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Organochlorine pesticides in the indoor air of a theatre and museum in the Czech Republic: Inhalation exposure and cancer risk

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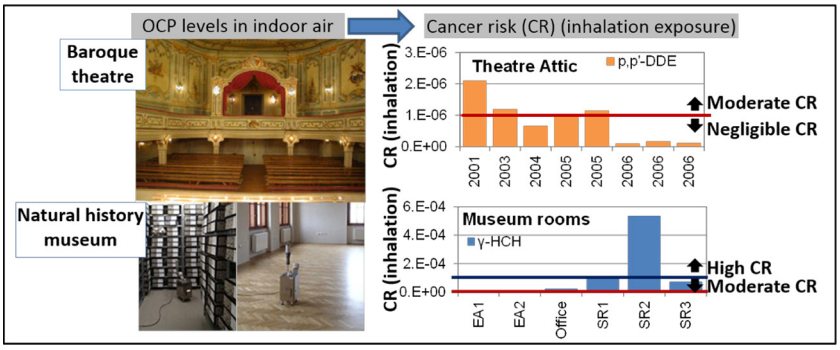
HIGHLIGHTS

- Indoor air in buildings of cultural and historical importance had high OCP levels
- Cancer risk (CR) from inhalation exposure to OCPs determined for workers
- CR from DDE exposure reduced by orders of magnitude after theatre restoration
- CR for museum workers from γ-HCH exposure were significant as to require mitigation
- Museum worker CR was reduced, but still moderate where γ-HCH granules were removed

GRAPHICAL ABSTRACT



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ABSTRACT

Organochlorine pesticides (OCPs) have been used to preserve the integrity of historical buildings or to protect collections of artefacts at potentially large volumes and often without detailed application records. Previous research has focused on the efficiency of remediation at contaminated sites (where identified), as well as improvement of preservation techniques and workplace health and safety. Few studies have assessed the human health risks from occupational exposure to OCPs in buildings of cultural and historical importance. Thus, potential risks may remain unidentified. In the present study, OCPs in indoor air were measured in a baroque theatre and a natural history museum in the Czech Republic, both of which had suspected past indoor application. In the theatre attic *p,p′*-dichlorodiphenyldichloroethylene (*p,p′*-DDE) levels in air were up to 190 ng m^{-3}, confirming past indoor use of *p,p′*-dichlorodiphenyltrichloroethane (*p,p′*-DDT). There was also evidence of γ-hexachlorocyclohexane (γ-HCH) use in the theatre (max γ-HCH in air of 56 ng m^{-3}). Yet, the cancer risk (CR) from occupational exposure via inhalation (Exp_i) to OCPs in the theatre was low ($CR < 4.0 \times 10^{-6}$). γ-HCH was found at elevated levels in air of the museum (max γ-HCH in air of 15,000 ng m^{-3}). CR from Exp_i in the museum was moderate to high ($>1 \times 10^{-4}$). Our results show the CR through Exp_i to OCPs in buildings, such as museums can still be significant enough to warrant mitigation measures, e.g., remediation.

1. Introduction

Inorganic and organic pesticides are regularly used as a protectant for wood used in building materials, e.g., impregnated into wood or used as a coating for wooden building materials (Unger et al., 2001). In the past, these wood protectant pesticides included organochlorine pesticides (OCPs) (e.g., γ-hexachlorocyclohexane (γ-HCH)), pentachlorophenol, dichlorodiphenyltrichloroethane (DDT) (Unger et al., 2001), most of which have since been replaced by other pesticides (e.g., synthetic pyrethroids) (Unger et al., 2001). The use of pesticides was also common practice amongst collectors of artefacts, biological specimens,

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etc. to prevent damage from pests, such as insects or fungi (Palmer et al., 2003; Unger et al., 2001). A range of pesticides has been detected in artefacts or significant artistic, cultural, historical, or scientific objects, as well as in the buildings (e.g., museums, herbariums) that store such items (Fellowes et al., 2011; Goldberg, 1996; Marcotte et al., 2014; Musshoff et al., 2010; Palmer et al., 2003; Schieweck et al., 2007). However, records of past pesticide application to protect collections from insects and other pests are often limited (Goldberg, 1996; Schieweck et al., 2007). For example, in Germany use of organic and inorganic pesticides in museum collections was largely undocumented or poorly documented prior to the 1970s (Schieweck et al., 2007). Some of the knowledge of the pesticides used is incidental, obtained through word-of-mouth; and the type of pesticides used varied according to the type of collection, efficacy of the pesticide, as well as human health and safety (Goldberg, 1996; Schieweck et al., 2007). Determination of pesticide use in artefacts or for the treatment of wooden building materials is therefore difficult.

Levels of pesticides in museum objects can be high due to repeated application (Wörle et al., 2012). In one case, objects shown in a museum were so heavily treated with DDT they emitted a strong odour, and decontamination methods for the artefacts was sought so they were safer to display (Wörle et al., 2012). Yet, evaluation of health outcomes from exposure to pesticides through indoor air in buildings housing important artefacts is rare, despite the potential for serious health effects. In the past, pesticides were applied by museum staff and hence exposure to the pesticides may have occurred during application, leading to acute effects such as nausea (Musshoff et al., 2010). Museum staff may also be exposed to the pesticides during their everyday work, which may include handling or cleaning contaminated objects (Glastrup, 2000; Marcotte et al., 2014; Musshoff et al., 2010; Schieweck et al., 2007).

Dermal uptake and ingestion through handling contaminated objects or contact with contaminated dust, as well as inhalation of particle-associated or volatile compounds are expected exposure routes in indoor environments such as museums (Covaci et al., 2006; Glastrup, 2000; Purewal, 2000; Schieweck et al., 2007). Exposure via dermal uptake or inhalation of particles or gas-phase compounds may also occur from museum artefacts used for ceremonial purposes (Palmer et al., 2003). Marcotte et al. (2014) assessed the daily inhalation and ingestion exposure in The Natural History Museum of Rouen, and neither exposure pathway was found to be significant in the short-term (i.e., inhalation and ingestion exposures were orders of magnitude less than occupational guidelines and permissible uptake limits, respectively). However, to date no other studies have assessed multiple exposure pathways (dermal uptake, inhalation and ingestion) to OCPs for workers or visitors in museums, or in historical buildings where people may work or visit, such as theatres or castles. In addition, long-term exposure in these indoor environments has been neglected. Therefore, the relative importance of these different exposure pathways in such environments is unknown.

The main objective of the present study was to assess potential risks related to pesticide exposure via inhalation exposure in a largely unexplored occupational setting in the Czech Republic – buildings of cultural and historical importance, specifically a theatre and a museum. In the Czech Republic, OCPs were used extensively in agriculture in the past and their volatilization from secondary sources such as contaminated soils into the ambient air has been well documented (Beránek and Havel, 2006; Beránek and Petrlík, 2005; Dvorska et al., 2008; Holoubek et al., 2007). Technical HCH (mixture of HCH isomers) and γ-HCH (also known as lindane) were also used for wood treatment (Beránek and Havel, 2006), which may be a source of this compound in indoor air (Kohoutek et al., 2005). Formulations such as Pentalidol (containing 2% DDT but also 5% pentachlorophenol (PCP) and 0.1% γ-HCH) were produced and used in the former Czechoslovakia for the treatment of different kinds of wood, construction material, furniture, floors and roofs against insects, fungi and mold in the late 1970s and early 1980s (Beránek and Havel, 2006; Kohoutek et al., 2005). Yet, there is no information available in the published literature on the use of OCPs in historical buildings of cultural significance or in museum collections in the Czech Republic. This is despite evidence of OCP use and residues in museum air and artefacts in other regions (Fellowes et al., 2011; Goldberg, 1996; Marcotte et al., 2014; Musshoff et al., 2010; Palmer et al., 2003; Schieweck et al., 2007).

We have investigated the levels of selected organochlorine pesticides (*p,p′*-DDT and its metabolites *p,p′*-dichlorodiphenyldichloroethylene (*p,p′*-DDE) and *p,p′*-dichlorodiphenyltrichloroethane (*p,p′*-DDD) and HCH isomers γ-, α- β- and δ-HCH), as well as industrial chemicals (hexachlorobenzene (HCB) and pentachlorobenzene (PeCB)) in a baroque theatre and a natural history museum. In the theatre, OCPs were used for preservation of the wooden structure of the building itself, and in the museum they were applied to protect historical collections. Air quality data were used to estimate occupational inhalation exposure and risk to the health (i.e., cancer risk (CR)) of workers at the baroque theatre and at the museum.

2. Methods

2.1. Sampling sites

2.1.1. Baroque theatre, Český Krumlov

Air sampling sites were located in the stage area and attic of the theatre (see Fig. S1). The site history is described in detail in Kohoutek et al. (2006, 2005). In brief, in the 1950s, wooden materials in the theatre were affected by dry rot and between 1966 and 1997, the theatre was closed to public due to restorations. During this time various fungicides, insecticides and conservation treatments were applied, but the type of pesticide used, the application volume, frequency, and technique was not well documented. Pentalidol (2% DDT; 5% PCP and 0.1% γ-HCH) use was documented since 1980, but this pesticide was most likely used earlier at the site; and Pentalidol use was restricted in 1983. It is suspected that pesticide application occurred on dusty surfaces in the theatre thus creating a large volume of heavily polluted mobile particles, which resulted in contamination of the theatre with a complex mixture of chemicals. In the early 1990s, there were reports of eye, membrane and skin irritation from people who had spent time in the theatre. Consequently, ~5 t of contaminated material, including contaminated dust, was removed from the theatre but acute health issues were still being reported when visitors returned. A sampling campaign occurred in summer 2001 to isolate contamination sources. Consequently, wooden floors, tarred cardboard and insulation were removed from the attic between 2002 and 2003, and the attic floor was covered with plastic to prevent particles from penetrating into the auditorium of the theatre. In summer 2003, wooden beams in the attic were tested to determine whether the white surface layers required removal. Trials carried out in spring 2006 showed the most appropriate procedure to remove the whitish surface layer of the timber, and reduce contamination, was dry planing and subsequent sanding of corners and other hard-to-access places. Planing and sanding was coupled with a high quality exhaust system to capture and collect dust. Dry planing allowed for the preservation of the authentic shape of the original material. However, this remediation was never completed. Results of building material and air sampling discussed below span from 2001, when acute health issues from past pesticide use were apparent, to 2006, a few years after site restoration and remediation trials. No further analysis of air or building materials occurred in the theatre since 2006. Given the persistent nature of the OCPs analyzed in the present study, as well as the fact that no further building works or site remediation have occurred in the theatre, it is expected that levels of OCPs are still high in indoor air.

2.1.2. Museum of South Bohemia, České Budějovice

The Museum of South Bohemia, located in České Budějovice, is an important historical building, part of which had been subject to interior