Influence of Parquet Flooring on the Indoor Air Quality of Private Residence: A Case Study

S. Paul

Corresponding Author: Dr Swaraj Paul
e-mail: s.paul@pppolymer.se
Affiliation: PP Polymer AB

Abstract

This paper presents results from a case study on IAQ in a residence where the occupants complained about health problems during a few years' time including infants after they changed the flooring to a new parquet flooring in both the floors. During the last years the health conditions of the children became very bad resulting into several emergency visits to the hospital. This study presents measured values for VOC and aldehydes under different conditions. Initial measurements showed that the values were very high and exceeded all the recommended health Hazard limits. This resulted into the decision that all the parquet flooring was removed. This study shows how the values of VOC and aldehydes decreased with time and also the decrease did not follow the general diffusion principles. Therefore, forced ventilation conditions under elevated temperature and very high relative humidity were used to accelerate the release rate. This study shows that elimination of volatiles was a very slow process and it took almost 30 days to achieve acceptable concentration levels both for the aldehydes and for the VOCs.

This case study shows for the first time that although such flooring material meets the standard, how they may influence the IAQ of residential houses. In case if such contaminations occur, this study also shows that how the reduction rates of chemicals and specially aldehydes in indoor air could be accelerated by using different accelerated ventilation conditions. The study shows that the health hazards due to the presence of aldehydes in indoor air are underestimated in normal IAQ control routines. Since, aldehydes are classified as carcinogens, the study shows that measurement of aldehyde concentrations in indoor air should always be included in the indoor air quality control to assure a healthy indoor air climate.

Keywords

Urea formaldehyde adhesive
Parquet
Wood Flooring
Aldehyde
Formaldehyde
Volatile Organic Compounds (VOC)
Total Volatile Organic Compounds (TVOC)

Abbreviations

VOC: Volatile Organic Compounds
TVOC: Total Volatile Organic Compounds
SVOC: Semi-Volatile Organic Compounds
UF: Urea Formaldehyde
U: Urea
F: Formaldehyde

REL: Reference Emission Levels
TLV: Threshold Limit Values
OEL: Occupational Exposure Limit values
TAK: Maximale Arbeitsplatzkonzentration
IAP: Indoor Air Pollutants
EPA: Environmental Protection Agency
$R_f C$: Reference Concentration
ATSDR: Agency for Toxic Substances and Disease Registry
OEHHA: California's Office of Environmental Health Hazard Assessment
WHO: The World Health Organization

Introduction

We breathe about 12 times per minute, *i.e.* more than 10 m^3 or 12 kg of air every day. Since people spend more than 90% of their time indoors, most of the air that we inhale is indoor air. It has been reported that people spend, on average, more than 20 hours per day inside their apartments, and therefore, they will be exposed to chemicals more at home than at their workplace. According to Meyer *et al.* (1985) people are exposed to chemicals at least three times more at home than at work.

As far as air quality at industrial workplaces are concerned, exposure guidelines and standards are very well defined. However, these values are only applicable for exposure levels during one working day, *i.e.* 8 hours. In workplaces, these values are commonly referred to as "Threshold Limit Values" (TLV) and "Occupational Exposure Limit values" (OEL) in the US, and "Maximale Arbeitsplatzkonzentration" (TAK) in Germany. Salthammer (1999), presented recommendations to apply similar limiting values for indoor air in non-industrial buildings, such as private houses and apartments. A very interesting review on formaldehyde in indoor air has earlier been presented by Salthammer *et al.* (2010). A recent publication succinctly summarizes the possible sources for different types Indoor Air Pollutants (IAP), including volatile organic compounds (VOC) and aldehydes, from 167 office buildings in 8 European countries (Spinazze *et. al.* 2019). Bradman *et al* (2017) reported air quality from 40 early childhood education (ECE) facilities serving children < 6 years old in California (ECE) facilities in California during the period 2010-2011. Formaldehyde and acetaldehyde were detected in 100% of samples. The median (max) indoor formaldehyde and acetaldehyde levels (µg/m3) were 17.8 (48.8) and 7.5 (23.3), respectively. The study showed that formaldehyde levels exceeded California 8-hour and chronic Reference Exposure Levels (both 9 µg/m3) for non-cancer effects in 87.5% of facilities. Acetaldehyde levels exceeded the U.S. EPA Reference Concentration in 30% of facilities. The buildings and furnishings investigated were generally >5 years old.

In literature, several recommendations have been reported, *e.g.* exposure values should be 1/10th of the TLV values (American Society of Heating 1990, Levin 1998), or 1/20th of the TAK values(Kunde 1982, VDI 2310), or 5% of TLV values (US EPA 1996), or 1/40th of the OEL values (Levin 1998). These recommended values are based on observations obtained from areas where the majority populace did not complain about any health problems during the major part of their residence. However, these values are not applicable for persons who are very sensitive to irritating compounds.

Although people are exposed to three times more chemicals in private homes than at their workplaces, as discussed above, it is remarkable that there exist no exposure limits or regulations for chemicals in indoor air in private apartments. Nielsen *et al.* (1997) suggested that, in cases where safe exposure values are missing, it may be suitable to use 1/40th of the OEL values as the limiting value for indoor air. These values, for private housing and apartments, are mainly aimed to obtain a healthy indoor air quality.

One of the main causes for affecting the indoor air quality is primary emissions from building materials, such as from floors, walls, roofing and insulation, besides paints and adhesives. In addition to these primary emissions, indoor air quality is also affected by secondary emissions, which occur when building materials, or the chemicals present in indoor air due to primary emissions, undergo further degradation.

This suggests that in order to assure the indoor air quality, it is important to determine the total concentration of volatile and semi-volatile organic compounds (VOC and SVOC)), their compositions, and also the presence of other chemicals, such as polyaromatics, amines and aldehydes, in indoor air. Most often, measurements of VOCs and SVOCs are not enough to assess the indoor air quality. This is because chemical compounds belonging to the latter group of chemicals are more hazardous, and have relatively low threshold values, compared to the commonly occurring VOC and SVOC compounds.

Meyer *et al.* (1985) reported several cases where the presence of very low concentrations of aldehydes in indoor air, specially formaldehyde arising from the Urea Formaldehyde (UF) adhesives, caused serious health problems in schools in Germany (Deimel 1978, Formaldehyde 1984).

Formaldehyde release in such adhesives arises due to three main reasons: 1) incomplete reactions between Urea (U) and Formaldehyde (F), 2) different molar ratios of U and F used during manufacturing and 3) the amount of the adhesive (as weight-%) used to bond wood. UF adhesives are mainly manufactured first by addition reactions of formaldehyde (F) with urea (U) which form different methylol derivatives, followed by curing of these intermediates at high temperatures (150-190°C) in order to obtain high molecular weight cured adhesives (Paul 1996). Final properties of UF adhesives depends mainly on the extent of polymerization and the molar ratio of urea and formaldehyde. UF resins have been identified as a significant contributor to the formation of indoor aldehydes (Hun et al 2010, Kelly et al 1999).

Among aldehydes, the main contributors for health concerns are formaldehyde, acetaldehyde and acrolein. U.S. Environmental Protection Agency (EPA) listed both formaldehyde and acetaldehyde as probable human carcinogens (U.S. EPA, 2012b; U.S. EPA, 2012c). Exposure to these compounds has been associated with increased risk of pediatric asthma and respiratory symptoms, including decreased lung function, inflammation, and airway obstruction Norbäck et al 1995, Wieslander et al 1997, Roda et al 2011, Hulin et al 2010).

The U. S. Agency for Toxic Substances and Disease Registry (ATSDR) has set a minimal risk levels for formaldehyde of 0.008 ppm (10 µg/m^3) for chronic exposures (one year or longer), as a screening level to protect the general public (ATSDR, 1999). Whereas, California set reference exposure levels (REL) for formaldehyde that tended to be lower than the international benchmarks, and range from 30-120 µg/m^3 for 8-hour exposure and the chronic REL value of 9 µg/m^3, or 0.007 ppm for non-carcinogenic effect (OEHHA 1999, 2001). France has established a long-term exposure benchmark of 10 µg/m^3, almost identical to the California's Office of Environmental Health Hazard Assessment (OEHHA) chronic REL. The

World Health Organization (WHO) has published a 30-minute standard of 100 μg/m^3 based on sensory irritation (Kaden et al 2010).

In general, children are more vulnerable to toxic substances in their environment because they have higher exposures per kilogram of body weight (Selevan et al 2000), and are less developed immunologically, physiologically, and neurologically (Cohen et al 2000, Lo et al 2005).

Acrolein is of concern for human health at very low concentrations compared to other aldehydes. Acrolein acts as an irritant to the eye and respiratory tract, and there is also evidence that it exacerbates asthma (OEHHA, 2014). The US-EPA (2013) recommended inhalation reference concentration ($R_f C$) of 0.02 μg/m^3, whereas Agency for Toxic Substances and Disease Registry (ATSDR, 2013) recommended a minimal risk level (MRL) of 0.09 μg/m^3. OEHHA (OEHHA, 2014) recommends a REL of 0.35 μg/m^3.

In context to all the above recommended concentrations, it is of interest to mention that the reported median outdoor concentrations (range) for formaldehyde and acetaldehyde are 2.3 μg/m^3 (1.5-4.0 μg/m^3) and 1.8 μg/m^3 (1.1-6.5 μg/m^3), respectively (Chan et al 2016).

In this paper, we present results from a case study from a private residence where the residing family started complaining about health problems, with similar symptoms as described above, after they renovated the villa with a new parquet flooring. Infants below 3 years of age started suffering breathing and asthma problems, which became more severe with time. This resulted in several emergency visits to the hospital. Since parquet does not comprise of whole wood, but instead is composed of wooden panels commonly glued with urea-formaldehyde (UF) adhesives, it was of great interest to investigate the Indoor Air Quality (IAQ) of the residence, and to assess whether their new health problems had any correlation to the IAQ.

Before starting our studies, the quality control routines for such flooring materials were investigated. It was of particular interest whether there existed any measured values for primary emissions from such materials. There was some data on the VOC and aldehyde emissions from parquet flooring material in technical data sheets (TDS), which were used to certify the product quality according to building standards. For certification, two standards were used: 1) ISO16000-3:2011, for sample preparation and 2) ISO16000-3:2011 or EN717-1, for analysis of aldehydes. According to ISO 16000-3:2011 standard, emission samples were collected from the flooring materials, placed in a chamber with controlled relative humidity and temperature, whereby both the back and the edges of the sample was covered with aluminum foil and tape. This suggests that during sample preparation, the emission path is restricted to emit through the surface. However, in fact, the total unbonded volatiles in the flooring material should be of more interest in determining the total primary material emissions from the flooring material. These values are more relevant in assessing the IAQ, and thereby in determining the impact on associated health problems.

This study presents the total primary emissions from the parquet flooring in question, with respect to VOC and aldehydes, as well as how this flooring material influenced the IAQ of the villa. To the best of our knowledge, this is for the first time such a study is reported in the literature. Since the initial primary emissions were very high, it was decided to remove all the new parquet in the house and thereafter follow the concentration changes of both volatiles and aldehydes. In this study, we also report decrease in VOC and aldehyde concentrations over time under normal and accelerated aging conditions.

Materials and Methods
To measure primary emissions from the material, we used sample material on the parquet flooring from the supplier, packed in the original packaging and stored for 3 years, as well as a sample material from the installed flooring that was regularly used for three years. The two-story house did not have any active ventilation, except some passive ventilation through old-fashioned ventilation openings in the windows. This study was performed during the period June 2019 to September 2019, which are summer months.

Since we were interested in determining the total amount of primary emissions for both VOC and aldehydes, we used a different method for sample collection than described in the standard ISO 16000-3:2011. According to our method, we placed a pre-weighed flooring sample into a tightly sealed dessicator and evacuated it using a rotary pump to a vacuum corresponding to 3-5 mm of mercury for 45 minutes. We evacuated the dessicator through an adsorbent tube.

For determination of VOC in indoor air, 10 liters of air sample was passed through the Tenax TA sampling tube using an Air-Check pump from SKC calibrated to 1 l/min. VOC analysis from the Tenax tubes were performed by using Thermal Desorption (TD) followed by GC/MS according to ISO 16000-6:2011 standard. TD was performed in a TD unity from Markes, Unity 2. We identified the significant peaks using mass numbers from the mass spectra and comparing the m/z ratios with NIST and our own libraries. The amounts of identified compounds were determined as μ_g toluene equivalents/m^3.

For aldehyde determinations, 80 liters of air sample was passed through the LpDNPH S10 adsorbent cartridge using SKC pump calibrated to 2 l/ min. Aldehyde analyses were performed according to ISO 16000-3:2011/ EN 717-1 whereby the adsorbent cartridge was first eluated with acetonitrile followed by analysis of the eluant using HPLC/UV. Aldehyde compounds were identified and quantified in absolute values using aldehyde calibration standards. All amounts presented are expressed as μ_g/gram sample weight for the material samples and μ_g/m^3 for the air samples.

Sampling strategy
As mentioned above, for the analysis of material samples, we used flooring samples that were in the original packaging from the supplier and a used sample from the residence.

Air samples from the following conditions were analyzed:

1. Under normal living conditions (June)
2. After the residence was empty and closed up for 3 weeks (July)
3. After removal of the parquet and ventilating the house for one week by opening the doors and windows for long periods (mid-August). It is important to note that during the sampling, it was quite warm, and the outdoor temperature was exceeding 30˚C during the daytime. The air samples were taking on both floors where the parquet floor was removed. Since the infant had severe health problems, we specially performed measurements close to the child´s room.
4. Since we did not observe any significant decrease in the VOC and aldehyde concentrations, we accelerated the emission process of all the absorbed chemicals in the residence by using heated blowers which raised the temperature to about 40˚C. During this heating process both the floors ventilated at least a few times per day by

opening all the windows and door to obtain a cross ventilation. In the night many of the windows were kept open. We measured the concentrations of VOC and aldehyde after one week.

5. The decay rate of the chemicals, and especially of aldehydes, were relatively slow and therefore, we increased the relative humidity of the residence to around 70-80%, while keeping the high ambient temperature. We determined the aldehyde and VOC concentrations after 3 weeks of accelerated treatment. We used very high humidity together with high temperature specifically to remove aldehydes, specially formaldehyde, because it is well known that formaldehyde reacts with moisture to form glycols, which are not hazardous to health.

Results and Discussions

VOC studies

The total VOC emission from the parquet floor samples from an unpacked batch and after 3 years of regular use and exposure, are summarized in table 1 in the appendix. Only the three major peaks were identified and quantified. The results show that the unopened batch contained very high amounts of free VOC per gram material. It was interesting to note that the TVOC value decreased substantially, by approximately 10 times, after 3 years of use. We also found a change in the chemical composition of the volatiles. These changes may be expected due to the reactions with other chemicals and ozone, as has been proposed earlier.

We also measured the free aldehyde contents in the unopened batch and after 3 years of exposure. The results are summarized in table 2. The results show that the formaldehyde concentration decreased to half after 3 years of use, and we could identify small amounts of new types of aldehyde that were not present initially in the parquet sample. This suggests that the aldehydes initially present in the material may have undergone further reactions during use and exposure, as has been proposed earlier (4).

To investigate the influence of parquet on the IAQ, we followed the measured VOC and aldehyde concentrations in the residential air. We performed measurements according to the measurement strategy, as described above, in the living room on the ground floor and near the infant's room on the 2nd floor. In our measurements we determined the Total Volatile Organic Content (TVOC), as well as identified and quantified 7-8 major compounds present in the air samples. The main aim of identification and quantification was to study changes in the chemical composition as a result of removing the parquet flooring, and after subjecting the indoor environment to severe ventilation measures. VOC results near the infant's room are summarized in table 3, and results from the living-room are summarized in table 4, in the appendix.

Table 3 shows relatively high TVOC level on the 2nd floor under normal living conditions, much higher than the recommended values. When the residence was closed for 3 weeks during the holidays, TVOC level increased substantially, with some changes in the chemical composition of the dominant compounds. This suggests that ventilation is very essential when parquet is used. The results show that TVOC levels increased 5 times when the parquet was removed and showed the presence of several new compounds. It is worth noting that the person who removed the flooring became dizzy and sick. This shows that the emissions from the material were accumulated under the flooring since they could not diffuse through the flooring material. The remaining measurements show that the TVOC levels improved after removal of the flooring and ventilating the 2nd floor. We found that the TVOC decreased very slowly when we used the normal ventilation conditions, *i.e.* through thorough ventilation of the 2nd floor. In order to confirm the values, we performed duplicate measurements after one day, and we confirmed that both the TVOC values and the composition were reproducible.

When forced ventilation was used, and the ambient temperature was raised to 35-45°C, the rate of decrease of TVOC increased substantially. The values reduced to half after only 8 days of forced ventilation at elevated temperature. In our next step, we raised the relative humidity level to 60-70%, while keeping the ambient temperature high using blowing heaters and ventilated the 2nd floor for 15 days. After this treatment, we found that TVOC level decreased remarkably and started to reach the normal TVOC levels, although it was still on the higher end of the acceptable spectrum. We also found that the chemical composition changed, in particular the contents of aromatic compounds decreased substantially.

Table 4, results from the living-room in the ground floor, shows a similar behavior, *i.e.* TVOC levels under normal living conditions, after removal of the parquet and finally after normal and forced ventilation, as performed for the 2nd floor. It was interesting to note that the TVOC values were somewhat lower than the 2nd floor as shown in table 3. The chemical composition also differed. This could be explained by the differences in the vapor pressure of the chemical compounds present in the air.

Aldehyde studies

We also measured the aldehyde concentrations on the ground and 2nd floor under similar conditions as VOCs. Table 5 summarizes the aldehyde values near the infant's room on the 2nd floor, and table 6 summarizes the living-room on the ground floor. It is very interesting to note that the aldehyde levels are very high under normal living conditions. Formaldehyde concentrations are very high compared to the recommended levels described earlier, and the formaldehyde concentration were almost equivalent for both floors. We could also identify other aldehydes, such as acetaldehyde and methacrolein, among others. Interestingly, the methacrolein level was almost double on the 2nd floor compared to the ground floor. In the tables we can also observe how the aldehyde concentrations and compositions changed as a result of forced weathering. We obtained very high decay rates of aldehydes after we raised the relative humidity at elevated ambient temperature. The results show that after 30 days of forced and accelerated ventilation, the aldehyde concentrations started approaching the REL values, described earlier. During this investigation process the family could not live in the villa. After reaching the safe levels, the family moved back and did not suffer the health problems experienced before removing the whole parquet flooring.

The study shows that diffusion of aldehydes from the flooring material is not a physical process because of the reactivity of aldehydes with the substrate material and therefore the normal diffusion principles such as Fick´s laws are applicable. This makes it very difficult to design proper indoor ventilation to reduce aldehyde concentrations or eliminate aldehydes in the indoor air to safe levels. The study reveals, for the first time, that special accelerated conditions are required to remove aldehydes and thereby obtain a healthy indoor air quality.

Acknowledgements
The author acknowledges his thanks to PP Polymer AB, Sweden to financially support this project and allowing the results to publish. The author will also like to thank Dr R N Kandathil for performing all the analytical work and Dr A Kargaard for proof reading of the manuscript.

Conflict of Interest Statement

The work was fully supported by PP Polymer AB; therefore no conflict exists relating performing this study and publishing the results. To avoid any commercial conflicts trade names on the products have not been disclosed in this paper.

References

Meyer B, Hermanns K (1985) Reducing Indoor Air Formaldehyde Pollution, J Air Pollution Control Assoc., 35 (8), 816-821.

Salthammer T (1999), Organic Indoor Air Pollutants, Wiley-VCH & Sons, 291-303

Salthammer T, Mentese S, Marutzky R (2010), Formaldehyde in the Indoor Environment, Chem. Rev., 110, 2536-2572

Spinazzè A, Campagnolo D, Cattaneo A, Urso P, Sakellaris I.A, Saraga D.E, Mandin C, Canha N, Mabilia R, Perreca E, Mihucz V.G, Szigeti T, Ventura G, Fernandes E. de O, Kluizenaar Y. de, Cornelissen E, Hänninen O, Carrer P, Wolkoff P, Cavallo D.M, Bartzis, J.G (2019), Indoor Gaseous Air Pollutants Determinants in Office Buildings—The OFFICAIR project. Indoor Air., 0 (0), 1–12

Bradman A, Gaspar F, Castorina R, Williams J, Hoang T, Jenkins P L, McKone T.E, and Maddalena R (2017), Formaldehyde and Acetaldehyde Exposure and Risk Characterization in California Early Childhood Education Environments, Indoor Air, 27 (1), 104-113

American Society of Heating, Refrigeration and Air-Conditioning Engineers, American National Standards Institute, Ventilation for Acceptable Indoor Air Quality, American Society of Heating, Refrigerating and Air-Conditioning Engineers: Atlanta, GA, 1990

Levin H (1998), Introduction to Indoor Air Guideline Values for Organic Acids, Phenols and Glycol Ethers, Indoor Air Suppl., 5, 5-7

Kunde M (1982): Erfahrungen bei der Bewertung von Holzschutzmitteln. In: Aurand K, Seifert B, Wegner J, (Hrsg.): Luftqualität in Innenräumen. Stuttgart: Gustav Fischer Verlag, S. 317–325

VDI-Guideline No. 2310: 1974, VDI-Handbuch ‘Reinhaltung der Luft’, VDI-Richtlinie 2310 ‘Maximale Immissionswerte’ Beuth-Vertriebs GmbH, Berlin und Köln

US EPA (1996): IAQ a concern in EPA’s planned 232-million research facility, Indoor air quality update, 9, 10:8–13

Nielsen G.D, Hansen L.F, Wolkoff P (1997), Chemical and Biological Evaluation of Building Material Emissions. Indoor Air, 7 (1), 17–32

Deimel M (1978), Erfahrungen über Formaldehyd-Raumluftkonzentrationen in Schulneubauten. In Organische Verunreinigungen in der Umwelt, Aurand, K, Ed., Schmidt: Hamburg, 416–427

Formaldehyde 1984: “Formaldehyde” Public Health Office, Federal Republic of Germany, October 1984, Berlin

Paul S (1996), Surface Coatings: Science and Technology, Paul S Ed., John Wiley, 195-201

Hun D.E, Corsi R.L, Morandi M.T, Siegel J.A (2010), Formaldehyde in Residences: Long-Term Indoor Concentrations and Influencing Factors. Indoor Air, 20 (3), 196–203

Kelly T.J, Smith D.L and Satola J (1999), Emission Rates of Formaldehyde from Materials and Consumer Products Found in Californian Homes, Environ Sci Technol, 33, 81-88

U.S.EPA (2012 b) Formaldehyde, U.S. Environmental Protection Agency

U.S.EPA (2012 c) Formaldehyde, U.S. Environmental Protection Agency

Norbäck D, Björnsson E, Janson C, Widström J, Boman G (1995), Asthmatic Symptoms and Volatile Organic Compounds, Formaldehyde, and Carbon Dioxide in Dwellings. Occup Environ Med, 52 (6), 388–395

Wieslander G, Norbäck D, Björnsson E, Janson C, Boman G (1997), Asthma and the indoor environment: the significance of emission of formaldehyde and volatile organic compounds from newly painted indoor surfaces. Int Arch Occup Environ Health., 69, 115–124

Roda C, Kousignian I, Guihenneuc-Jouyaux C, Dassonville C, Nicolis I, Just J and Momas I (2011), Formaldehyde Exposure and Lower Respiratory Infections in Infants: Findings from the Paris Cohort Study, Environ Health Persp, 119, 1653-1658

Hulin M, Caillaud D, Annesi-Maesano I (2010), Indoor Air Pollution and Childhood Asthma: Variations between Urban and Rural Areas. Indoor Air, 20 (6), 502–514

ATSDR, 1999, Toxicological profile for Formaldehyde, Atlanta, Georgia, Agency for Toxic Substances and Disease Registry.

OEHHA (1999), (2001), Determination of acute reference exposure levels for airborne toxicants, Office of Environmental Health Hazard Assessment: California US1999 and 2001

Kaden D.A, Modin C, Nielesen G.D and Wolkoff P (2010), Formaldehyde, WHO Guidelines for Indoor Air Quality: Selected Pollutants, World Health Organization, Geneva

Selevan S.G, Borkovec L, Slott V.L, Zudová Z, Rubes J, Evenson D P (2000), Semen quality and reproductive health of young Czech men exposed to seasonal air pollution. Environ Health Perspect., 108, 887–894

Cohen Hubal E.A; Sheldon L.S, Burke J.M, McCurdy T.R, Berry M.R, Rigas M.L, Zartarian V.G, Freeman N.C (2000), Children's Exposure Assessment: A Review of Factors Influencing Children's Exposure, and the Data Available to Characterize and Assess That Exposure. *Environmental Health Perspectives*, 108 (6), 475–486

Lo B and O'Connell M, Eds (2005), Ethical Considerations for Research on Housing-Related Health Hazards Involving Children, National Research Council and Institute of Medicine of the National Academies, Washington D C, The National Academies Press

Chan W.R, Sidheswaran M, Sullivan D.P, Cohn S, Fisk W.J (2016), Cooking-Related PM2.5 and Acrolein Measured in Grocery Stores and Comparison with Other Retail Types. Indoor Air, 26 (3), 489–500

Appendix

Table 1: Total primary VOC emissions from the parquet flooring material

Sample	TVOC μg toluene equivalent/ m^3	Identification and quantification of the main components in μg toluene equivalent/ m^3
From original packing	587.6	Toluene: **84.2**; 1,4-dioxane: **57.7**; 4,4,6-trimethyl-bicyclo [3,1,1] hept-3-en-2-one: **21.7**
After 3 years of use	55.3	2,2,4-trimethyl-1,3-pentanediol diisobutyrate: **5.2**; hexanal: **3.7** ; β-pinene:2.5

Table 2: Total aldehyde concentrations from the parquet flooring material

Aldehyde types	Original package (ng/g sample)	After 3 years of use (ng/g sample)
Formaldehyde	583.17	266.18
Acetaldehyde	-	5.50
Valeraldehyde	-	2.29
Benzaldehyde	-	-
Hexaldehyde	45.78	11.03
2-butanone	-	3.22

Table 3: VOC results of the Indoor Air near the infant's room 2nd floor under different conditions

Sample nomenclature	TVOC (μg tol.ekv/m^3)	Concentration of main components (μg tol.ekv/m^3)
Under normal living conditions	192	limonene: **14,02**; α –pinene: **12,02**; nonanal: **10,45**; propanoic acid, 2-methyl-2-ethyl-1-propyl-1,3-propanediyl ester: **8,46**; hexanal: **7,70**; β-pinene: **10,13**; ethylacetate: **5,09**; 2-phenoxyethanol: **0,96**
House was closed for 3 weeks during holidays	267	2,2,3,4-tertramethyhex-5-en-3-ol: **21,54**; propanoic acid, 2-methyl-2-ethyl-1-propyl-1,3-propanediyl ester: **15,16**; xylene: **14,12**; α –pinene: **13,00**; nonanal: **7,60**; limonene: **3,56**; 2-phenoxyethanol: **0,32**
After removal of parquet on the 2nd floor, and after 7 days of normal ventilation*	1195	toluene: **233,3**; heptane: **183,6**; hexanal: **64,0**; propanoic acid, 2-methyl-2-ethyl-1-propyl-1,3-propanediyl ester: **45,05**; 1-ethyl-1-methyl cyclopentane: **42,08**; α –pinene: **41,43**; 3-methyl hexane: **38,76;** dioxane: **32,51;** nonanal**:** **31,26**; 2-phenoxyethanol: **1,19**
Duplicate sample from the 2nd floor in nearby vicinity, as sample above after 8 days of normal ventilation	1009	toluene: **187,3**; heptane: **128,0**; hexanal: **53,0**; propanoic acid, 2-methyl-2-ethyl-1-propyl-1,3-propanediyl ester: **47,07**; nonanal: **35,29**; 3-methyl hexane: **27,77**; 1-ethyl-1-methyl cyclopentane: **26,62**; dioxane: **23,15**; β-pinene: **22,52;** 2-phenoxyethanol: **0,90**

After 15 days of ventilation: 7 days normal ventilation and 8 days of blow heating**	446	hexanal: **29,45**; propanoic acid, 2-methyl,2-ethyl-1-propyl-1,3-propanediyl ester: **23,76**; α –pinene: **23,43**; β-pinene: **22,96**; nonanal: **22,07**; ethylacetate: **10,94**; toluene: **4,56**; 2-phenoxyethanol: **0,93**
After 30 days of ventilation: 7 days normal ventilation and 8 days of blow heating followed by 15 days of blow heating at high humidity***	145,13	propanoic acid, 2-methyl,2-ethyl-1-propyl-1,3-propanediyl ester **11,74**; nonanal: **8,36**; 2-pyrrolidinone,1-methyl: **8,00**; xylene: **5,55**; hexanal: **3,49**; benzaldehyde: **1,84**; 2-phenoxyethanol: **0,24**

***ventilation by opening doors and windows a few times per day**
****Blow heater at ambient temperature of 35-40°C**
*****Blow heater at ambient temperature of 35-40°C and RH at 60-70%**

Table 4: VOC results of the Indoor Air near the living room, ground floor, under different conditions

Sample nomenclature	**TVOC (µg tol.ekv/m³)**	**Concentration of main components (µg tol.ekv/m³)**
Under normal living conditions	208,3	limonene: **22,7**; 2-phenoxyethanol: **9,94**; xylene: **9,28**; nonanal: **9,06;** α –pinene: **8,10**; propanoic acid, 2-methyl-2-ethyl-1-propyl-1,3-propanediyl ester: **7,98**; hexanal: **6,80**; β-pinene: **6,80;** ethylacetate: **2,70**
After removal of parquet from the ground floor and after 7 days of normal ventilation	668,1	toluene: **128,6**; heptane: **59,6**; propanoic acid, 2-methyl-2-ethyl-1-propyl-1,3-propanediyl ester: **24,4**; hexanal: **21.87**; β-pinene: **14,73;** 3-methyl hexane: **13,92**; 1-ethyl-1-methyl cyclopentane: **13,53**; α –pinene: **12,22;** 2-phenoxyethanol**: 1,35**
After 15 days of ventilation. 7 days normal ventilation and 8 days of blow heating	407	hexanal: **27,50**; α –pinene: **20,40;** β-pinene: **19,77**; propanoic acid, 2-methyl,2-ethyl-1-propyl-1,3-propanediyl ester: **17,30**; nonanal: **11,08**; ethylacetate: **7,44**; toluene: **4,73**; 2-phenoxyethanol: **0,99**
After 30 days of ventilation: 7 days normal ventilation and 8 days of blow heatingfollowed by 15 days of of blow heating at high humidity	121,99	nonanal: **8,43**; propanoic acid, 2-methyl,2-ethyl-1-propyl-1,3-propanediyl ester: **4,53**; hexanal **3,88**; benzaldehyde **1,59;** 2-phenoxyethanol: **0,21**

Table 5: Aldehyde concentrations at the 2nd floor near infants' room

Aldehydes ng/m^3	2nd floor			
	Under normal living conditions	After removal of the parquet	After 7 days normal ventilation 7 days forced ventilation	After 30 days of ventilation: 7 days normal ventilation and 8 days hot blowers followed by 15 days of hot blower at high humidity
Formaldehyde	46,91	43,74	39,35	11,07
Acetaldehyde	20,10	32,44	19,99	2,20
Hexaldehyde	34,15	30,42	17,05	4,42
Benzaldehyde	7,56	5,48	4,48	-
Valeraldehyde	4,84	6,01	3,82	-
Metacrolein	3,49	2,94	1,09	-
2-butanone	-	-	-	-

Table 6: Aldehyde concentrations on the ground floor in the living-room

Aldehydes ng/m^3	Living-room			
	Under normal living conditions	After removal of the parquet	After 7 days normal ventilation 7 days forced ventilation	After 30 days of ventilation: 7 days normal ventilation and 8 days hot blowers followed by 15 days of hot blower at high humidity
Formaldehyde	46,96	35,70	34,23	13,57
Acetaldehyde	17,88	16,07	16,98	2,18
Hexaldehyde	25,80	21,04	20,50	3,01
Benzaldehyde	5,74	3,08	2,23	-
Valeraldehyde	6,20	4,27	2,64	-
Metacrolein	6,49	2,68	1,91	-
2-butanone	2,10	0,69		-