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Project Summary

Physical and Numerical Modeling of ASD Exhaust Dispersion Around Houses

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A study has been completed to physically model, in a wind tunnel, the dispersion of exhaust plumes from active soil depressurization (ASD) radon mitigation systems in houses. The wind tunnel testing studied the effects of three exhaust locations: midway up the roof slope, simulating an ASD stack within the house; at the eave, simulating an exterior stack; and grade-level exhaust (no stack). Plume dispersion effects were studied using both qualitative smoke visualization and quantitative tracer gas techniques, as the house, wind, and exhaust characteristics were systematically varied. The tracer gas results show that grade-level exhausts consistently result in the highest tracer concentrations against the face of the house, although these concentrations may not be serious if exhaust concentrations are low. The highest concentration measured at one point against the side of the house over all runs with grade-level exhaust would correspond to 30 Bq/m³ (0.8 pCi/L) if the exhaust contained 3,700 Bq/m³ (100 pCi/L), and 300 Bq/m³ (8.1 pCi/L) if the exhaust contained 37,000 Bq/m³ (1,000 pCi/L). Exhaust at the eave resulted in substantial reductions in the concentrations seen against the side of the house and resulted in a maximum concentration corresponding to 163 Bq/m³ (4.4 pCi/L) at one point against the roof of the house for an exhaust containing 37,000 Bq/m³ (16 Bq/m³, or 0.4 pCi/L, for an exhaust containing 3,700 Bq/m³). Exhaust midway up the roof slope gave the best chance for the plume to escape, resulting in a maximum concentration corresponding to 122 Bq/m³ (3.3 pCi/L) at one point against the roof for an exhaust containing 37,000 Bq/m³ (12 Bq/m³, or 0.3 pCi/L, for an exhaust containing 3,700 Bq/m³).

This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Currently, radon mitigation standards issued by the U. S. Environmental Protection Agency (EPA) require that the exhaust from an active soil depressurization (ASD) system for residential radon reduction be discharged above the eave of the house. This requirement is intended to ensure that very little of the exhaust is re-entrained into the house, to minimize the exposure of the occupants. It is also intended to ensure that the exhaust effectively disperses outdoors, to minimize exposures to persons in the yard or in neighboring houses.

This requirement for exhaust above the eave can increase the installation cost of the ASD system and can detract aesthetically from the house. It might discourage some owners from installing a mitigation system. The objective of the current study was to identify if there are conditions under which the ASD exhaust for a typical house can safely be released at grade level.

Project Description

The project involved physical modeling using a wind tunnel to study the circulation of ASD exhaust gases around typical suburban houses, to determine whether consistently acceptable conditions for grade-level exhaust can be defined. In an effort to permit extension of these results to conditions beyond those tested in the wind tunnel, an attempt was also made to use the wind tunnel data to validate various analytical and numerical models describing exhaust buildup in the building cavity, plume dispersion, and the fluid dynamics of flows around buildings.

Models of four typical suburban houses, on a 1:35 scale, were constructed and tested in a wind tunnel having a cross section of 3.66 by 2.13 m (12 by 8 ft). These four houses differed according to the number of stories (1 vs. 2 stories) and the roof pitch (gentle vs. steep slope). The testing addressed four wind directions (0°, 45°, 90°, and 180°), three ratios of exhaust velocity to approaching wind velocity, and three exhaust locations (midway up the roof slope, simulating an interior stack; above the roof eave near the rain gutter, simulating an exterior stack; and horizontally away from the house at grade, simulating no stack).

In wind tunnel testing of plume dispersion, the primary scaling factor is the ratio of stack exhaust velocity W to approaching wind speed U. Three W/U velocity ratios were tested in the wind tunnel: 0.25, 1.0, and 2.5. This range covers a broad spectrum of actual exhaust and wind velocities. At an exhaust velocity of 1.25 m/s – corresponding to a discharge of roughly 10 L/s (20 cfm) assuming a 10 cm (4 in.) diameter stack – this range of W/U ratios would represent wind speeds of 1.25 to 5 m/s (about 2.5 to 11 mi/hr). At an exhaust velocity of 6 m/s (corresponding to about 50 L/s, or 100 cfm), this range would cover wind speeds of 2.4 m/s (about 5 mi/hr) and higher.

The testing included smoke visualization tests and quantitative tracer gas release tests. In the tracer gas testing, pure ethane tracer gas was released from the model stacks; samples for ethane analysis were drawn at 45 locations around the face of the house and downwind.

Since the house models did not have porous faces (simulating openings in the house shell), the wind tunnel testing could not provide a direct simulation of actual re-entrainment into the structures. However, these tests did provide a direct simulation of dispersion around the house, and hence of possible exposures to persons in the yard or in neighboring houses. Moreover, from the concentrations against the faces of the model houses, some indication is provided regarding the potential threat that re-entrainment might pose to the occupants.

Initial Validation of Wind Tunnel Profiles

Before undertaking the primary experimental program, an initial series of tests was conducted to confirm that the vertical velocity and turbulence profiles being established in the wind tunnel adequately represented the expected boundary layer profiles that would exist in a suburban setting in the field. This testing showed that the wind tunnel was reproducing the expected suburban field boundary layer reasonably well, especially at the position where the model house was located, based upon empirical models of field profiles.

It was also necessary to demonstrate that the concentration profiles established in the tunnel by dispersion from a "passive" source – i.e., a source injected parallel to the bulk wind flow at the same speed as the wind – would be the same as those that would be expected in a suburban field setting. These tests, with passive injection of ethane tracer gas, confirmed that the concentration profiles established in the wind tunnel were consistent with those predicted by the Pasquill-Gifford model for an urban setting, in the appropriate Pasquill-Gifford C-D category, especially at the location of the model house.

This validation testing confirmed that both the velocity and concentration profiles, when appropriately normalized, are independent of the Reynolds number (i.e., the wind speed).

Results

Wind Tunnel Smoke Visualization Tests

Smoke visualization tests were conducted at 96 conditions: 2 house heights x 2 roof pitches x 4 wind directions x 2 W/U velocity ratios x 3 exhaust locations.

The smoke results confirm (and provide additional insights on) the tracer gas results discussed below. The plumes from grade-level exhausts commonly are either blown back against the face of the house (when the exhaust is on the upwind side) or caught in the downwind recirculation cavity (for sidewind and downwind locations), even at W/U values corresponding to the highest exhaust velocities. Exhaust midway up the roof slope has the best chance of penetrating the near boundary layer over the roof and escaping the downwind cavity, especially when the stack is on the upwind side of the house, although some recirculation is seen even with such mid-roof exhausts. Exhaust at the eave generally results in less recirculation than does grade-level exhaust but is less effective in avoiding some capture in the recirculation cavity than is mid-roof exhaust.

Wind Tunnel Tracer Gas Concentration Tests

The tracer gas concentration testing involved 144 experiments, representing a complete test matrix: 2 house heights x 2 roof pitches x 4 wind directions x 3 W/U ratios x 3 exhaust locations.

The complete detailed results of these 144 experiments are presented in the full report.

Table 1 summarizes the results in the following format: If the exhaust stack were discharging either 3,700 or 37,000 Bq/m^3 (100 or 1,000 pCi/L) of radon, what would be the worst-case radon concentration seen at given locations around the face of the house and downstream, based on all of the wind tunnel data for the specific exhaust location? The figures in Table 1 represent the worst-case house configuration, wind direction, and W/U ratio for each exhaust location at each sampling point.

Analytical and Numerical Modeling

Existing analytical (mathematical) models describing plume dispersion near, and remote from, buildings were applied to the conditions being physically modeled in the wind tunnel. These analytical models predicted higher concentrations around the face of the house, and downwind, than those measured in the wind tunnel.

An existing numeric fluid dynamic code, FLUENT, was applied to several of the conditions tested in the wind tunnel. At this time, it is impossible to comment on the quantitative reliability of the concentrations predicted by the numeric model.

Conclusions

1 Some ASD exhaust gases will be caught in the recirculation cavity behind the building even with roof-level discharges, whenever the stacks are located downwind of the crest of the house's roof.

2 The at-grade wall exhaust usually leads to the highest tracer gas concentrations on the face of the building. The eave exhaust (simulating the exterior stack) leads to somewhat higher concentrations on the building face than does the exhaust midway up the roof slope.

3 If the exhaust were to contain 100 pCi/L of radon, the highest radon concentration that would result at any

Table 1. *Summary of Worst-Case Radon Concentrations* Expected Around House and Downwind, Based on Wind Tunnel Data*

Sampling	Predictions when Exhaust Contains 100 pCi/L			Predictions when Exhaust Contains 1,000 pCi/L		
Point No.	Mid-Roof Exhaust	Eave Exhaust	Grade Exhaust	Mid-Roof Exhaust	Eave Exhaust	Grade Exhaust
Locations on side of house (same side as exhaust point)						
1	<0.1	0.1	0.5	0.7	1.1	5.3
2	<0.1	<0.1	0.8	0.5	0.9	8.1
3	<0.1	<0.1	0.7	0.4	0.8	6.7
4	<0.1	0.1	0.4	0.8	1.4	4.1
5	<0.1	0.2	0.7	0.5	1.7	6.7
6	<0.1	<0.1	0.6	0.4	0.8	6.2
Locations on roof of house (same side as exhaust point)						
7	0.3	0.2	0.1	3.2	2.2	1.4
8	0.1	0.4	0.3	1.0	4.3	3.0
9	<0.1	0.1	0.3	0.4	1.2	2.6
10	0.2	0.3	0.1	2.1	3.1	1.2
11	0.3	0.4	0.2	3.3	4.4	2.0
12	0.1	0.3	0.2	1.0	2.6	2.1
15 m (about 50 ft) downwind, at grade level						
39	<0.1	0.1	<0.1	0.7	1.0	0.8

* Concentrations in pCi/L (1 pCi/L = 37 Bq/m^3).

single point on the face of any of the four buildings resulting from grade-level exhaust would be 0.8 pCi/L, under specific wind conditions, based on these results. If the exhaust were to contain 1,000 pCi/L, the highest radon concentration contributed by the grade-level exhaust against the face of the building would be 8 pCi/L, again under specific conditions at particular locations. But even for the 1,000 pCi/L exhaust, face concentrations contributed by the grade-level exhaust would be less than 0.4 pCi/L on the three sides of the building remote from the exhaust location.

4 If the exhaust were to contain 100 pCi/L, neither roof-level exhaust location would result in concentrations as high as 0.4 pCi/L against any face of any of the buildings, except in two cases with eave exhausts where the maximum concentration would just reach 0.4 pCi/L. If the exhaust concentration were 1,000 pCi/L, the maximum face concentration resulting with an eave exhaust is predicted to be about 4 pCi/L; that with an exhaust midway up the roof slope would be about 3 pCi/L.

5 Efforts to model the measured near-field wind tunnel tracer gas concentrations using available analytical and numerical models were unsuccessful in developing or validating the models for this application.

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***D. Bruce Henschel** is the EPA Project Officer (see below).*
The complete report, entitled "Physical and Numerical Modeling of ASD Exhaust Dispersion Around Houses," (Order No. PB94-188117; Cost: $36.50, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
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