

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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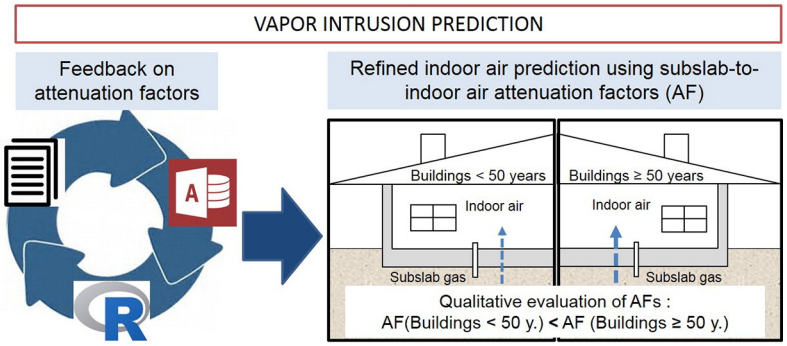
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HIGHLIGHTS

- 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.

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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).

Table 1
Data subsetting according to screening criteria.

Data filtering	No. of AFs	No. of schools	No. of towns	Work step	Comment on screening process
No filter: Raw dataset	5042	51	38	–	• Paired data (ratio of indoor air concentration and subslab or 1 m-deep soil gas concentration) provided by the "Sensitive Establishments" campaign between 2012 and 2016
- Baseline filters - Selected 8 compounds and 2 HC fractions - **All pathways**	698	50	37	Screening process	• Focus on data representative of VI. • Selection of the most frequent compounds
- Baseline filters - Selected 8 compounds and 2 HC fractions - **Subsurface-**to-indoor air pathways[a] - Slab thickness indicated[b]	398	38	33	PCA	• Focus on most frequent pathway. • Exclusion of paired data associated with incomplete information about environmental parameters.
- Baseline filters - **HVOC** selected[c] - **Subsurface-**to-indoor air pathways[a] - Slab thickness indicated[b]	114	28	26	Hypothesis tests	• Selection of tracer compounds screening out data affected by secondary sources.
- Baseline filters - **HVOC** selected[c] - **Subslab**-to-indoor air pathway[a]	102	26	24	Descriptive statistics calculation	• Exclusion of paired data related to 1-m deep soil gas to indoor air pathway.

[a] Subsurface-to-indoor air pathways include 1-m deep soil gas-to-indoor air and subslab gas-to-indoor air.
[b] Slab thickness is sometimes missing from reports of environmental assessments.
[c] HVOC are used as tracers to investigate vapor intrusion in schools.

- "Source Strength Screen": for subslab soil gas screening out source-strength concentrations < 50× of the 90th percentile of background levels.

However, Song et al. (2011) recommend screening out concentrations < 300× the 90th percentile of background level.

Due to the presence of mainly weak to very weak sources in schools, only the baseline filters were applied and a tracer choice approach was preferred to screen out data affected by background sources.

After applying these filters (Table 1), the statistical analysis shows the most frequent pathways and compounds. The most frequently paired data are subsurface soil gas (1-m deep soil gas and subslab) to indoor air pathways. The most frequent compounds are selected as having >30 attenuation factors each and <85% of indoor air concentrations below the quantification limit. Using these criteria, the following eight compounds and two hydrocarbon fractions were chosen:

- Ammonia
- BTEX: benzene, toluene, ethylbenzene, *m*,*p*-xylenes and *o*-xylene.
- Chlorinated solvents: 1,1,1-trichloroethane, trichloroethylene (TCE),
- HC fractions: C_8-C_{10} aliphatic hydrocarbons, C_8-C_{10} aromatic hydrocarbons.

Principal Components Analysis (PCA) was used for statistical analysis. This method allows possible correlations between the variables and the general data trends to be evaluated. It also allows the data from several quantitative variables to be structured and simplified, without preferring one variable to the detriment of another. Principal Components Analysis is an orthogonal linear transformation that transforms the data to a new coordinate system so that the greatest variance by any projection of the data comes to lie on the first coordinate (called the first principal component), the second greatest variance on the second coordinate, and so on. PCA returns a new basis which is a linear combination of the original basis that contain as much of the variance of the input data as possible.

Principal Components Analysis was conducted on seven variables recorded during the environmental assessments: building age, outdoor temperature, outdoor pressure, slab thickness, outdoor control concentration, 1-m deep soil gas or subslab concentration, concentration in indoor air. The batch of data formed for PCA statistical analysis includes 398 attenuation factors and good data distribution over France (Table 1, Fig. 1). PCA is used to determine which variables explain the greatest data variability. After this multivariate analysis, tracer compounds for vapor intrusion were chosen to minimize the bias shown by the secondary sources in calculating attenuation factors. As shown in the results (3.2), these are halogenated volatile organic compounds (HVOC). These tracer compounds are confirmed by the study of Canha et al. (2016) which looks into indoor air pollutants in nursery and school in France. This study shows that HVOC such as trichloroethylene and tetrachloroethylene are negligible and excluded from the statistical analysis. HOVCs are therefore relevant tracer compounds for vapor intrusion in French schools.

On the basis of the PCA results, the variables that correlate more with the main axis are discretized and the existence of significant differences between the groups formed is confirmed or overturned by running a hypothesis test (generalized Wilcoxon test) on the data restricted to HVOC (Table 1). To refine attenuation factors, we selected environmental variables that show significant attenuation factor differences.

In this study, descriptive statistics of attenuation factors distribution is determined for the general subslab-to-indoor air pathway and according to selected environmental variables for this pathway (Table 1). The batch of data formed to calculate the descriptive statistics for this pathway includes 102 attenuation factors and good data distribution over France (Table 1, Fig. 1).

Table 1 presents the characteristics of the database and how the batch of data changed after data selection.

2.3. Statistical analysis: tools

All of the statistical analyses used the R software, in particular because of its packages developed specifically to take account of values below the quantification limit (R Core Team (2016). The principal components were analyzed using the package "FactoMineR" (Le et al., 2008). Given that >30% of the data is below the quantification limit and that the data does not exhibit normal distribution (Shapiro-Wilk test for $p = .05$), the concentrations were transformed by ranking (Helsel, 2010a; Helsel, 2010b). The variable "attenuation factor" was not directly integrated into the PCA because it comes from the ratio of the concentration of soil gases to the concentration in indoor air and is therefore directly correlated with these variables. The generalized

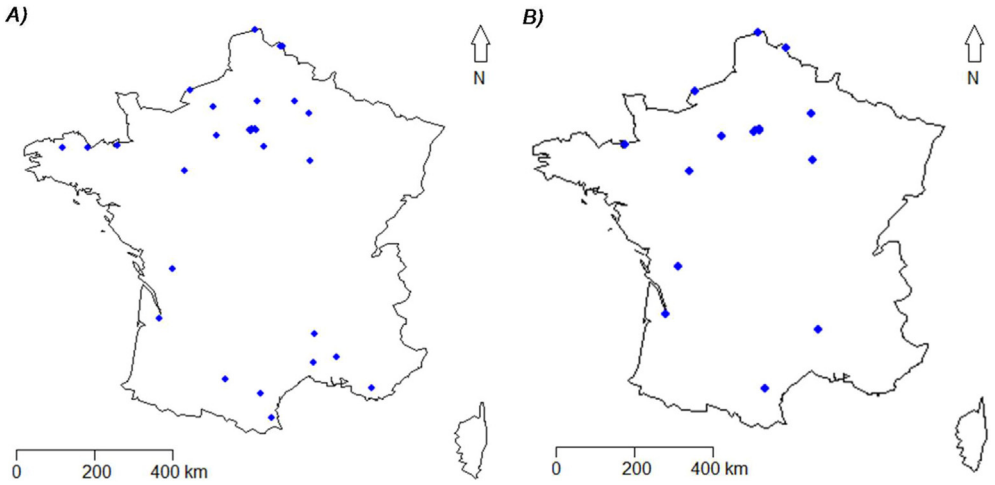


Fig. 1. Location of the dataset for PCA (A) and 95th percentile calculation (B).

Wilcoxon test used the cendiff function of the NADA package (Helsel, 2011). The percentiles are calculated by the Kaplan-Meier method (cenfit function - "NADA" package by R (Helsel, 2011; Lee, 2013)).

3. Results and discussion

3.1. Principal Components Analysis on subsurface to indoor air pathways

A Principal Components Analysis (Fig. 2) is run by gathering the most frequent paired subsurface soil gas (subslab and 1-m deep soil gas) to indoor air concentration data. This batch of data is restricted to cases where the slab thickness is included in the database (Table 1). This PCA allows us to evaluate quantitative variables that best explain variability in vapor intrusion phenomena. By applying the elbow method to the screetest, the first two principal components are selected for interpretation (Fig. 2).

The first two axes concentrate 52% of the total variability. Axis 1 represents 33% of the total variability. This axis is correlated with the variables "building age," "outdoor pressure," "slab thickness," and to a very small degree, with "outdoor temperature."

The substantial contribution of the environmental variables "building age," "outdoor pressure," and to a lesser extent "slab thickness" in the main axis is explained on the basis of knowledge of vapor intrusion (Pennell et al., 2016; US EPA, 2015a):

- As buildings age we may assume increased gas permeability and increased vapor intrusion by advection in cracks in addition to diffusion through the slab,
- Increased atmospheric pressure limits advection of soil gases to indoor air.
- Increased slab thickness limits the diffusion of soil gases towards indoor air through the concrete slab, yet the thickness does not tell us

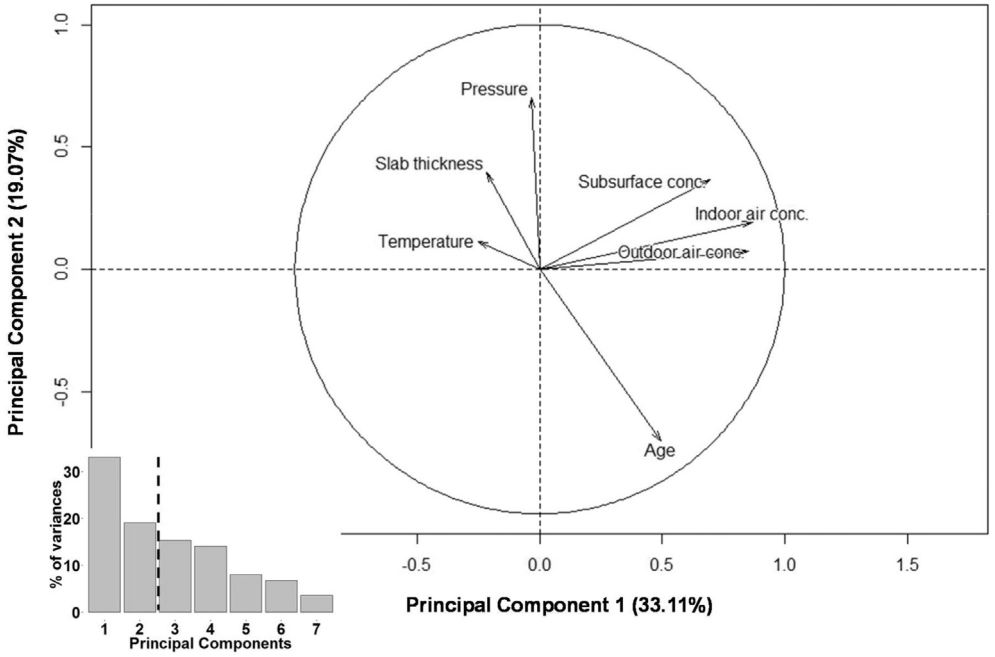


Fig. 2. Principal Components Analysis for all of the 8 compounds and 2 hydrocarbon fractions studied for paired subsurface to indoor air concentration data. Main graphic: representation of variables on the first two axes. Arrows represent the 7 environmental variable with the percentage of variance for each axis. Small graphic: screeplot - percentage of variance for each principal component.

about the gas permeability of the concrete slab or the presence of cracks in the slab.

The minor contribution of the environmental variable "outdoor temperature" may be explained by the fact that, the outdoor temperature integrates contrary phenomena, i.e. increased outdoor temperature correlated with increased compounds volatility – an effect that boosts vapor intrusion and with increased air renewal by opening windows – an effect that limits the impact of vapor intrusion (Langer et al., 2016). Furthermore reduced outdoor temperature is correlated with the stacking effect for indoor/outdoor heat differential – an effect that boosts vapor intrusion (Nicol, 2001). These contrary effects may explain the fact that the outdoor temperature correlates little with the first principal component.

Axis 2 represents 19% of the total variability. This axis is correlated with the volatile organic compound concentrations measured in the various media (subsurface, indoor air and outdoor air). The substantial correlation of the variable "outdoor concentration" with Axis 2 confirms the need to select tracer compounds for vapor intrusion that are free of secondary sources coming from indoor air or outdoor air (Kwon et al., 2016; MacNeill et al., 2016; Yao et al., 2015a).

3.2. Quality of media (Component 2) and choice of tracer compounds

The principal component 2 of the PCA (3.1) shows the possible influence of sources other than the compounds from subsurface soil gases on indoor air quality. In fact, there are confirmed secondary sources for compounds like BTEX (road traffic, paint and cleaning products) or HVOC (solvents, adhesives). The presence of these secondary sources artificially increases the attenuation factors calculated from the ratio of indoor air and subsurface soil gas concentrations. Directly correcting indoor air concentrations by subtracting the concentrations of the indoor and outdoor controls to set aside the influence of secondary indoor or outdoor sources is not always possible for the following reasons. There are few indoor controls in the environmental assessments because of the absence of stories, or if they were present, non-representative activity compared with the medium investigated, and therefore insufficient data for analysis in the database. Moreover, the concentrations of outdoor controls include 80% of data below the quantification limit. The correction of indoor air concentrations by the control values equal to the quantification limit would minimize the calculated attenuation factor and therefore would bias the vapor intrusion assessment. For these reasons, it is desirable to select tracer compounds for which the attenuation factor calculations are least biased and most representative of vapor intrusion.

Compounds with fewer secondary sources are identified as those that have less paired data:

- with quantification in indoor air in the absence of quantification for these compounds in subsurface soil gas or,
- with concentrations higher in indoor air than in subsurface soil gases.

Fig. 3 reports for all studied compounds the proportion of such paired data for tracer compound identification.

Among the eight compounds and the two hydrocarbon fractions studied, ammonia, BTEX and the two C8-C10 hydrocarbon fractions include between 22% and 49% of pairs of compounds that have been quantified in indoor air without being quantified in subsurface soil gases or that have indoor concentrations higher than subsurface soil gases concentrations (blue bars on Fig. 3). In contrast, the lowest frequencies for these configurations correspond to the HVOC studied (1,1,1-trichloroethane and trichloroethylene) with respectively 8% and 5%. These results are consistent with regulations on HVOC that prohibit or limit their uses to specific professional sectors and that are therefore not used in schools.

Since HVOC are compounds that include fewer possible secondary sources than BTEX or hydrocarbon fractions, they were selected as the tracer compounds and their attenuation factors are used to determine attenuation factors representative of vapor intrusion (Section 3.4).

3.3. Discretization of environmental variables (Component 1)

The attenuation factors are shown in Fig. 4 as a function of the environmental variables that correlate most with the principal component 1 of the PCA (Fig. 4-A to C) with an indication of whether concentrations in indoor air are lower or higher than the quantification limit (QL). Only data on HVOC are stored so that the analysis is not biased or is as little biased as possible by secondary sources within or outside the building (3.2). The continuous environmental variables are discretized so that we could calculate attenuation factor per category (Fig. 4-D to F). The discretization criteria per type of variable are as follows: (1) for building age, we chose the value of 50 years from reading the change in slope in Fig. 4-A; (2) for outdoor pressure, we chose the value of 1013 hPa as a limit between highs and lows; (3) for slab thickness, we chose the values of 10 and 20 cm thick by reading Fig. 4-C. The attenuation factors are shown as a function of environmental variables discretized using boxplots and scattergrams (Fig. 4-D to F).

We apply the generalized Wilcoxon test (Helsel, 2011) to validate the existence of significant differences between the attenuation factors grouped by discretized variable. This test applied to attenuation factors as a function of environmental variables showed that only the groups formed by the discretization of the "building age" variable were significantly different (p value $< .05$ of .03). The groups formed by the discretization of "outdoor pressure" and "slab thickness" variables were not significantly different ($p > .05$ of $p = .14$ and $p = .11$ respectively). These variables were not therefore selected for refining attenuation factors. In light of this, only the environmental variable "building age" was selected to refine these factors.

3.4. Descriptive statistics of subslab-to-indoor air attenuation factor distribution

A conservative determination of generic attenuation factors consists in selecting the 95th percentile (US EPA, 2012) of the distribution of empiric attenuation factors from the tracer compounds (i.e. HVOC) by using the Kaplan-Meier non-parametric method (Table 2). Because the 1-m deep soil gas to indoor air pathway had too few data (12 AF) and too much of the data was below the quantification limit (94%), we could not calculate low quantiles (Helsel, 2011). Therefore no descriptive statistics of attenuation factor distribution were calculated for this pathway. The subslab-to-indoor air pathway is the most frequently encountered pathway in the "Sensitive Establishments" campaign and also the most relevant for evaluating people's exposure to vapor intrusion above the building (Pennell et al., 2016). Descriptive statistics for the subslab-to-indoor air attenuation factor are shown in Table 2.

The environmental variable chosen for refining this factor was "building age." The attenuation factors were refined to form a contingency table depending on building age, discretized into two groups of over and under 50 years. Descriptive statistics for the refined attenuation factors are also shown in Table 2.

No generic attenuation factor was determined from the 95th percentile for the subslab-to-indoor air pathway since the latter would have been too conservative due to high censored data proportion (between 70 and 80%). However, qualitative comparison of attenuation factors according to the building age shows that attenuation factors observed for building < 50 years are lower than attenuation factors for buildings 50 years old and above (Table 2).

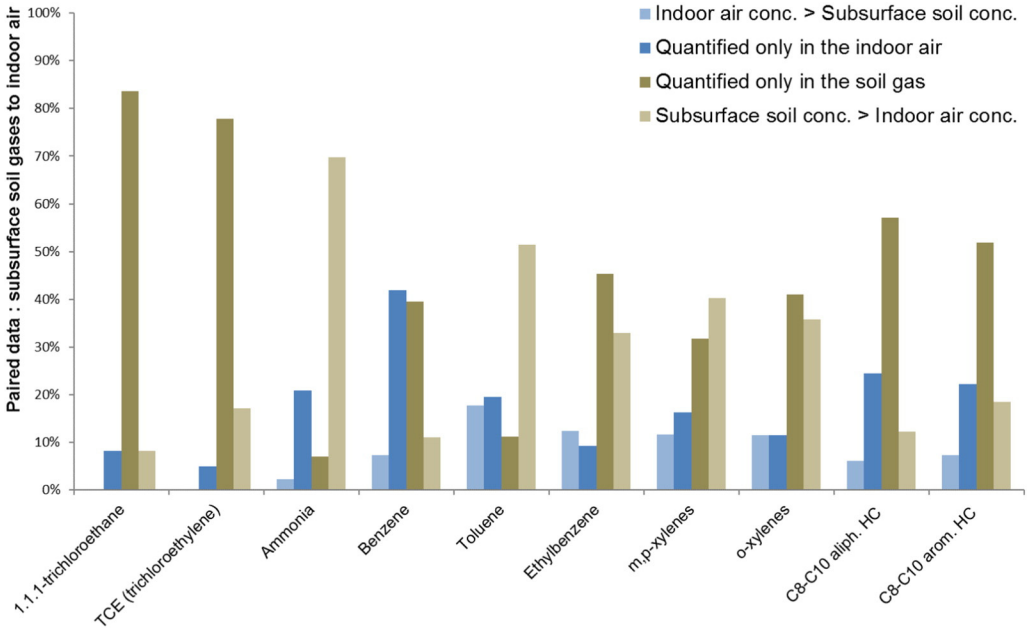


Fig. 3. Proportion of paired measurements per compound according to the concentrations and the quantification of compounds in subsurface soil gases and indoor air concentration.

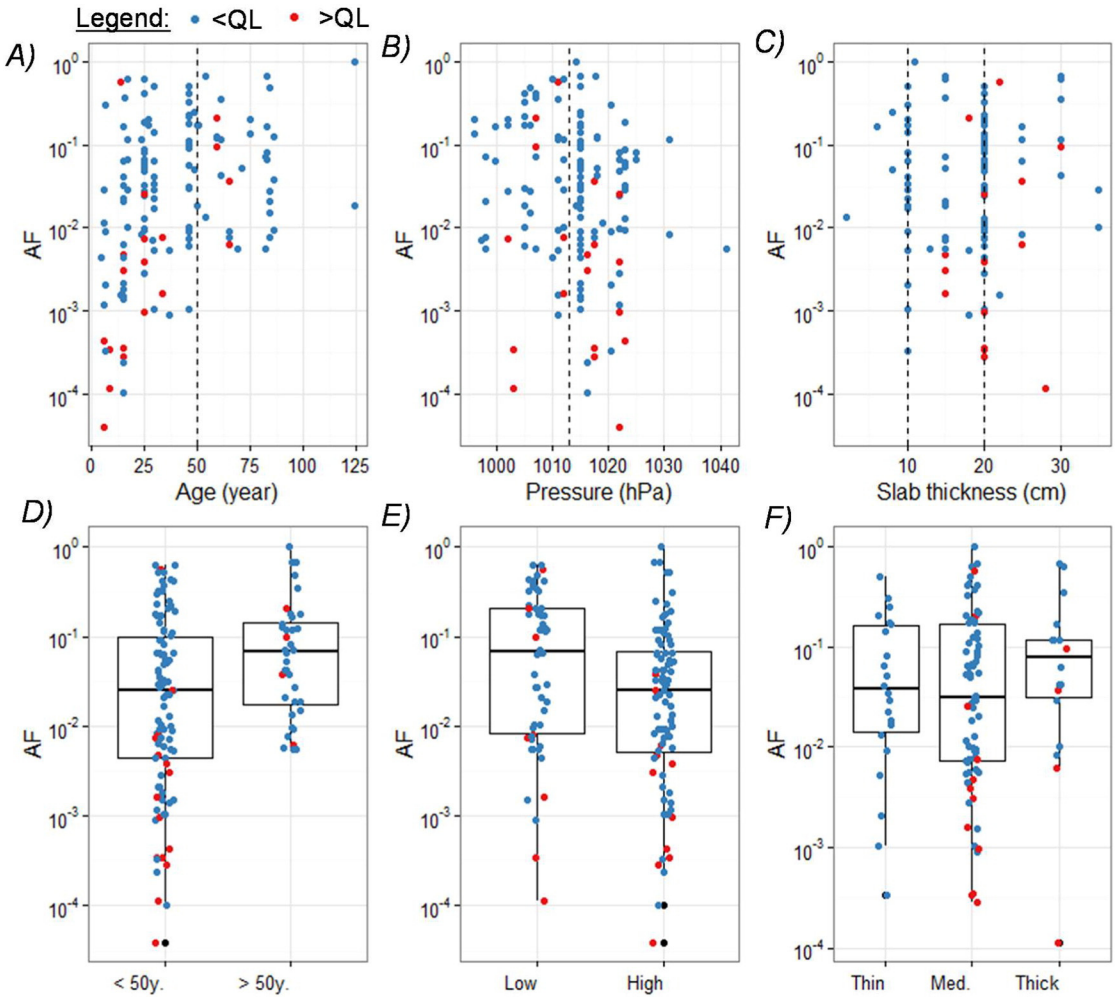


Fig. 4. Graphs (A to C) and boxplot/scattergram (D to F) for attenuation factors as a function of variables correlated with the principal component 1 of the PCA for HVOC.

Table 2
Values for subslab-to-indoor air attenuation factors.

Statistic	Subslab-to-indoor air pathway
Site number	26
Observation number	102
Observation number > QL	17
% < QL	83%
Attenuation factor (−)	
Median	0.0004
75th percentile	0.0039
90th percentile	0.0078
95th percentile	0.0369

Refining the subslab-to-indoor air attenuation factor

Statistic	Building age	
	<50 years	50 years and above
Site number	16	13
Observation number	70	32
Observation number > QL	13	4
% < QL	81%	88%
Attenuation factor (-)		
Median	0.0003	–
75th percentile	0.0035	0.006
90th percentile	0.0075	0.037
95th percentile	0.0078	0.097

3.5. Using generic attenuation factors

3.5.1. Methodology

The generic attenuation factors used to estimate the concentration of a volatile compound in indoor air from a measurement made in subsurface soil gas is one tool used among others to evaluate risks related to vapor intrusion. The strategy used for this evaluation is based on an approach using multiple lines of evidence (US EPA, 2015a) that produces a global and the most complete possible vision of the site to overlay on a conceptual scheme. In France, a similar approach has been developed in revising methodological texts for contaminated land management (Ministry for the Ecological and Inclusive Transition, 2017), which includes the use of attenuation factors among other tools (e.g. modelling) when there are doubts on the quality of the indoor air away from a contaminated site (e.g. residential areas near a polluted site). The choice of attenuation factors should be weighed with an understanding of the site on a case by case basis as also recommended by the US EPA (2015a).

3.5.2. Limits

The main limits related to the use of generic attenuation factors are as follows:

- The use of set values for attenuation factors may be debated particularly because they are too generic (Brewer et al., 2014). This study does however propose a modulation for attenuation factors according to a specific site parameter.
- Temporal and spatial variability in the vapor transfer phenomenon has not been widely studied in this database because there have only been one or two sampling campaigns per site and because of the lack of data on environmental parameters influencing gas transfers. Those parameters include concrete porosity, the building's air renewal rate, and the soil's permeability or organic material content (Cotel et al., 2015; Traverse et al., 2013). However, the statistical approach developed in this study based on a large amount of data spread over France partially compensates for this variability for calculating the generic attenuation factor (Yao et al., 2013).

This study based on a dataset with high censored data (around 80%) could not allow for a robust statistical determination of a generic attenuation factor. Indeed the present database contains mainly sites with weak sources and only 15% of them required risk management measures related to vapor intrusion. However, qualitative comparison of attenuation factors according to the building age shows that attenuation factors observed for building < 50 years old are lower than attenuation factors for buildings 50 years old and above. This suggests that a less conservative generic attenuation factor could be used for building < 50 years old.

3.5.3. Advantages

The use of attenuation factors however remains useful when the input parameters for the classic transfer models are not known or not characterized on the study site (Yao et al., 2015a). They prevent us from using unverified generic parameters from the classic transfer models.

By using attenuation factors we can quickly separate sites that pose no problems from those that require further investigation. Even conservative attenuation factors could be useful to screen out sites with no vapor intrusion issue. The refined attenuation factors are especially of interest being more site-specific and less conservative for recent buildings. Attenuation factors are not a direct evaluation tool for vapor transfer but are indeed a useful decision-making tool to use along with all of the other information collected (MEDEP, 2016).

4. Conclusion

As we understand it, this feedback and the database on subsurface soil gases and indoor air in schools created as part of the "Sensitive Establishments" campaign is the first of its kind in Europe. This study compiled data on 51 French schools and >5000 measurement pairs gathered between 2012 and 2016. The need to improve the use of attenuation factors through specific onsite parameters have led to the creation of a French database and its use for statistical analysis, as described in this study.

Since the collected data are mainly related to weak sources (only 15% schools required risk management measures related to vapor intrusion), this study shows the utility of choosing tracer compounds (here HVOC) that screen out data affected by secondary sources to calculate attenuation factors. The choice of HOVC is supported by a study by Canha et al. (2016) outlining that HCOV are negligible in the VOCs analyzed in French schools outside any contaminated land issue.

This feedback on the attenuation factors also shows that some environmental variables, usually collected during an environmental assessment, can help refining attenuation factors, particularly the "building age" variable. The latter can be attached to concrete aging and the presence of cracks in foundations. Qualitative estimation of AFs shows AF values for buildings < 50 years to be lower than AF value for buildings 50 years old and above. Finally, this study demonstrates how useful a database is as a tool complementary to modelling to study vapor intrusion.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2018.01.118.

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