THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

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TECHNOLOGY TYPE:	**BUILDING PRESSURE CONTROL**
APPLICATION:	**VAPOR INTRUSION ASSESSMENT**
TECHNOLOGY NAME:	**Building Pressure Control for the Assessment of Vapor Intrusion**
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ETV Joint Verification Statement

The U.S. Environmental Protection Agency (EPA) has established the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by accelerating the acceptance and use of improved and cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the design, distribution, financing, permitting, purchase, and use of environmental technologies. Information and ETV documents are available at www.epa.gov/etv.

ETV works in partnership with recognized standards and testing organizations, with stakeholder groups (consisting of buyers, vendor organizations, and permitters), and with individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field and laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance (QA) protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

The Advanced Monitoring Systems (AMS) Center, one of six verification centers under ETV, is operated by Battelle in cooperation with EPA's National Risk Management Research Laboratory. The AMS Center recently evaluated the performance of the building pressure control technique for the assessment of the impact of vapor intrusion on the concentrations of contaminants of concern (CoCs) in indoor air. The pressure control technique was conducted by the technology vendor, GSI Environmental, Inc.

VERIFICATION TEST DESCRIPTION

Vapor intrusion is the migration of volatile chemicals from the subsurface (from soils and/or groundwater) into the air of overlying buildings. Adverse health effects may result from inhalation exposure to certain CoCs such as the volatile organic compounds trichloroethylene (TCE), 1,1-dichloroethylene (1,1-DCE), tetrachloroethylene (perchloroethylene, PCE), and benzene. Reducing or controlling the risk to human health related to inhalation exposure to CoCs due to vapor intrusion is the stated goal of many regulatory and governmental agencies. However, the ubiquity of background sources of CoCs typically confounds efforts to attribute measured indoor air CoC concentrations to vapor intrusion. The objective of this verification test was to generate performance data on the use of the building pressure control technique as a method to understand the impact of vapor intrusion on the concentrations of CoCs in indoor air. The data generated from this verification test are intended to provide organizations and users with information on the ability of such a methodology to assess vapor intrusion impacts.

This verification test was conducted at two different buildings, the Arizona State University Vapor Intrusion Research House (the ASU House) near Hill Air Force Base in Layton, UT, and at Building 107 at Naval Air Station Moffett Field, near Palo Alto, CA (Moffett Field Building 107). These sites were selected in large part because VI is a known concern at both buildings. Testing was conducted at the ASU House from Monday, October 4 through Thursday, October 7, 2010, and at Moffett Field Building 107 from Sunday, October 31 through Wednesday, November 3, 2010. Beginning late in the afternoon on the first day of testing, and lasting over the next three consecutive days, each building was maintained for 24 hours at each of three pressure conditions: baseline (no pressure perturbation), induced negative pressure , and induced positive pressure . SF_6 tracer gas was released at each building over the entire testing interval to measure building ventilation rates. Moreover, the cross-foundation sub-slab differential pressure was measured over the entire test interval, as was the indoor/outdoor differential pressure (the pressure across the building envelope). Each differential pressure measurement was performed using a separate calibrated real-time differential pressure instrument. During all testing interior doors remained open, the fan to induce the appropriate pressure perturbation was kept running, exterior windows were closed, but building egresses were not controlled and building occupants were allowed to come and go freely. During the first 12 hours at each pressure condition, the building atmosphere was allowed to come to equilibrium, after which the next 8 to 12 hours was taken to characterize the concentrations of various species in indoor air, ambient air, and sub-slab gas in and around each building.

Beginning on the morning of the second, third and fourth days of testing; corresponding to October 5, 6, and 7 at ASU House and November 1, 2, and 3 at Moffett Field Building 107; and corresponding to baseline, induced negative pressure, and induced positive pressure conditions, respectively; indoor air, ambient air and sub-slab gas was sampled to measure various CoCs , SF_6, and radon. Three discrete indoor air and sub-slab samples were collected at spatially distributed locations. Specific indoor sampling points were selected as a compromise between attaining spatial representativeness while minimizing disturbance to building occupants and activities. Ambient sampling locations were selected nominally upwind of the test building, away from obvious sources of CoCs.

In order to characterize the concentrations of CoCs, SF_6, and radon in indoor air and ambient air, several different types of air samples from inside and outside the building were collected and analyzed. While the building was under each of the three pressure conditions, indoor air concentrations of CoCs, SF_6, and radon were measured at three different spatially distributed locations throughout the building and at a single outdoor location. Sampling commenced in the early morning and ended in the early afternoon on each day. For analysis of CoCs and SF_6, 8-hour time-integrated samples were collected into evacuated stainless steel sampling canisters. For radon, grab samples were collected in the early afternoon into polyvinyl fluoride bags.

Concentrations of CoCs, SF_6, and radon were also measured in sub-slab gas. CoCs and SF_6 were collected as single grab samples at each sub-slab sampling point into individual evacuated stainless steel canisters. Sub-slab radon was measured using a near real-time instrument. These samples were taken in the afternoon on days 2, 3, and 4 of testing.

At the completion of each test day, canister samples were shipped by common carrier to Columbia Analytical Services (Simi Valley, California) for analysis of CoCs and SF_6, and the polyvinyl fluoride bags were similarly shipped to the University of Southern California, Department of Earth Sciences for radon analysis. Analysis of canister samples for CoCs was performed using cryogenic preconcentration GC/MS according to the procedures outlined in EPA Compendium Method TO-15, with TO-15 scan for CoCs in sub-slab gas and TO-15 with selected ion monitoring for CoCs in indoor air and ambient air. Canister samples for SF_6 were analyzed using GC with electron capture detection according to procedures in National Institute of Occupational Safety and Health Method 6602. Radon concentrations were measured by way of alpha scintillation counting.

The pressure control technique was evaluated using the following types of performance parameters.

- Decision-making support
- Comparability
- Operational factors

In general, the goal of implementing the building pressure control method is to obtain a better understanding of vapor intrusion in a building. If the control of building pressure results in clear changes in building conditions, such as indoor/outdoor differential pressures and concentrations of radon and CoCs, then the pressure control method may yield results that are useful for decision-making (i.e., is vapor intrusion a concern for this building?). The effectiveness of the building pressure control method to support decision-making was evaluated using the following three metrics.

1. Building pressure differential: Did the pressure control method control building pressure?

2. Vapor intrusion enhancement and reduction: Did the pressure control method increase the mass discharge of radon from subsurface sources through the building foundation under induced negative pressure conditions and/or decrease the mass discharge of radon from subsurface sources through the building foundation under induced positive pressure conditions?

3. Fractional contribution of vapor intrusion to indoor CoC concentrations (F_{VI}): Did the pressure control method provide an improved understanding of the contribution of vapor intrusion to the concentration of individual CoCs detected in indoor air?

Additional support to decision-makers was also provided by qualitative trends, with respect to changes in building pressure, in concentrations of compounds in indoor air, as well as trends in the changes of compound mass discharges.

Beyond the three metrics comprising decision-making support, the performance metric of comparability was assessed for the pressure control technique as the similarity of the indoor/outdoor differential pressures achieved under induced negative pressure and positive pressure conditions at each of two buildings. The final performance metric was comprised of an assessment of operational factors such as ease of implementation of the pressure control technology, the expertise required to carry out the field work and interpret the results, and costs to perform the testing.

QA oversight of the verification testing was provided by Battelle, Naval Facilities Engineering Command (NAVFAC) Atlantic, and EPA. NAVFAC Atlantic QA staff conducted a technical systems audit during testing at both buildings, and also conducted two audits of data quality of at least 10% of the test data. This verification statement, the full report on which it is based, and the Quality Assurance Project Plan for this verification test are available at www.epa.gov/etv.

TECHNOLOGY DESCRIPTION

Intentionally inducing negative pressure or positive pressure in a building by use of a fan to drive indoor air out of the building, or ambient air into the building, should either enhance or reduce vapor intrusion, respectively. This is the conceptual basis for the building pressure control technique.

Implementation of the building pressure control technique for the assessment of the impact of vapor intrusion on the indoor air at a given building takes place over approximately 3½ days. Over the first half day, the building is prepared for testing. Over the next 24 hours, the building is maintained under baseline pressure in which the building pressure is not intentionally manipulated. Over the following 24 hours, a negative pressure is induced in the building. Over the final 24 hours, a positive pressure is induced in the building. To accomplish building pressurization and depressurization, windows, and other openings are closed and a fan is installed in a doorway or window.

During each 24 hour period of baseline, induced negative pressure, and induced positive testing, a known concentration of the inert tracer gas, SF_6, is released at a known flow rate from a centralized location in the building. To the extent possible, interior doors remain open throughout testing to enhance mixing of the indoor air. Using the known flow rate of SF_6 and measurements of indoor SF_6 concentrations, the flow rate of ambient air into the building, that is, the building's ventilation rate may be determined. The indoor/outdoor differential pressure is measured using a real-time instrument.

Finally, several different types of air samples from inside and outside the building – for indoor air and ambient air, respectively – are also collected and analyzed to characterize concentrations of various CoCs, SF_6, and radon. Gas samples for analysis of CoCs and SF_6 are collected into stainless steel sampling canisters whereas samples for radon analysis are collected into polyvinyl fluoride bags. While the building is under each of the three pressure conditions, concentrations of CoCs, SF_6, and radon are measured at three different spatially distributed locations throughout the building and at a single outdoor location. Canisters and polyvinyl fluoride bags are delivered to separate off-site contract analytical laboratories for gas analysis. Note that for routine application of the technology, sub-slab sampling is not required.

VERIFICATION RESULTS

The verification of the pressure control technique for the assessment of vapor intrusion is summarized below.

Building Pressure Differential

For both buildings, the building pressure control method achieved a measureable negative pressure gradient under induced negative pressure both across the building envelope (the indoor/outdoor differential pressure) and the building foundation, as well as a measureable positive pressure gradient across the building envelope and building foundation under induced positive pressure. Furthermore, during each of the pressure perturbations at the two buildings, the mean indoor/outdoor differential pressures were either below (under induced negative pressure) or above (under induced positive pressure) the target pressure of -1 Pa and 1 Pa, respectively. These results indicate that some degree of building pressure control was achieved under both pressure perturbation conditions at both buildings.

Vapor Intrusion Enhancement and Reduction

At both buildings, the building pressure control method had the expected qualitative effect on the mass discharge of radon from subsurface sources through the building foundation. That is, under induced negative pressure, the mass discharge of radon from subsurface sources through the building foundation increased compared to baseline, indicating that radon vapor intrusion had been enhanced; and under induced positive pressure, the mass discharge of radon from subsurface sources through the building foundation decreased compared to baseline, indicating that radon vapor intrusion had been reduced. However, in none of these four cases (negative pressure and positive pressure comparisons to baseline at two buildings) was the difference in mass discharges found to be statistically significant – due to the large estimated errors in the measured radon mass discharges. Radon concentrations in indoor air and ambient air under induced positive pressure were also compared to ascertain if radon vapor intrusion had been stopped under induced positive pressure. For both buildings, indoor air and ambient air radon concentrations were not found to be statistically different, indicating an absence of radon vapor intrusion under induced positive pressure.

Fractional Contribution of Vapor Intrusion to Indoor CoC Concentrations

The pressure control method had the expected qualitative effect on CoC concentrations in indoor air. For both radon (that has a known subsurface source) and the CoCs with expected subsurface sources (TCE, 1,1-DCE, and

PCE), concentrations in IA were greater than in ambient air under induced negative pressure, but similar to concentrations in ambient air under induced positive pressure. For the CoCs without expected subsurface sources (benzene and toluene), concentrations in indoor air were similar to concentrations in ambient air for all pressure conditions. Similar trends were seen in mass discharges: mass discharges of the CoCs with expected subsurface sources varied under application of the building pressure control technique similarly to radon, but compounds without expected subsurface sources had a pattern different than radon under pressure perturbation.
The building pressure control technique generated less definitive quantitative results. F_{VI} is the fraction of the measured indoor air concentration of a given CoC (under baseline conditions) that is due to vapor intrusion. By definition, F_{VI} is expected to be between 0 and 1 (i.e., between 0% and 100% of the CoC concentration in indoor air is attributable to vapor intrusion). Under each induced pressure condition, and at both buildings, a total of 16 F_{VI}s were calculated: for the two CoCs expected to have subsurface sources – TCE and 1,1-DCE at ASU House and TCE and PCE at Moffett Field Building 107 – and for two CoCs expected only to have indoor/ambient sources – benzene and toluene at both buildings (2 buildings · 2 pressure conditions · 4 CoCs). F_{VI} values of less than zero or greater than one are indicative of either variability in the dataset used for the calculations or incorrect model assumptions. Of the 16 F_{VI} values, five were greater than one and three were less than zero. In addition, the Monte Carlo uncertainty analysis indicated that uncertainties in the F_{VI} values are likely larger than calculated values. Nonetheless, the F_{VI} values for the two CoCs with expected subsurface sources were close to or greater than one in seven of eight cases, and the F_{VI} values for the two CoCs without expected subsurface sources were close to or less than zero in seven of eight cases. In general, the variability in measured concentrations limited the quantitative interpretation of the F_{VI} values.

Comparability

The comparability of the building pressure differential achieved at the two buildings was assessed as the relative percent difference between the mean pressure differentials measured under both induced negative pressure and induced positive pressure. Relative percent differences were 71% and 116% under induced negative and positive pressures, respectively. In general, lower relative percent differences indicate better comparability. Thus, while pressure control was achieved at both buildings, the magnitude of the induced pressure gradients varied, most likely due to differences in building characteristics such as heating, ventilating and air conditioning systems. Moreover, implementation of the pressure control method in only two buildings provided a limited dataset for evaluation of comparability.

Operational Factors

A minimum of two people were required to execute the field work, and at least one of these personnel must have the experience and specialized knowledge in indoor and outdoor air sampling, the use of analytical instrumentation required for a typical vapor intrusion field investigation, and the ability to install sub-slab sampling points. No detailed instruction manual or written guidance was available that provided guidance on how to execute various test procedures; however, such guidance is expected to be available in the future. Settings on one pressure differential measurement instrument had to be reconfigured during the test; no issues were encountered with the real-time radon instruments. No canisters (out of 47) were rejected during pre-sampling integrity checks (based on pressures as received). The pressures did increase (i.e., the vacuum decreased) in three canisters (out of 47; 6%) after sampling and before analysis, indicating that these samples had been slightly diluted with gas of unknown composition. Two polyvinyl fluoride bags (out of a total 48; 4%) failed pre-sampling checks and were not used; these failures did not impact study outcomes. One bag (out of 48; 2%) arrived at the analytical laboratory at a lower volume than the others, potentially indicating a leak.

For the routine implementation of the technology at a given site, the field work is expected to require approximately 80 person-hours (2 staff · 4 days · 9 hours/day). Additional costs would include travel and expenses, as well as time for data evaluation and reporting after the field work is completed. One differential pressure instrument ($1,500) is required to perform the indoor/outdoor monitoring. The cost for laboratory analysis of the basic set of canisters (for CoCs and SF_6) and polyvinyl fluoride bags (radon) samples is approximately $6,000, including media and shipping. This cost covers analysis of 9 IA samples, 3 ambient air samples, and two field duplicates. Note that sub-slab sampling is not required for routine implementation of this technology.

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