limonene	2.1
2,2,4,6,6-pentamethyl heptane	2.1
undecane	2.0
ethylbenzene	2.0
dodecane	1.9
2,6-bis-(1,1-dimethylethyl)-4-methylphenol (butylated hydroxytoluene)	1.9
1,2,4-trimethylbenzene	1.9
benzene	1.8
TXIB	1.8
butanal	1.8
hexadecane	1.7
heptane	1.6
1-ethyl-4-methylbenzene	1.5
2-butanone	1.4
tetradecane	1.3
decamethyl cyclopentasiloxane	1.3
3-carene	1.2
5-Methyl-2-(1-methylethyl)-cyclohexanol	1.1
2-(2-butoxyethoxy)ethanol acetate	1.1
tridecane	1.1
2-ethyl-1-hexanol	1.1
5-methyl-2-isopropyl cyclohexanone	1.0
1-methyl-2-pyrrolidinone	1.0
nonane	0.9
Total concentration of identified compounds	92.0
number of identified compounds	33.0
Total concentration of volatile organic compounds (TVOC)	**136.3**
number of compounds included in TVOC (conc.> 0.1µg/m3)	209.0

customer	Østfoldhallen
sample id	pipe 709 20.13-22.35
active sampling on Tenax adsorption tubes	18 October 2005

Compound	Concentration (µg/m3)
toluene	19.4
acetone	8.6
p-and m-Xylene (1,4 and 1,3 dimethylbenzene)	7.6
alpha pinene	6.8
formaldehyde	5.1
benzothiazole	3.9
2-hydroxybenzoic acid methylester	3.2
acetaldehyde	3.0
limonene	3.0
cyclohexane	2.9
nonanal	2.8
decane	2.7
2-methylhexane	2.7
2,2,4,6,6-pentamethyl heptane	2.6
2,6-bis-(1,1-dimethylethyl)-4-methylphenol (butylated hydroxytoluene)	2.3
heptane	2.3
undecane	2.3
TXIB	2.2
ethylbenzene	2.2
1,2,4-trimethylbenzene	2.1
dodecane	2.0
benzene	2.0
1-ethyl-4-methylbenzene	2.0
phenol	1.6
hexadecane	1.6
3-carene	1.5
tetradecane	1.5
5-methyl-2-isopropyl cyclohexanone	1.5
decamethyl cyclopentasiloxane	1.4
methylcyclohexane	1.4
acetic acid	1.3
tridecane	1.2
5-Methyl-2-(1-methylethyl)-cyclohexanol	1.2
Total concentration of identified compounds	108.1
number of identified compounds	33.0
Total concentration of volatile organic compounds (TVOC)	**161.1**
number of compounds included in TVOC (conc.> 0.1µg/m3)	230.0

Appendix II

Sampling in Østfoldhallen

Sampling in Valhall

Manglerudhallen with ventilation hatches in the roof

Sampling in Manglerudhallen

Rubber granulate from Valhall

Rubber granulate from Manglerudhallen

Rubber granulate from Østfoldhallen

Norwegian Institute for Air Research (NILU)

Postboks 100, N-2027 Kjeller

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Measurement of air pollution in indoor artificial turf halls</td><td colspan="2">PROJECT MANAGER
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<tr><td>KEY WORDS
Artificial turf</td><td>Airborne dust</td><td colspan="2">Indoor environment</td></tr>
<tr><td colspan="4">SUMMARY
This report describes the air quality for three indoor artificial turf pitches. The measurements were taken in a hall with recently laid rubber granulate (SBR rubber), a hall with rubber granulate (SBR rubber) which had been in use for one year and a hall which used granulate made from thermoplastic elastomer. Parameters covered are the quantity and chemical composition of airborne dust and the concentration of volatile organic compounds (VOC) and polycyclic aromatic hydrocarbons (PAH). The study will be used as a basis for exposure calculations and the assessment of health effects. The results show that using rubber granulate from ground car tyres (SBR rubber) causes a significant indoor environmental problem.</td></tr>
<tr><td colspan="4">TITLE
Determination of air pollutants in indoor artificial turf areas</td></tr>
<tr><td colspan="4">ABSTRACT
In this work the air pollution level has been measured in indoor artificial turf areas. The synthetic turf consisted of SBR rubber and thermoplastic elastomer. The results revealed significant air pollution in the turf areas based on SBR rubber.</td></tr>
</table>

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The State programme for pollution monitoring covers the monitoring of pollution conditions in the air and precipitation, forests, groundwater, watercourses, fjords and maritime areas.

The monitoring programme covers long-term studies of:

• over fertilisation of freshwater and coastal areas
• acidification (acid rain)
• ozone (on the ground and in the stratosphere)
• greenhouse gases
• environmental toxins

The monitoring programme will provide information on the condition and development of the pollution situation and demonstrate any adverse developments at an early stage. The programme will meet the authorities' needs for information concerning pollution conditions, record the effect of measures that have been initiated to reduce the pollution and provide a basis for assessing further measures. The Norwegian Pollution Control Authority is responsible for executing the monitoring programme.

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