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The predictable influence of soil temperature and barometric pressure changes on vapor intrusion

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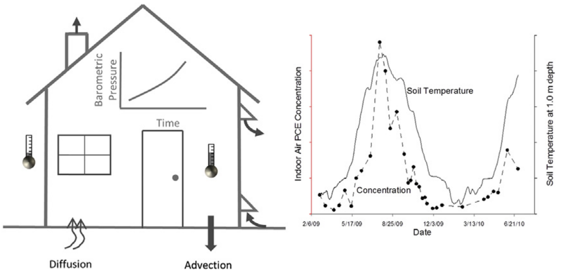
HIGHLIGHTS

- Small soil temperature increases cause large indoor air VOC concentration increases.
- Measure indoor air VOC concentration after a 2 kPa decrease in barometric pressure.
- Soil temperature controls diffusion rates by controlling concentration gradients.
- Building ventilation is critical in controlling indoor air VOC concentrations.

GRAPHICAL ABSTRACT



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ABSTRACT

Intrusion of volatile organic compounds in the gas phase has impacted many buildings in many different locations. Various building and environmental factors such as buoyancy of heated air and changes in barometric pressure can influence indoor air concentrations due to vapor intrusion in these buildings resulting in seasonal and daily variability. One environmental factor that previous research has not adequately addressed is soil temperature. In this study we present two northern region study sites where the seasonal trends in indoor air VOC concentrations positively correlate with soil temperature, and short-term (days) variations are associated with barometric pressure changes. We present simple and multivariate linear relationships of indoor air concentrations as a function of soil temperature and barometric pressure. Results from this study show that small changes in soil temperature can result in relatively large changes in indoor air VOC concentrations where the gas phase VOCs are sourced from non-aqueous phase liquids contained in the soil. We use the results from this study to show that a five degree Celsius increase in soil temperature, a variation in soil temperature that is possible in many climatic regions, results in a two-fold increase in indoor air VOC concentrations. Additionally, analysis provides insight into how building ventilation, diffusion, and the relative rate of soil-gas flow across the slab both from the subsurface into the building and from the building into the subsurface impact short term variations in concentrations. With these results we are able to provide monitoring recommendations for practitioners.

1. Introduction

Movement of volatile organic compound (VOC) vapors emanating from subsurface contamination into buildings is a well-known problem impacting the air quality of buildings in many

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locations (ITRC, 2007; EPA, 2015). Conceptually the movement of VOC vapors from a subsurface source to inside a building is well understood (ITRC, 2007; EPA, 2015; Johnson and Ettinger, 1991; Little et al., 1992). While the conceptual model is simple in theory, many environmental and building factors can influence indoor air concentrations. Thus, even with the understanding of how these factors may influence concentrations, we still in many cases obtain unpredictable results, both long term (seasonally) and short term (hours or days).

Many attribute the most prevalent cause of seasonal variations in indoor air concentrations of intruding volatile organic compounds (VOCs) into buildings to stack effect (EPA, 2015). Under these conditions, as warm buoyant air is exhausted through vents or openings in elevated areas of buildings, indoor air VOC concentrations in buildings with tightly sealed envelopes will increase owing to the advective flux of gas phase contaminants through openings in the slab and the lack of dilution from outside air. Hence, indoor air concentration trends generally show peak values in the winter months in regions where heating is required. Others have shown this general seasonal trend in different studies on radon and VOC intrusion (Holton et al., 2013; Arevla et al., 1988; Folkes et al., 2009; Brenner, 2010). Counter to this trend, several have shown peak values occurring in summer months, particularly in warm climates where homeowners keep their homes tightly shut and cooled with refrigerated air (Johnston and Gibson, 2014). Stack effect cannot be the cause of this type of trend. Johnston and Gibson (2014) suggest the summer peak values are due to warm soils below the impacted building; however, these researchers did not measure soil temperatures at their study site. Bekele et al. (2014) investigated the influence of soil temperature and moisture on vapor movement in subsurface soils. These researchers concluded that soil temperature has the potential to influence indoor air VOC concentrations; however, direct measurement of indoor air VOC concentrations was not included in their study. Owing to the temperature dependency of phase changes and diffusive and advective flux rates of VOCs, it is likely that soil temperature will influence indoor air VOC concentrations. However, this relationship has not been quantified.

In the most extensive documented vapor intrusion study to date, Holton et al. (2013) shows long term trends of higher and lower indoor air concentrations dependent on season, but day-to-day variations that are wide and unpredictable. Different studies have attributed short term variations in indoor air VOC concentrations to several environmental factors including atmospheric temperature, wind, barometric pressure changes, and soil moisture (Johnston and Gibson, 2014; EPA, 2012; Robinson and Sexto, 1995). Others have investigated how these factors influence the similar problem of radon intrusion (Hubbard et al., 1992; Tsang and Narasimhan, 1992; Robinson and Sextro, 1997). At any site impacted by vapor intrusion, some level of ability to predict indoor air concentrations is necessary for establishing sampling frequencies and assessing risk.

Our objective for this study is to quantify the influence soil temperature has on indoor air VOC concentration. The two study sites chosen for this study are unique in the assemblage of vapor intrusion sites in that they are located in Fairbanks, Alaska, a northern climate that experiences a wide range in seasonal temperatures. Moreover, one of the vapor intrusion impacted buildings chosen for this study was unheated and rarely entered. These factors reduced the influence of the stack effect on indoor air VOC concentrations and minimized ventilation of the building through doors. The other vapor intrusion impacted building chosen for this site was a heated bookstore. In the process of satisfying the objective we were also able to quantify the influence changing barometric pressure has on indoor air VOC concentrations at both the heated site and the unheated site. With these results we show that changing barometric pressure, in combination with other building and environmental factors, contribute to short term variations in indoor air VOC concentrations. Finally, from these results we draw some conclusions on how soil temperature and barometric pressure changes impact indoor air VOC monitoring and provide general guidance on likely conditions that will lead to measuring relatively high VOC concentrations in impacted buildings.

2. Experimental methods

2.1. Site descriptions

Fairbanks, Alaska is located in the interior of Alaska between the Alaska Range to the south and the Brooks Range to the north. The climate in this region is subarctic continental characterized by very cold winters and warm summers. On average, January is the coldest month with an average minimum temperature equal to −28 °C. July is the warmest month with an average monthly maximum equal to 23 °C. Precipitation is low and irregular (Shulski and Wendler, 2007).

Both of the sites chosen for this study are located in the downtown area of Fairbanks, and they are known as the Wendell Site and the Gaffney Site. These sites are situated in the collective floodplain of the Tanana and Chena rivers. Péwé et al. (1976) characterizes the surficial geology in the floodplain as well-stratified layers of unconsolidated coarse sand and gravel interbedded with poorly stratified layers and lenses of unconsolidated silt and sandy silt. Seasonal frost depths range between approximately 1 to 3 m depending on surface conditions and soil type. The interior of Alaska is a region of discontinuous permafrost; however, we did not encounter permafrost at either study site. Vapors from separate tetrachloroethylene (PCE) releases contaminated the indoor air in each building during the time of the study (February 2009 to June 2010). A distance of more than 0.5 km separates each building.

The Wendell Site has been an operating laundry facility under different owners since 1953. Most likely, proprietors first used PCE at the location for dry cleaning operations starting in the late 1960s. At the time of this study, dry cleaning operations had ceased, and the site was a coin-operated laundromat. The building is slab-on-grade construction and consists of two main areas: a heated portion, and an unheated portion. The heated portion contained the coin operated laundry operation and an area that once served as the dry cleaning operation. The current owners used the unheated portion for storage during the study. This study focused on vapor intruding into the unheated portion of the building.

A visual survey indicated that there was no PCE stored in the building during the study period. It is possible that usage of laundry products containing PCE (such as spot removers) in the coin operated laundry section of the building could be a periodic source of PCE. However, we assume this contribution is minor given the separation between the laundromat section of the building and the monitoring location and the active ventilation in the laundromat section of the building. The slab in the unheated portion was in poor condition with greater than centimeter wide cracks in the concrete distributed throughout. A subsurface characterization study indicates a layer of silt exists between layers of medium to coarse grain sand underneath the building. To help differentiate between the two sites, we will also denote this site as the “unheated” site.

Site characterization studies indicate that the source of contamination at the Wendell site was a combination of disposal of PCE from the dry cleaning operation in the laundromat to leaky