Chapter 1

Introduction

1.1 Indoor Air Quality Perspective

Concerns about air quality are as old as civilization itself, ranging from beliefs that disease is caused by bad air - a *miasma*, to more recent concerns about exposure to combustion particulates. Since industrialization the number of potential hazardous pollutants has increased significantly, followed by increased concerns about air quality. At the same time, people now spend more time indoors now than ever before, with Americans spending up to 90% of their waking time indoors[**?**]. This change in human habitation has put a special emphasis on indoor air quality.

Some early scientific inquiries into indoor air quality focused on pollutant sources that were generated in the home, such as heating and cooking systems. Increased levels of carbon monoxide, sulfur dioxide, and various nitrous oxides could be detected due to these systems[**?**]. These types of pollutants are still relevant today, but of particular concern in developing countries[**?**].

Some indoor air pollutants may be emitted from building materials, such as asbestos from older types of insulation, or formaldehyde from pressed-wood products, and various petroleum or chlorinated compounds may be emitted from common household product. Molds are another common indoor quality concern[**?**].

Indoor air quality may be significantly affected by external contaminant sources as well, with Radon being perhaps one of the most well-known cases of this. Radon is a radioactive gas produced by the natural decay of Uranium 238, which is commonly found in many rocks and minerals. These in turn are often found in the soil or bedrock and the Radon gas enter the overlying buildings, exposing the inhabitants.

1.2 Vapor Intrusion

A recent addition to the myriad of indoor air quality concerns is vapor intrusion (VI) - a process that is similar to Radon intrusion. As with Radon intrusion, VI contaminants are typically originate from underneath a building, migrate through the soil, entering it, and exposing the inhabitants. VI is different from Radon intrusion because it is more broad and general; the contaminant sources are usually of anthropogenic origin, and not limited to the soil. As such, Radon intrusion can be thought of as a subset of VI, but they are typically considered separately. In VI, the primary contaminants of concern are chlorinated solvents, e.g. trichloroethylene (TCE),

tetrachlorethylene (PCE), vinyl chloride, chloroform, and organic compounds, e.g. benzene.

The prototypical VI scenario is one where groundwater has been contaminated with one or many of these contaminants. Contaminant vapors evaporate from the groundwater, and are transported through the soil into the overlying buildings through small cracks and breaches in the foundation. While this simple example is helpful for gaining a rudimentary understanding of VI, it fails to capture much of the complexities of an actual VI site.

Determining if vapor intrusion occurs at a house or structure is often difficult. One might be tempted to believe that taking an air sample inside the house would be sufficient, i.e. that vapor contaminant concentrations is over some threshold in the house is proof of VI; absence of contaminant vapors is proof of no VI. The reality is that indoor air samples can be problematic for a few reasons. Due to their distributive nature, the residents or owners of the structure may be unwilling to let indoor samples to be taken. Indoor air samples are also susceptible to false positives and negatives.

Many common consumer products contain the same contaminants that is often of concern in VI. The presence of these contaminants in a house is thus not necessarily proof of VI but rather a line-of-evidence. Great care should be and is taken to remove any potential indoor contaminant sources before any VI investigation can begin (contributing to the distributive nature of these investigations).

There can be significant temporal variability of indoor contaminant concentrations and some sites may have "active" and "inactive" periods, thus the absence of indoor contaminant is not proof that VI is not occurring, but yet another a line-of-evidence. This temporal variability occurs on different time-scales as mean indoor contaminant concentrations often fluctuate across seasons, and may even significantly vary across weeks, days, or even within a day.

Another approach might be to collect groundwater and/or soil-gas samples, but this also has it's inherent issues as well. The presence of contaminant in the groundwater or surrounding soil-gas (even if found right underneath the foundation) is evidence that VI occurs. Likewise, the absence or low concentration of contaminants may only indicate that there is significant spatial variability in contaminant concentration or that the source has not been found (hidden preferential pathways may especially be issues in the latter case). The result of these samples is the same as indoor samples, they may only be used as a line-of-evidence for VI.

The combination of these line-of-evidence are usually required to prove that VI occurs; the presence of contaminant in the groundwater, in the soil-gas underneath the structure, and finally inside the structure would be good evidence that VI occurs. This multiple line-of-evidence (MLE) approach is necessary when conducting VI investigations and is recommended by the US EPA.

1.3 Research Motivation

To reduce the uncertainty in VI investigations, further research is required to improve our understanding of VI, with a particular focus on the temporal variability.

1.4 Numerical Modeling of Vapor Intrusion

1.5 Research Objective

The aim of this thesis is to explore the dynamic processes that drive the temporal variability in VI. This is achieved by developing numerical models of VI scenarios from a first-principles approach.

1.6 Outline