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Environmental assessments on schools located on or near former industrial facilities: Feedback on attenuation factors for the prediction of indoor air quality

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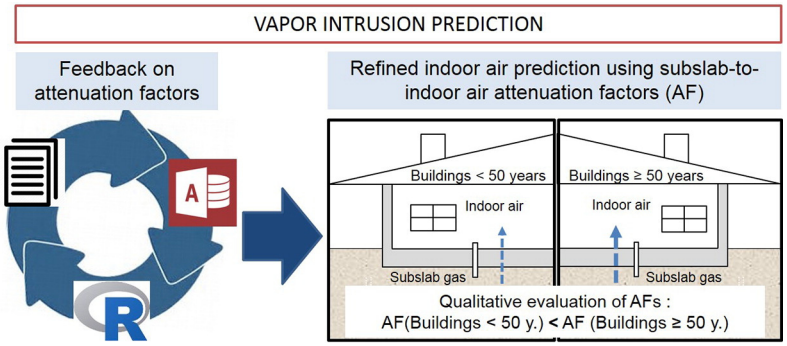
HIGHLIGHTS

- Refined attenuation factors (AFs) based on feedback can improve site-specific VI assessments.
- Halogenated organic compounds are tracers for calculating AFs in schools.
- Qualitative estimation of AFs shows lower AF values for buildings less than 50 yr. than for buildings50 yr. old and above.
- The use of AFs is recommended to manage contaminated soils off-sites facing vapor intrusion issues in France.

GRAPHICAL ABSTRACT



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ABSTRACT

One of the goals of the French national campaign called "Etablissements Sensibles (Sensitive Establishments)" is to evaluate indoor air degradation in schools because of vapor intrusion of volatile compounds from soil gases towards the indoor air, related to the presence of former industrial sites on or near the establishment. During this campaign, as recommended by the United States of Environmental Protection Agency (US EPA), indoor air quality was evaluated from soil gas concentrations using generic attenuation factors, and extra investigations into soil gases and indoor air were performed when the estimated values exceeded target indoor air concentrations. This study exploits matched data on subsurface soil gases and indoor air that came from the "Sensitive Establishments" campaign. It aims to consolidate and refine the use of attenuation factors as a function of environmental variables acquired routinely during environmental assessments. We have been able to select the measured environmental variables that have the most influence on vapor intrusion using Principal Components Analysis and hypotheses tests. Since the collected data are mainly related to weak sources (only 15% schools required risk management measures related to vapor intrusion), halogenated volatile organic compounds (HVOC) were selected as tracer compounds for vapor intrusion for this study. This choice enables the exclusion or minimization of background sources contributions.

From the results we have calculated the descriptive statistics of the attenuation factors distribution for the subslab-to-indoor air pathway and refined the attenuation factors for this pathway through an easily obtained parameter, building age. Qualitative comparison of attenuation factors according to the building age shows that attenuation factors observed for building less than 50 years are lower than attenuation factors for buildings

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50 years old and above. These results show the utility of creating databases for consolidating and refining attenuation factors and therefore improving their use.

1. Introduction

In France indoor air quality in residences and schools has been evaluated in national campaigns, outside any contaminated land issue, by the "Observatoire de la Qualité de l'Air Intérieur" [OQAI, the Observatory for Interior Air Quality] (Canha et al., 2016; Langer et al., 2016; Raffy et al., 2017). However the quality of a building's indoor air can also be degraded because of the presence of volatile pollutants in the subsurface. In unsaturated zone near the building, the main vapor intrusion mechanisms are advection of the air and gaseous diffusion through building foundations (concrete slab). Preferential pathways (elevator cages, piping, cracks in concrete slabs) may boost vapor intrusion into the buildings (McHugh et al., 2017a). In contrast, barriers to vapor intrusion may also exist (clay saturated with water, ventilated crawl spaces, building with positive pressure) (McHugh et al., 2017b). It is challenging to prove or predict this type of phenomenon by field measurements or modelling due to these various elements and the sensitivity of vapor intrusion to many environmental parameters related to soils, buildings and climactic conditions. This active research subject is being widely studied (Guo et al., 2015; Holton et al., 2015; Johnston and Gibson, 2013; McHugh et al., 2017b; NESDI, 2015; Pennell et al., 2016; Reichman et al., 2017; Shen and Suuberg, 2016; Soucy and Mumford, 2017; Yao et al., 2015a; Yao et al., 2015b). As well as research projects, the work of the United States of Environmental Protection Agency (US EPA) has led to the publication of a guide to evaluating vapor intrusion. As part of a global case by case analysis, this guide recommends the use of attenuation factors as one decision-making tool among others for continuing complementary investigations (US EPA, 2015a). The attenuation factors recommended in this guide have been determined by statistical analysis of a database developed by the US EPA.

The attenuation factor (AF) is a non-dimensional parameter defined as the ratio between the concentration of a compound in indoor air and its concentration in subsurface soil gases at the interface with the source or at a given depth under the building's foundations (Johnson et al., 2009). This factor may also be defined by calculating the ratio of concentrations in different building compartments. The most frequently encountered pathway for calculating attenuation factors is measuring subslab soil gases together with indoor air.

This study shows the experiences of the French national campaign called "Etablissements Sensibles (Sensitive Establishments)" that began in 2010 and is still underway. The goal of this campaign is to check the quality of media above schools located on or near former industrial sites in France. One of the media that was part of this national campaign is indoor air in schools. To evaluate possible degradation of indoor air because of the presence of polluted soils, setting aside the presence of volatile compounds in indoor air from the building itself (adhesives, cleaning products, etc.) or from the surrounding environment (road traffic, etc.), samples of soil gases are preferred at first over direct sampling of indoor air. By using the attenuation factor we can then estimate the indoor air quality from soil gas concentrations measured as close as possible to the place of exposure. The choice of attenuation factors used mainly lies on feedback from the US EPA's experiences (US EPA, 2004, 2008, 2011, 2012, 2015a, 2015b) and from the Johnson-Ettinger (1991) model. The purpose of this study is to consolidate the use of attenuation factors in France and to refine this by means of specific environmental variables at sites collected during the environmental assessments.

2. Materials and methods

2.1. Data sources and databases

Feedback on attenuation factors is supported by the design, development and implementation of a specific database using Access®. The data comes from environmental assessments made using the "Sensitive Establishments" campaign between 2012 and 2016 in nine regions in France. All of the data comes from active sampling (tubes) of subsurface soil gases or indoor air and subsequent chemical analysis of volatile organic compounds (VOCs) listed during the assessments of historical site activities (a total of 38 compounds). Homogeneity was ensured in sampling and analysis protocols throughout the campaign by standardized technical method development and onsite controls. Paired data were established with relevant proximity of subsurface soil gas and indoor air sampling locations to calculate attenuation factors. This study focuses on two most frequent pairings: subslab or 1-m deep soil gas to indoor air concentrations, although other pairings such as crawl space to indoor air or basement air to first floor were also entered into the database. At this time the database includes data on environmental assessments at 51 schools. From these investigated schools, 15% of the schools required risk management measures that did not necessarily affected the whole schools but most often a few classrooms. The dataset includes mostly schools with weak sources. Therefore, vapor intrusion assessment will require the identification of tracer compounds, to minimize background sources contributions. From the database we can calculate the concentrations ratios associated with each of the 38 compounds, giving a total of 5042 calculated attenuation factors (Table 1). In the database we input environmental parameters such as outdoor temperature and pressure, slab thickness and building age.

2.2. Statistical analysis: methodology

Prior to statistical analysis of the database, we selected the paired measurements relevant for assessing vapor intrusion through three filters based on US EPA's baseline screens (US EPA, 2012). These three baseline filters are:

- a "source" filter (1)
  Removal of paired data when the lower location concentration (e.g. 1-m deep soil gas; subslab gas) is below the quantification limit, in order to exclude data not representative of vapor intrusion;
- a "secondary source" filter (2)
  Removal of paired data when the lower location concentration is below the upper location concentration, in order to exclude cases when indoor air is significantly influenced by secondary sources (adhesives, cleaning products, road traffic, etc.);
- a "data consistency" filter (3)
  Removal of paired data for paired samples with more than a four-day time lapse.

The US EPA applies two other filters: "indoor source" and "source strength" to screen out data affected by background sources:

- "Indoor Air Screen": screening out indoor air concentrations less than the 90th percentile of background levels or less than the quantification limit (if quantification limit is greater than the 90th percentile).