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The effect of ventilation on the indoor air concentration of PCB: An intervention study

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ABSTRACT

The impact of increased ventilation on polychlorinated biphenyl (PCB) air concentration by installation of mechanical balanced ventilation units was studied. The intervention was carried out in three PCB-contaminated rooms; one classroom in an elementary school and two small bedrooms in an apartment in a residential building. In the classroom, the air exchange rate (ACH) was raised from 0.2 (without mechanical ventilation) to 5.5 h^{-1} during the intervention. In the two bedrooms, the highest ACH was 6.6 h^{-1} and 0.5 h^{-1} without mechanical ventilation. The corresponding concentration decrease achieved from the intervention was 30% and in one of the bedrooms 45%. Emissions of PCB rose dramatically during periods of increased ventilation as the drop in concentration did not match the increased ACH. When ventilation in the bedrooms was increased incrementally from 0.5 to 2.2, 4.5, and 6.6 h^{-1}, emissions were found to increase linearly with increasing ACH. Compared with the sparse literature regarding estimated reductions due to ventilation, the measured effect on concentrations was less than expected.

1. Introduction

Polychlorinated Biphenyls (PCBs) were used as plasticisers in construction products from 1950, until their use was phased out in many countries during the 1970s and early 1980s [1]. Possible sources of indoor PCBs include caulks, transformers, fluorescent light ballasts, ceiling tiles [2,3]. The indoor air of buildings with PCB-containing materials might be contaminated to a considerable degree [2,4].

Exposure to PCBs is known to cause adverse immunological, reproductive, and dermatological effects. PCBs increase the risk of obesity and type-2 diabetes and affect the cardiac system [5–7]. PCBs are observed to affect the neuropsychological function and to cause poorer cognitive development [8,9]. Furthermore in 2013 all PCBs were categorised as *Group 1* carcinogenic to humans by the International Agency for Research on Cancer *IARC* [10].

According to the *Danish Health and Medicines Authority* (DHMA), air concentrations of PCB_{total} above 300 ng/m^3 might pose a health risk. This air concentration is set as a guiding action level in Denmark. DHMA suggest interventions reducing concentration below this action level. PCB_{total} is defined as 5 multiplied by the sum of the 7 indicator congeners PCB-28, PCB-52, PCB-101, PCB-118, PCB-138, PCB-153, and PCB-180 [11]. The Danish guideline action level and calculation of PCB_{total} are based on German recommendations, based on assessments of the Tolerable Daily Intake (TDI) [12].

Few reports are available regarding the effect of ventilation on the indoor air concentration of PCB and conclusions vary. In an elementary school in Massachusetts, different selected engineering controls were implemented to lower PCB indoor air concentrations. Increased ventilation, being one of the mitigation methods, significantly lowered the PCB concentration from 423 to 173 ng/m^3 (room mean values). Unfortunately, the particular air exchange rate (ACH) is not available for the respective rooms nor is the effect of ventilation on a highly contaminated room [13].

In Lyng et al. 2014 [14], the effect of ventilation is given for a compilation of 26 case rooms in 8 different buildings with air measurements of PCB concentrations respectively with and without mechanical ventilation turned on. In these cases, the effect of ventilation resulted in a mean decrease of about 51% of the air concentration. However, the effect varied greatly between the

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different case buildings: between a 100% decrease and an increase of 83% of the concentration. Differences in the effectiveness of the ventilation are assumed to be caused by differences in source strengths, e.g. concentration, surface area, and location as well as type of ventilation. The ACH was unknown in most case rooms.

PCBs are categorised as Semivolatile Organic Compounds (SVOCs), which are known to redistribute from the originally introduced SVOC containing building material (primary sources) to all indoor surfaces (secondary sources). Further, the SVOCs have the property of being adsorbed or emitted depending on the surrounding concentration in the air. PCB can also migrate from primary sources to adjacent material (secondary sources) [15]. Therefore, remediation of SVOCs is problematic since simple removal of the original source is often insufficient [16]. Ventilation can dilute the concentration of indoor contaminants, if emissions of the contaminants are constant and independent of ventilation. In the case of PCBs (SVOCs) transport mechanisms depend on a range of factors like source/sink capacity and their concentrations, air concentrations, presence of airborne particles, ventilation, indoor and outdoor temperatures [4,16,17].

Liu et al. (2014) [18] made a mass balance model describing the fate of SVOCs (e.g. PCBs) in indoor air of a model room with highly contaminated flooring. The model includes factors like emission, sinks, ACH, and particle dynamics. The model estimates a 60% decrease in air concentration by a tripled air exchange rate from 0.6 to 1.8 h^{-1} for SVOCs with log K_{OA} (octanol/air partition coefficient) between 9 and 13. Log K_{OA} for the 7 PCB indicator congeners ranges from 8 to 11.3 (SPARC online calculator [19]). Thomas et al. (2012) [20] estimated a halving of the room air concentration at every doubling of the air exchange rate from 0.5 to 4 h^{-1}. The calculations in this model are based on emissions from caulks solely.

The purpose of the present intervention study was to determine the effect of ventilation on PCB levels in air. In this study, three highly contaminated rooms were investigated and the concentrations of PCB in the air as well as ACHs were measured. In one classroom the test conducted was with and without mechanical ventilation. The effect of four different ACHs was investigated in two bedrooms.

2. Materials and methods

2.1. Design

The effect of the ventilation was measured at two different locations: in one elementary school classroom and in two identical bedrooms in one apartment.

For the classroom, the measurements were carried out between February and November 2012. During the entire period, the existing ventilation system was turned off and inlets and outlets were sealed with plastic and duct tape from inside the room. The intervention consisted of installing; two compact *Air Handling Units* (AHU) (Duplex 370 EC4, with a max capacity of supply and extract air of 390 m^3/h, Atrea® s.r.o., Jablonec nad Nisou, CZ) with heat recovery and an electrical heating element. Inlets and outlets to and from the room were created by replacing two casement windows with wooden boards mounted with exhaust and inlet ducts. The two AHUs ensured a constant air supply and exhaust and increased the air exchange rate in the classroom during the intervention period. The intervention lasted two months from 25 April to 26 June 2012.

In the apartment, the two small bedrooms were each ventilated by one AHU (Duplex 370 EC4, Atrea® s.r.o., Jablonec nad Nisou, CZ) similar AHU as described above. The AHC was kept at four different levels for a period of one week each. The operation was balanced so that differential pressure was kept at a minimal by an equal amount of supply and exhaust air for all four ACHs. The measuring and intervention period lasted from 22 January to 4 July 2013.

2.2. Building and room characteristics

The elementary school located in Hundested, Denmark, consist of seven school buildings (Table 1). Block 6 was originally constructed with PCB caulks (primary sources) in the facade i.a. around window frames and between interior concrete wall elements. The length of the PCB caulks was measured to be 35 m; width and mass of the caulk are unknown. The classroom had west-facing wooden-framed windows, walls covered with painted sack cloth wallpaper, linoleum floor, and metal-suspended ceiling tiles.

The apartment building is located in Farum, Denmark and forms part of a large building complex, *Farum Midtpunkt*. The building of the investigated Apartment 427A was built with PCB caulks (primary sources) around interior doors and parts of the window facade. Around the door of each small bedroom, the PCB caulk in linear length was measured to be 5 m, with a width of 1.4 cm, mass of caulk was unknown. Presence and possible amount of PCB caulks near the window and balcony door were unknown. Both bedrooms had a small west-facing fixed-casing window with wooden frame and a single balcony door, painted concrete walls, ceilings, and wooden block floors.

During the measurement period, none of the two buildings was in use and the rooms investigated had no furniture. Doors were kept closed, although unintentional transfer of air between rooms may occur. In a previous attempt to reduce PCB emission from the primary sources, all visual PCB caulks as well as some centimetres of the highly contaminated adjoining materials were encapsulated by aluminium foil and covered by wooden panels. In the classroom, the encapsulation was done one year prior to the intervention, and for the bedrooms, the encapsulation was 3 years and 6 months earlier than the intervention. All other contaminated surfaces were accessible and emissions of PCBs in the study derived from these surfaces with contamination accumulated over the years. The heating system was in operation during the measurement periods.

2.3. Indoor PCB levels

Sampling of air was done actively using pumps (type: GilAir 5, Sensidyne, St. Petersburg, FL, US) with a flow of 1.9 L min^{-1} ± 10%. The pumps were connected to sampling tubes of the type SKC 226-58 with quartz filter, two zones of XAD-2 and PUF (SKC Inc., Eighty Four, PA, US) fitted with small PTFE nozzles giving an inlet velocity of 1.25 m/s. No pre-filters were mounted, thus suspended dust was included in the sample. Sampling tubes were placed horizontally 1 m above the floor. In the classroom, air samples were taken before, during and after the intervention. Sampling of air was done 54 and 23 days before and 2, 13, 50 and 134 days after the intervention. During the intervention air samples were taken on days 1, 2, 4, 8, 16, 31, 38 and 62. Measurements of concentration were made as duplicate determination (at a distance of 2 m) for all but one of the sampling days, resulting in $n = 16$ samples during the intervention and $n = 11$ samples without mechanical ventilation. The duration of sampling was 21–47 h resulting in sample volumes of 2.4–5.5 m^3;. For the two bedrooms, air was sampled before and after the entire intervention and on days 1, 2 and 7 of the changed ACH. Since measurements were taken three times for each of the four ACH in both bedrooms, the total number of samples were $n = 24$. The duration of sampling was approx. 24 h (22.7–25.6 h) resulting in a mean sample volume of 2.9 m^3 (range: 2.7–3.2 m^3). The first day of sampling (day 1) was in all cases initiated less than two hours after ventilation was turned on or changed. Air samples