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Building Materials Identified as Major Emission Sources

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ABSTRACT

Building materials can be considered as emission sources in buildings due to the large surface areas exposed to the indoor air. A critical review of the international literature concerning emission of volatile organic compounds from building materials has been performed. The final report includes 24 case studies where various building materials have been identified as major emission sources. Some earlier unpublished Scandinavian field studies are included. In most cases, the emission sources have been identified by parallel measurements, e.g., a climate chamber. Each field study has been selected to represent a specific type of emission source and/or pollutant. The review does not include radon or formaldehyde, since the sources for these compounds are generally recognized. This article summarizes the findings in the final report.

INTRODUCTION

Emission of volatile organic compounds (VOCs) from building materials is often mentioned as a reason for bad indoor air in buildings. However, with the exception of materials emitting radon or formaldehyde, building materials are rarely described as major, long-term, and original emission sources in the international literature. Since materials in construction, especially large amounts on surface areas, are permanently exposed to the indoor air, it is crucial to have a view as to what extent building materials contribute to indoor air pollution. Therefore, it was decided to review case studies identifying building materials as emission sources.

The final report[10] includes 24 case studies in which various building materials have been identified as major emission sources. In most cases, the emission source has been identified by parallel measurements (e.g., in a climate chamber), an approach proposed earlier.[9,31,42] The review is based on the international literature, conference proceedings, etc., as well as some earlier unpublished Scandinavian case studies. For case studies in Scandinavian languages, literature references in this article are made to the final report. The review does not include volatile compounds from fungi, etc., gases from incinerators, emissions from impregnated wood, and neither radon nor formaldehyde, since these sources are generally recognized. Each case study has been selected to represent a specific type of emission source and/or pollutant. This article summarizes the findings in the final report.

IDENTIFIED EMISSION SOURCES

Floor coverings based on polymeric resins often contain monomers and solvents that may emit to the indoor air. The occurrence of 4-PC (4-phenylcyclohexene) is frequently reported in buildings with newly installed *textile flooring with latex backing* (e.g., references 30,33). Even emission of styrene is reported from latex backing.[44] Styrene has also been found in office air due to emission from *rubber floor tiles.*[45] Floor tiles based on *cork and phenolic resin* have given rise to strong odor of phenol in indoor air.[12]

Vinyl wall-to-wall carpets have in different cases been identified as major emission sources. Industrial solvents used in the manufacture of vinyl floor covering, such as 2,2,4-trimetyl-1,3 pentanediol diisobutyrate, "TXIB,"[27] and dodecylbenzene[13] have been detected in indoor air. Dodecene has been detected in office air and seems to be a decomposition product of dodecylbenzene formed in the manufacturing process of vinyl floor carpeting.[14] Ethylhexylacrylate has been emitted from vinyl floor coverings due to a deficiency of the UV-curing of the surface lacquer layer of the carpet.[16]

Vinyl wall-to-wall carpets often contain more than 20% plasticizers by weight. The most common plasticizers are phthalate esters such as diethylhexylphthalate, DEHP, which may hydrolyze, giving rise to emission of ethylhexanol. The hydrolysis of, e.g., DEHP is strongly dependent on the Ph and the moisture content in the underlying concrete; Ph values of 14 have been measured in pore solution of cement pastes.[25]

Especially in Scandinavia, higher alcohols such as ethylhexanol in the range of a few micrograms per m^3 are rather frequently detected in indoor air. This is because the floor covering often is laid before the underlying concrete has been allowed to dry out properly.[1] Adhesive seems to increase the migration of higher alcohols from the carpet to the concrete.[24] To reduce the level of higher alcohols in indoor air, it may often be necessary to remove the adhesive and the upper layer of the floor base. Odorous compounds such as phenol and methylphenol (pcresol) can be emitted from vinyl flooring with phosphor-containing plasticizers due to moisture-induced degradation.[17] These types of plasticizers also act as flame retardants in vinyl floor coverings.

A smooth floor base can be applied with a *self-leveling floor-topping compound* directly on the concrete. Since the composition of such a compound is rather similar to concrete, even

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floor-topping compounds with high pH may induce hydrolysis of phthalic esters. Some floor-topping compounds contain casein as a superplasticizer, and high pH and moisture content may give rise to emission of gaseous ammonia due to the decomposition of casein. Ammonia is known to stain oak, e.g., in parquet flooring.[29] Another volatile decomposition product of casein is o-aminoacetophenone, odorous at ppt level.

Linoleum carpet, with its content of cured linseed oil, can sometimes give rise to an unpleasant smell due to oxidation of fatty acids. Linoleic acid and other unsaturated fatty acids in the carpet are split to aldehydes with lower molecular weight. Also, paint based on linseed oil (*alkyd paint*) may emit aldehydes to the indoor air and even carboxylic acids at increased temperatures on radiators.[37] *Acrylic paint* intended for outdoor use only has been applied indoors, followed by release of butylmethacrylate.[18] Indoor use is reported of an odorous *building sealant* intended for outdoor use and containing sulfuric compounds.[45] *Moisture repellent for other walls* may emit white spirits into living rooms (4) even up to 6 mg/m^3.[15] Moistened *mineral wool* may emit aldehydes and ketones.[38] These types of volatiles are produced during microbiological growth.[26] *Damp-proof membrane* containing coal tar is reported as a source for odorous naphtalenes.[5]

In most cases, the emission from building materials can be considered as simple off-gassing of volatile compounds. Most obvious is the initial emission of solvents from paint and varnish. However, paint and varnish may also release VOCs even after the drying phase. More than six months after application, *waterborne paints* may emit film-forming agents,[46] and glycol ethers,[45] and *polyurethane lacquers* may give measurable amounts of various solvents.[28] Paints have also been reported as a source for PCB[35] and for dibutylphthalate, causing chlorophyll deficiency followed by whitening of plant leaves.[40]

Decay of Building-Related VOCs

Vinyl wall-to-wall carpets are reported as emission sources long after they have been installed. Compounds such as dodecene,[14] TXIB,[27] and ethylhexylacrylate[16] have been quantified in the 50 $\mu g/m^3$ level even years after installation. Carpets with styrene-butadiene backing have given rise to levels of styrene in a school of more than 3 mg/m^3 eight years after installation.[44] The occurrence in the indoor air of compounds with rather low volatility, such as phthalates[39] PCB and TXIB, seem to be very much due to adsorption on dust and airborne particles. Adsorbed compounds can be released when dust is heated to 70 °C or more on electric bulbs, radiators, and cooling panels on refrigerators.[20]

The total level of volatile organic compounds (TVOC) in newly constructed buildings with no inhabitants has been measured for almost a year.[19] In five out of six houses, the levels have been reduced by about half or more during the first six months. In the house with the almost constant level of TVOC, the pollutants are assumed to be absorbed and desorbed in the ventilation plant. Measurements of air contaminants, typical for indoor air, in a newly built preschool were reduced by two-thirds within the first six months.[2] Even other investigations show that the contaminant level is heavily reduced during the first six months of occupation.[43] The VOC levels in buildings at different air exchange rates have been measured.[3,21,36]

CONCLUSIONS

Certain building materials have been identified as major emission sources in buildings. Especially solvent- or monomer-containing surface materials such as paint and carpets are reported as emission sources. It is well known that increased levels of volatile compounds may affect health or comfort, but even electronic equipment can develop problems.[32]

Since very few investigations of VOCs in unoccupied and unfurnished buildings have been reported, the relative contribution of pollutants emanating from building materials cannot be generally estimated. Furthermore, the occurrence of individual VOCs may vary considerably over time, e.g., hexanol is reported to be at a level about 100% higher due to increased emission from kitchen cupboards and other wood materials during the warm period.[46] The disparity in composition and level of VOCs between buildings has been demonstrated in different investigations[7,22,23,41] and is often due to different human activities (restoration, etc.).

The most common measure for reducing emissions in buildings is naturally to remove the source. For flooring materials, it may also be necessary to remove the adhesive, especially if the adhesive contains odorous compounds such as higher alcohols released from the floor covering (e.g., references 16,24). In order to minimize emission from remaining compounds, concrete floorings have successfully been covered with polyurethane[44] or epoxy lacquer layers.[5] In cases with excessive emission, increased ventilation does not seem to reduce the magnitude of the emission source.[4,24] Ventilation with heated air, "bake out," may, however, in certain cases reduce the emission from building materials.[8]

Especially in product development, a deeper knowledge of the chemical mechanisms involved in the release of compounds is essential. Minimized emission also presumes that relevant testing methodology is available. Climate chambers are useful tools in emission factor determination,[6,34] but there is also a need for routine test methods in product development and in production control. Small-scale devices for emission measurements have been reviewed.[11] An emission cell both for industrial applications and source identification on site in buildings has recently been designed.[47]

RECOMMENDATIONS

- The client/contractor buying building materials is recommended to require information about the manufacturer's Quality Assurance System, especially for products based on solvents and monomers. Without the QAS, single emission data or information about the material constituents is less valuable.
- Building materials have to be protected from moisture during construction and after installation. This is especially important for linoleum, mineral wool, casein-containing floor-topping compounds, and vinyl flooring with a high content of plasticizers. Concrete has to dry out before the floor covering is started.
- Building materials must be applied in a proper way. Sealants and paints for outdoor use should not be used indoors. Moisture repellents for outer walls should be used with caution.
- Formulation of building materials in the product development phase provides a wide range of possibilities; e.g., for waterborne construction paints, constituents can be substituted in order to minimize the long-term emission.
- The building material producers have to know more about the chemical mechanisms influencing the release of volatile compounds. The producers may also take advantage of the development of test methods in product development.

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REFERENCES

[1]Andersson, B., et al. 1984. "Mass spectrometric identification of 2-ethylhexanol in indoor air: Recovery studies by charcoal sampling and gas chromatographic analysis at the micrograms per cubic metre level." *Journal of Chromatography*, Vol. 291, pp. 257-263.

[2]Berglund, B., et al. 1982a. "A longitudinal study of air contaminants in a newly built preschool." *Envir. Int.*, Vol. 8, pp. 111-115.

[3]Berglund, B., et al. 1982b. "The influence of ventilation on indoor/outdoor air contaminants in an office building." *Envir. Int.*, Vol. 8, pp. 395-399.

[4]Bloeman, H.I., et al. 1990. "Indoor air pollution after the application of moisture repellent." *Proc. 5th Int. Conf. on Indoor Air Quality and Climate*, Vol. 3, pp. 569-574.

[5]Brown, V.M., et al. 1990. "Investigations of the volatile organic compound content of indoor air in homes with an odorous damp proof membrane." *Proc. 5th Int. Conf. on Indoor Air Quality and Climate*, Vol. 3, pp. 575-580.

[6]Commission of European Communities. 1991. *Guideline for the characterization of volatile organic compounds emission from indoor materials and products using small test chamber.* COST Project 613 Indoor Air Quality and its Impact on Man, WG 8 (to be published).

[7]DeBortoli, M., et al. 1985. *Measurements of indoor air quality and comparison with ambient air.* Luxembourg, Commission of the European Communities (Report EUR 9656 EN).

[8]Girman, J.R., et al. 1990. "Building bake-out studies." *Proc. 5th Int. Conf. Indoor Air Quality and Climate*, Vol. 3, pp. 349-354.

[9]Grimsrud, D.T. 1987. "Characterization of sources and emissions in field studies." Chairman's Summary, Session III. *Atm. Envir.*, Vol. 21, No. 2, pp. 359-360.

[10]Gustafsson, H. 1990. *Kemisk emission från byggnadsmaterial—beskrivning av skadefall, mätteknik och åtgärder.* SP rapport 1990:25 Statens Provningsanstalt (120 ref.). (To be published in English as SP report 1991:30, ISBN 91-7848-271-2, Swedish National Testing and Research Institute.)

[11]Gustafsson, H., and B. Jonsson. 1991. *Review of small devices for measuring chemical emission from materials*, SP report 1991:25. Swedish National Testing and Research Institute.

[12]Ibid., case study no. 2 (phenol).

[13]Ibid., case study no. 3 (dodecylbenzene).

[14]Ibid., case study no. 5 (dodecene).

[15]Ibid., case study no. 10 (white spirits).

[16]Ibid., case study no. 16 (ethylhexylacrylate).

[17]Ibid., case study no. 17 (p-cresol).

[18]Ibid., case study no. 23 (butylmethacrylate).

[19]Ibid., chapter 2.3.

[20]Hirvonen, A., et al. 1990. "Thermal desorption of settled household dust." *Proc. 5th Int. Conf. on Indoor Air Quality and Climate*, Vol. 3, pp. 743-746.

[21]Hodgson, A.T., and J.R. Girman. 1989. "Application of a multisorbent sampling technique for investigations of volatile organic compounds in buildings. Design and protocol for monitoring indoor air quality. *ASTM STP 1002*, pp. 244-256.

[22]Krause, C., et al. 1987. "Occurrence of volatile organic compounds in the air of 500 homes in the Federal Republic of Germany." *Proc. 4th Int. Conf. on Indoor Air Quality and Climate*, Vol. 1, pp. 102-106, West Berlin.

[23]Lebret, E., et al. 1986. "Volatile organic compounds in Dutch homes." *Envir. Int.*, Vol. 12, pp. 323-332.

[24]McLaughlin, P., et al. 1990. "Higher alcohols as indoor air pollutants: Source, cause, mitigation." *Proc. 5th Int. Conf. on Indoor Air Quality and Climate*, Vol. 3, pp. 587-591.

[25]Page, C.L., and . Vennesland. 1983. "Pore solution composition and chloride binding capacity of silica fume cement pastes." *Material and Structures*, Vol. 16, pp. 19-25.

[26]Pasanen, P., et al. 1990. "Emissions of volatile organic compounds from air conditioning filters of office buildings." *Proc. 5th Int. Conf. on Indoor Air Quality and Climate*, Vol. 3, pp. 183-186.

[27]Rosell, L. 1990. "High levels of a semi-VOC in indoor air due to emission from vinyl floorings." *Proc. 5th Int. Conf. on Indoor Air Quality and Climate*, Vol. 3, pp. 707-712.

[28]Schriever, E., and R. Marutzky. 1990. "VOC emissions of coated parqueted floors." *Proc. 5th Int. Conf. on Indoor Air Quality and Climate*, Vol. 3, pp. 551-555.

[29]Sell, J., and H. Kuhne. 1967. "Verfärbungen von Eichenparkett durch flüchtige Alkalien aus Zusatzmitteln für Beton." *Holzforschung und Holzverwertung*, Vol. 19, p. 5.

[30]Seifert, B., et al. 1989. "Volatile organic compounds from carpeting." Man and his Ecosystem, *Proc. 8th World Clean Air Congress*. Vol. 1, pp. 253-258.

[31]Sheldon, L., et al. 1988. *Indoor air quality in public buildings*, Vol. 2 PB 89-102511, Section 8. Research Triangle Institute, North Carolina.

[32]Shields, H.C., and C.J. Weschler. 1990. "Three years of indoor/outdoor VOC measurements." *Proc. 5th Int. Conf. on Indoor Air Quality and Climate*, Vol. 2, pp. 771-776.

[33]Singvi, R., et al. 1990. "4-phenylcyclohexene from carpets and indoor air quality." *Proc. 5th Int. Conf. on Indoor Air Quality and Climate*, Vol. 4, pp. 671-676.

[34]Tichenor, B.A. 1989. *Indoor air sources: Using small environmental test chambers to characterize organic emissions from indoor materials and products.* EPA-600 8-89-074. Air and Energy Engineering Research Laboratory, U.S. Environmental Protection Agency.

[35]Todd, A.S. 1987. "A unique source of PCB contamination in public and other nonindustrial buildings. *Practical control of indoor air problems*," pp. 104-109.

[36]Turiel, I., et al. 1983. "The effect of reduced ventilation on indoor air quality in an office building." *Atm. Environ.*, Vol. 17, pp. 51-64.

[37]Ullrich, D., et al. 1982. "Einfluss von Lackanstrichen auf die Innenraumluftqualität am Beispiel von Heizkörperlacken." *Luftqualität in Innenräumen (K. Aurand et al., eds.), pp. 283-298. Stuttgart: Gustav Fischer.*

[38]*van der Wal, J., et al. 1987. "Thermal insulation as a source of air pollution." Proc. 4th Int. Conf. on Indoor Air Quality and Climate*, Vol. 1, pp. 79-83, West Berlin.

[39]Vedel, A., and P.A. Nielsen. 1984. "Phthalate esthers in the indoor environment." *Proc. 4th Int. Conf. on Indoor Quality and Climate*, Vol. 3, pp. 309-314.

[40]Virgin, H.I., et al. 1981. "Effect of di-n-butyl-phthalate on the carotenoid synthesis in green plants." *Physiologia Plantarum*, Vol. 53, pp. 158-163.

[41]Wallace, L. 1987. *The total exposure assessment methodology (TEAM) study: Summary and analysis.* Vol. 1. U.S. Environmental Protection Agency 600/6-87/002a, June.

[42]Wallace, L., et al. 1987a. "Emissions of volatile organic compounds from building materials and consumer products." *Atm. Environ.*, Vol. 21, No. 2, pp. 385-393.

[43]Wallace, L., et al. 1987b. "Volatile organic chemicals in 10 public access buildings." *Proc. 4th Int. Conf. on Indoor Air Quality and Climate*, Vol. 1, pp. 188-192, West Berlin.

[44]Winfield, M. 1987. "A case history: Odor and health problems in a Texas public school building." *Practical control of indoor air problems*, pp. 111-118.

[45]Wolff, P. 1990. "Proposal of methods for developing healthy building materials: Laboratory and field experiments." *Envir. Tech*, Vol. 11, pp. 327-338.

[46]Wolkoff, P., et al. 1990. "The Danish twin apartment study: Part 1, formaldehyde and long term VOC measurements." *Proc. 5th Int. Conf. on Indoor Air Quality and Climate*, Vol. 2, pp. 657-662.

[47]Wolkoff, P., et al. 1991. "Field and laboratory emission cell: FLEC." *Healthy buildings*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers.