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Comparative Emission Studies of Flooring Materials with Reference to Nordic Guidelines

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ABSTRACT

The measurement and evaluation of emissions from materials become more meaningful when there are published guidelines and policies. In this paper, Nordic guidelines on the subject are presented and evaluated against results of emission measurements from various common flooring materials. The measurements were performed using Nordtest emission chambers and different collection techniques and analytical methods. The TVOC (total volatile organic compounds) emissions and the most abundantly emitting single compounds have been analyzed for each material. A short review of emissions and emission sources typical for each material is given, because knowing the emission sources helps development of low-emission products.

INTRODUCTION

It is known that emissions from building materials may contribute to indoor air problems, and there is an urgent need to start procedures for diminishing the adverse comfort and health effects caused by chemical compounds outgassed from building materials.

Product declaration procedures have been proposed in order to get more information on material emissions and to begin the development of low-emitting building materials. The discussion of product declaration has included suggestions for either declaring solely the contents of the material or performing emission measurements in chambers to predict the impact of materials emissions on concentrations of volatile organic compounds (VOC) in indoor air.

Measuring material emissions and developing low-emitting materials require testing of materials with standardized procedures in emission chambers. Guidelines for performing such measurements will be published soon.[1-3] Evaluation of material test results can primarily be made by predicting the impact of the total amount of volatile organic compounds (TVOC) on indoor air, with the exception of a few single compounds for which health data are available.[4]

Regulating and subsequently diminishing VOC concentrations in indoor air is of interest to authorities and designers. Two approaches for coping with the subject have been presented in the Nordic countries.

1. Developing low-emitting materials that consist of chemical compounds with minimized adverse comfort and health effects.

The Nordic Committee on Building Regulations (NKB) has published a guideline, *Indoor Climate—Air Quality*,[5] which refers to common values of total volatile organic compounds (TVOC) measured in indoor air. These values are examples of "normal" indoor air and should be reached using air exchange rates common in Nordic and even other countries. "Normal" indoor air TVOC scales are a useful target measure in evaluation of the emission levels of materials.

2. Designing the ventilation to meet the additional demands for efficiency caused by the impact of material emissions on indoor air quality.

Guidelines of the Scandinavian Association of HVAC Engineers (SCANVAC)[6] classify indoor air into quality classes and building materials into emission groups according to the emission strength. To reach the different indoor air quality groups, the "quality classes" of materials impose varying demands on the efficiency of the ventilation. Thus, the guidelines can be used for material selections and for designing ventilation requirements for buildings.

This paper summarizes emissions from commonly used flooring materials and discusses the results of this analysis in reference to the two above-mentioned approaches to regulate VOCs in indoor air.

GUIDELINES

Nordic Committee on Building Regulations

The Nordic Committee on Building Regulations (NKB) is a joint Nordic organ consisting of national representatives from Scandinavian authorities responsible for national building codes and regulations. In 1987, the NKB set up an indoor climate committee, which drew up a five-year plan in which one of the tasks was to revise the section on air quality in NKB Report No. 40, *Indoor Climate*, originally published in 1981. The aim of the revision was to incorporate the knowledge that has become available since 1981, especially knowledge concerning the effect of materials on indoor air quality. This effect is among other measures incorporated in referring to levels of volatile organic compounds in "normal" indoor air (Table 1). These normal levels of VOCs include the emissions from both activities and materials.

SCANVAC

The SCANVAC guidelines are the result of a joint project carried out by SCANVAC, the Federation of Scandinavian

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HVAC Societies, and published by the Swedish Indoor Climate Institute for voluntary application in Scandinavia. The guidelines are intended for purchasers and planners and can be used as a basis for assessment of indoor climate quality, as a reference of indoor climate systems, and in designing an appropriate indoor climate quality for different applications. The guideline also accounts for material emissions in planning or regulation. The planning guidelines divide the indoor air into three quality classes, according to a PPD (predicted proportion of dissatisfied) index. To attain these IAQ classes, the emissions of volatile organic compounds from materials into indoor air have to meet demands expressed in Table 2. Materials are divided into three emission classes (MEC) by their emission strength in Table 3.

The SCANVAC guideline consists of equations and nomograms, among other things, that can be used to calculate the ventilation rates needed to reach wanted IAQ classes using materials belonging to different emission classes, or it can be used to show how much the ventilation rate must be increased if the same IAQ class is to be reached using a lower-class, MEC-B or MEC-C, material instead of an MEC-A material.

As an example, if one uses a flooring material belonging to emission class MEC-A with a loading of 0.5 m^2/m^3, a ventilation rate of 1.8 $L/s \cdot m^2$ is needed to reach the AQ1 IAQ class, but when the same IAQ class is to be reached using a medium-emitting MEC-B class flooring material, the ventilation rate must be increased to 4 $L/s \cdot m^2$.

EXPERIMENTAL

Materials

Flooring materials constitute a large emitting area in buildings, and the emissions are, in many cases, long lasting. Moreover, the odor and emissions from flooring materials are frequently the subject of complaints. Fifteen flooring materials of different types, ages, and brands were supplied for testing, including a few "complaint" materials. (The materials selected for testing are described in Table 6.)

Sampling and Measuring Methods

The materials were conditioned for one week in the laboratory before being transferred to the test chamber and conditioned for two days in the chamber before starting the sampling. The material emissions were collected from stainless steel chambers according to Nordtest draft method NT Build 358.[1] In this method, the size, i.e., loading factor, of the material to be tested is chosen to correspond to the loading of the material in actual conditions. Since the loading factor of the material to be tested is defined, the steady-state emission results can be expressed either as concentration in the chamber (mg/m^3) or as emission rate ($mg/m^2 \cdot h$).

The operational parameters of the chambers are listed in Table 4, and the methods of collection and analysis are shown in Table 5. The samples were collected from the outlet with a volumetric sampling rate not exceeding the airflow rate needed for maintaining the air change rate in the chambers.

RESULTS

The history of the flooring materials tested and the results of the TVOC emission rates are given in Table 6. The bar graph in Figure 1 illustrates the concentrations of the emissions from these materials in the Nordtest chambers. Figure 1 also includes the TVOC levels given in the NKB and SCANVAC IAQ guidelines. Detailed results are given in the appendix.

TABLE 1
NKB TVOC in "Normal" Indoor Air

Site	TVOC [mg/m^3]
Outdoor air	0.01-0.04
Dwellings	0.05-0.4
Offices	0.05-1.3
Schools, day nurseries	0.05-0.3

TABLE 2
SCANVAC Indoor Air Quality—Acceptable Levels of Pollutants in Indoor Air

Pollutant	Exp.time	Max. permissible quantity [mg/m^3]		
Volatile organic compounds		AQ1	AQ2	AQX
-total (TVOC)	0.5 h	0.2	0.5	as specified
-formaldehyde	0.5 h	0.05	0.1	as specified

TABLE 3
SCANVAC Material Emissions Classes

Emission group	Max. emission factor at 20 °C and 50 % RH
MEC-A, low emission material	40 $\mu g/m^2$ h
MEC-B, medium emission material	100 $\mu g/m^2$ h
MEC-C, high emission material	several hundreds

TABLE 4
Chamber Test Conditions

Chamber sizes	120 l and 1000 l
Temperature	23.0 °C
Relative humidity	45 +/- 3%
Air change rate	0.50 +/- 0.013 h^{-1}
Loading factor	0.41 m^2/m^3

The TVOC results indicated in Table 6 are based on sampling on Tenax TA and quantification using model compounds as references. The detailed results shown in the appendix also originate from Tenax determinations, since the XAD-2 adsorbent did not give much additional information on emissions. The results indicate that different types of flooring materials emit compounds that are characteristic of each material type and can, to some extent, be predicted from the raw materials and manufacturing processes. The levels of the TVOC emissions, however, differ considerably between different material types and even within the same type.[7]

Typical emissions from wood are formaldehyde and higher aldehydes together with pinene, camphene, and 3-carene. The TVOC emissions from fresh woodboard reach the levels of many synthetic materials.

The lacquers for wooden or parquet board floors used to be acid-hardening UF resins, and the industrial parquet boards were glued to the support layer using UF resins. The result of using these resins was, frequently, the emission of formaldehyde. The industry is now striving for products with less harmful emissions. Faulty process parameters, however, can have a negative effect on the emissions of the product (material 3).

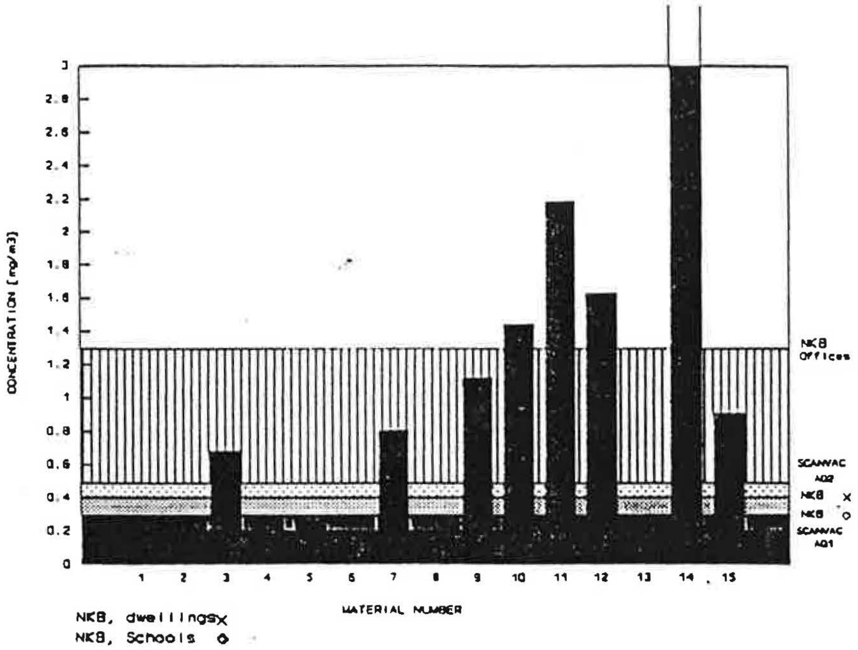

Figure 1 Material emissions and air quality

TABLE 5
Collection and Analysis Methods

Compound	Collection media	Sample size [l]	Anal.method
VOC	Tenax TA	15	ThD, GC/MS
SVOC*	XAD-2	1000	GC/MS
Aldehydes	DNPH/2 n-HCl	200	HPLC
Phenol	0.1-n NaOH	1000	HPLC

TABLE 6
TVOC Emission Rates from Flooring Materials

No Material	Age [Years]	History	Emission rate [mg/m²h]
1 Untreated pinewood	-	New in plastic wrapping	0.216
2 Industrial birchwood	0.1	Experim.surface coating	0.157
3 Industrial pinewood	0.1	Experim.surface coating	0.682
4 Industrial birchwood	0.1	Experim.surface coating	0.272
5 Pinewood	1	UF-lacquered on site	0.264
6 Linoleum	30	Subject to complaint	0.064
7 Cork	0.3	New material	0.805
8 Cork	2	Subject to complaint	0.007
9 English PVC-covering	1	Unused, taken from roll	1.122
10 Finnish PVC-covering	< 0.5	Unused 2nd quality from roll	1.443
11 Finnish PVC-covering	0.5	Unused from roll	2.192
12 Finnish PVC-covering	1	Unused from roll	1.629
13 Finnish PVC-covering	2-3	Subject to complaint	0.273
14 Central Europ. PVC	1-3	Subject to complaint	7.034
15 Swedish PVC-covering	1-2	Subject to complaint	0.91

Emissions from linoleum flooring are characterized by fatty acids originating from the linseed-oil-based raw materials. Fatty acids have a very strong odor, even if the emission levels detected are low.

Cork materials emit high-molecular-weight paraffinic hydrocarbons, diols, and formaldehyde. Cork tiles are often PVC-coated, which gives rise to additional emissions typical for PVC materials.

PVC materials contain many types of additives that contribute to the emissions.[8] A very typical emission is a viscosity modifier frequently used as a processing aid. Examples of viscosity modifiers are technical products based on hexyleneglycol, dodecylbenzene, or aliphatic hydrocarbons and sometimes even cyclohexanone. Traces of these compounds are often encountered in PVC emissions. One of the most frequent pollutants in PVC emissions is 2-ethyl-1-hexanol. It is believed to be either a hydrolytic product of the DOP plasticizer originating from impure DOP or the result of an alkaline hydrolytic reaction caused by the chemicals in wet concrete or leveling agents. It was found, however, even in unused PVC materials with high-quality DOP, which originally did not contain 2-ethyl-1-hexanol.[8]

DISCUSSION

The TVOC emission rates of new flooring materials vary considerably between material types. Only one of the materials tested, the old cork tile, complies with the SCANVAC MEC-A material class, although it was a former complaint material because of its odor. Of the other materials, only the linoleum flooring (also a complaint material) meets the MEC-B emission class requirements. The others fall into lower emission classes with higher emission rates. The emission rates of some relatively new flooring materials give rise to indoor air concentrations that already exceed the normal indoor air concentration levels indicated in the NKB draft guidelines and SCANVAC guidelines.

Today the wooden industrial flooring materials show the most promise of meeting strict emission requirements, provided that the appropriate knowledge of raw materials selection and processing is used.

The PVC floorings are, in some cases, characterized by strong emissions that decrease slowly. The outgassing depends partly on the emitting compounds. The emissions can be relatively easily characterized by the typical analytical techniques used today and, subsequently, the emissions could be lowered by appropriate product development.

The results in this study support the opinion that a reliable product declaration must be based on emission measurements, since the chosen raw materials and process variables may change the emission behavior of a material from batch to batch.

The new guidelines give a good reference basis for developing low-emission materials. The chamber test methods are becoming important in material classification, product development, and marketing. It is, therefore, of utmost importance to develop and standardize the measuring methods in detail to ensure that emission measurements are comparable, even internationally. All of the testing parameters and analytical procedures are not yet defined in detail.

RECOMMENDATIONS

Evaluation and classification of materials should be made using standardized chamber methods. These methods often allow some choice in testing parameters. The following parameters and procedures should be agreed on internationally:

- define at what age the sample is tested or how the effect of decreasing emissions is approximated in calculations;
- agree on test temperature, humidity, and air exchange rate;
- define the collection methods, including the adsorbents used;
- define the methods of analysis and how the amount of TVOC is given.

Future work on emission testing should focus on defining target compounds relevant for indoor air quality.

ACKNOWLEDGMENT

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APPENDIX

FLOORING MATERIALS: EMISSION RATES OF MAIN POLLUTANTS (mg/m^2*h)

1.Untreated pinewood	
Pentanal	0.145
Hexanal	0.004
pinene	0.020
Camphene	0.003
3-carene	0.075
TVOC	0.216
Formaldehyde	0.010
2.Industrial birchparquet	
Pentanal	0.011
Hexanal	0.040
Styrene	0.007
pinene	0.019
3-carene	0.004
Limonene	0.003
Ethoxyethanol	0.006
TVOC	0.157
Formaldehyde	0.239
3.Industrial pineparquet	
Pentanal	0.003
Methylmetacrylate	0.407
Styrene	0.002
pinene	0.007
3-carene	0.020
Ethoxyethanol	0.003
TVOC	0.682
Formaldehyde	0.081
4.Industrial birchparquet	
Hexanal	0.051
Methylmetacrylate	0.001
Styrene	0.003
pinene	0.003
3-carene	0.003
TVOC	0.272
5. Pine parquet, old	
Pentanal	0.001
Hexanal	0.001
pinene	0.006
3-carene	0.012
Limonene	0.005
Methylpentane	0.003
TVOC	0.264
6. Linoleum covering	
3-methylpentane	0.008
Cyclopropane	0.002
Cyclohexane	0.001
Toluene	0.006
Propanoic acid, 2-methyl	0.001
Trimethylbenzene	0.001
Xylenes	0.001
Cyclohexen,1,2-dimethyl	0.001
Hexadecanoic acid	0.004
pinene	0.001
3-carene	0.001
Other fatty acids	0.034
TVOC	0.064
7. Cork, new	
Dioxalan,4-methyl	0.037
2-propanediol	0.713
2-furancarboxalde hyde	0.006
2,2,4,6,6-pentamet hylheptane	0.035
Diethylenglycol-n-monobutylether	0.001
Hydrocarbon	0.002
TVOC	0.805
Formaldehyde	0.015
8. Cork, old	
1,2-propandiol	0.002
Docosane	0.004
TVOC	0.007
Formaldehyde	0.003
9. PVC, unused	
Toluene	0.015
Isobutylacetate	0.012
Xylenes	0.007
Cyclohexanol	0.012
Hydrocarbons	0.123
2,2,4,6,6-penta-methylheptane	0.014
1,2,4-trimethylbezene	0.006
Decane	0.035
Hydrocarbons	0.040
Diethyleneglycol-monobutylether	0.013
Hydrocarbons	0.107
2,4,6-trimethyloctane	0.069
Hydrocarbons	0.171
Aromatic hydrocarbons	0.024
TXIB	0.307
Aromatic hydrocarbon	0.019
TVOC	1.122
10. PVC, unused	
1-butanol	0.048
2-ethoxyethanol	0.010
Toluene	0.006
Methylglycolacetate	0.043
Xylenes	0.027
2-hexanal	0.052
1,3,5,7-octateraene	0.145
2-butoxyethanol	0.074
Decane	0.122
2-ethyl-1-hexanol	0.147
Hydrocarbons	0.042
Diethylenglycolmono-butylether	0.044
Hydrocarbons	0.042
Naphtalene	0.015
Hydrocarbons	0.086
Tridecene	0.060
Tridecane	0.049
Hydrocarbons	0.072
Aromatic hydrocarbons	0.018
TXIB	0.159
Aromatic hydrocarbons	0.020
TVOC	1.443
11. PVC, unused	
2-propanol	0.026
Butanol	0.018
Toluene	0.136
Xylenes	0.009
2-butoxyethanol	0.008
2,2,4,6,6-pentamet-hylheptane	0.083
Hydrocarbons	0.015
2-ethyl-1-hexanol	0.214
Hydrocarbon	0.072
1-octanol	0.025
Diethylenglycol-n-monobutylether	0.022
Hydrocarbons	0.052
TXIB	1.440
Aromatic hydrocarbons	0.017
TVOC	2.192
Phenol	0.095
12. PVC, unused	
Propanediol	0.007
Toluene	0.010
Xylenes	0.004
2,2,4,6,6-penta methylheptane	0.060
Hydrocarbons	0.014
2-ethyl-1-hexanol	0.211
Hydrocarbons	0.100
Hydrocarbons	0.053
TXIB	1.200
Hydrocarbons	0.008
TVOC	1.629
Phenol	0.040
13. PVC, complaint material	
Cyclopentanone	0.025
Hydrocarbons	0.012
Aromatic hydrocarbons	0.028
Hydrocarbons	0.023
Hydrocarbons	0.017
TXIB	0.041
TVOC	0.273
14. PVC, complaint material	
Hydrocarbons	0.043
2-methoxyethanol	0.045
1,2-propanediol	0.177
Xylenes	0.013
2-butoxyethanol	0.046
Caramic acid, phenyl ester	0.225
1-pentanol,2-ethyl-4-methyl	0.484
Hydrocarbons	0.202
TXIB	4.825
TVOC	7.034
15. PVC, complaint material	
1,2-propanediol	0.11
Xylenes	0.027
1,3,5,7-cyclo-octa-teraene	0.019
Benzoylchloride	0.005
Decane	0.013
Hydrocarbon	0.010
Aromatic hydrocarbons	0.041
Hydrocarbon	0.013
Hydrocarbons	0.146
Naphtalene	0.006
TXIB	0.305
TVOC	0.910
Phenol	0.0002