1990

WIND-TUNNEL MODELING OF THE DISPERSION OF ODORANTS AND TOXIC FUMES ABOUT HOSPITALS AND HEALTH CENTERS

by

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Presented at

Session 16 - Air Pollution DIspersion Modeling
10:55 am Thursday, May 3, 1990

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Introduction

The concentration field produced by a source located on or near a hospital complex can be significantly modified from that predicted by conventional diffusion formulae. Such formulae contain the implicit assumptions that the flow field has straight parallel streamlines, modest velocity gradients, and distribution of turbulence energy and length scales which result from surface features that remain unchanged over long distances. Near large hospital buildings the flow field becomes highly complex. Curved streamlines, sharp velocity discontinuities, and non-homogeneous turbulence disperse effluents in a complicated manner uniquely related to source configuration and building geometry. Research and teaching hospitals or health centers in particular often contain laboratories, disease wards, incinerators, and radiological treatment facilities which can release particularly noxious odorants and toxic gases. These facilities tend to grow

Figure 2 Sampling Point Diagram for the Biomedical Research Center

Figure 1 Sampling Point Diagram for the School of Nursing

Figure 3 Concentration Level [illegible] Wind Direction for Low Speed Conditions

Figure 4 Concentration Level for East Wind Direction and Low Speed Conditions

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and add extensions, wings or entire buildings which complicate the placement of air handling units intended to mitigate re-entrainment of effluents.

Some general guidance exists about the flow field around building complexes in the ASHRAE Handbook and Product Directory, and monograph chapters on turbulent diffusion near buildings.[1,2,3] If concentrations predicted by such methods are marginal or the building configuration is unique then field or laboratory (wind tunnel) sampling at critical locations are proposed. This paper presents the results of case studies of ventilation problems associated with such a health center.

Cases studies to be considered include a) dispersion from fume hoods and exhausts of the University of Colorado Health Sciences Center (UCHSC), Denver, and b) transport of traffic exhaust into air handlers for the proposed Biological Research Center (BRC), University of Colorado, Denver.[4,5]

Fluid Modeling Criteria

Successful fluid modeling requires simulation of the characteristic turbulent scales of the atmospheric boundary layer and the replication of scaled flow around hospital buildings. Similarity criteria and wind-tunnel metrology are reviewed by Snyder (1981), Plate (1982), and Meroney (1986).[6,7,8] Critical to accurate estimation of isolated plume dispersion will be the reproduction of approach wind and turbulence profiles as characterized by friction velocity, u_*, and roughness length, z_o, or velocity profile power-law exponent, α.

Often atmospheric turbulence may cause only weak effects compared to the turbulence generated by a hospital complex and local terrain. Yet the magnitude of the building induced perturbations depends upon the incident flow turbulence scale and intensity, details of the hospital shape and surface roughness, and size of the hospital compared to the boundary layer depth. Geometrical scaling implies that the ratio of the hospital building height to length scale must be matched and, of course, that all other building length scales be reduced to this same ratio.

Golden (1961) measured the concentration patterns above the roof of model cubes in a wind tunnel.[9] Frequently, modelers quote Golden's experiments as justification for presuming dispersion invariance when obstacle Reynolds numbers exceed 11,000. Halitsky (1968) observed that for dispersion in the wake region, no change in isoconcentration isopleths from passive gas releases was found to occur for values of Reynolds number as low as 3300.[10]

In addition to modeling the turbulent structure of the atmosphere in the vicinity of a test site it is necessary to properly scale the plume source conditions. When one considers the dynamics of gaseous plume behavior the following nondimensional parameters of importance are identified: Momentum flux ratio, $\rho_s W_s/\rho_{ref} U_{ref}$; Densimetric Froude number, $Fr = \rho_{ref} U^2_{ref}/[(\rho_s - \rho_{ref})L]$; and plume Reynolds number, $Re_D = W_s D/\nu$. Exhaust gases released from fume hoods and small ventilators are typically at ambient temperatures and densities; thus, model plumes are also set to ambient density. Plume exit Reynolds number need only be large enough to ensure turbulent conditions, i.e., $Re_D > 2500$.

Data Acquisition and Analysis Techniques

The experiments were performed in the Environmental Wind Tunnel (EWT) of the Fluid Dynamics and Diffusion Laboratory at Colorado State University. This wind tunnel, especially designed to study atmospheric flow phenomena, incorporates special features such as an adjustable ceiling, a rotating turntable and a long test section to permit adequate reproduction of micrometeorological behavior. Mean wind speeds of 0.1 to 15 m/sec in the EWT can be obtained. Boundary-layer thickness up to 1.2 m can be developed over the downstream 6 m of the EWT test section by using vortex generators at the test section entrance and surface roughness on the floor. The EWT roof is adjustable in height to reduce blockage and permit the longitudinal pressure gradient to be set at zero.

Flow Visualization Techniques. A visible plume was produced by passing the metered simulant gas through a smoke generator (Fog/Smoke Machine manufactured by Roscolab, Ltd.) and then out of the modeled stack. The visible plumes for each test were recorded on either VHS or S-VHS video cassettes with a Panasonic Professional/Industrial camera/recorder system (AG-450). Flow visualization provides insight into how architectural features lead to shortened dispersion paths between source and receptor locations. Often visualization suggests changes in exhaust location, stack height, or other architectural modifications which eliminate re-inhalation situations. Observations of visualization tests were examined to note the presence or absence of phenomena such as building downwash, plume descent, and cavity vortices.

Concentration Measurements. The experimental measurements of concentration were performed using a Hewlett Packard gas-chromatograph and sampling systems designed by Fluid Dynamics and Diffusion Laboratory staff. The lower limit of measurements is imposed by the instrument sensitivity and the background concentration of tracer within the air in the wind tunnel. Background concentrations were measured and subtracted from all data quoted herein. Concentrations were presented as normalized concentrations, $K = \chi U_H/Q$, for all tests.

Test Program and Data

Exhaust fumes from seed storage and drying operations, animal pens, and chemical fume hoods are released at many points over the roofs of the UCHSC. Occasionally these fumes enter the air handling units resulting in odors and contaminated air throughout the School of Medicine. Another problem is to locate inlet ventilators for the new Biomedical Research Center (BRC) in order to avoid vehicle exhaust entrainment.

A physical modeling study of the UCHSC venu buildings was performed to assist in predicting environmental impacts for several proposed stack-building configurations. This involved:

1) The 1:150 reduced scale construction of all buildings within 300 feet of the School of Medicine site,
2) The placement of this model into a wind tunnel facility with the appropriate upwind roughness for this site,
3) Acquisition of velocity and turbulence profiles approaching and at the modeled UCHSC site,
4) Video taping of six different model plumes for 16 different wind directions, and
5) Concentration measurements at either 48 (for the School of Medicine) or 45 (for the Biomedical Research Center) different sampling locations for two wind speeds and eight wind directions.

Model Construction. Based on atmospheric data over the UCHSC area, the size of the concentration grid, and modeling constraints discussed above, a model scale of 1:150 was selected. Since the Environmental Wind Tunnel has a 3 m turntable this allowed the reduced scale construction of all significant buildings within a 900 foot radius of the UCHSC site. The terrain upwind of the turntable area was modeled with a generic 2.54 cm roughness.

Ventilator buildings incorporated large ventilator plenums and accurate placement of inlet and exhaust openings. The primary ventilator buildings are the Biomedical Research Center (BRC) and the School of Medicine (SOM). Sampling and source points surveyed during concentration measurements are indicated for the UCHSC in Figure 1 and for the BRC in Figure 2.

Test Plan School of Medicine. The emissions from the Research Bridge and Hospital roofs, a highly toxic gas from a stack on the hospital (ETO), and fumes from a stack on the SOM roof (EF-91) were all simulated. Additionally the intakes on the Hospital roof, on the roof of the SOM, and on the SE annex of the SOM were modeled.

Test Plan Biomedical Research Center. The emission from the Research Bridge roof tops, the emission from the BRC roof top, and the traffic from the Colorado Boulevard were evaluated. The observations were divided into building downwash, plume descent and vortices situations.

Discussion of Typical Results

Selection of the final intake and exhaust stack configuration for the UCHSC and BRC sites will be based upon the consideration of its visual appearance, zoning regulations, and mitigation of environmental impact. The environmental effects of exhaust from the ventilator stacks will depend upon traffic volume, ventilator flow rates, state and federal ambient air-quality regulations, building and plume aerodynamics, and local meteorology. This study evaluates through fluid modeling the influence of building and plume aerodynamics on plume dilution.

Conclusion from smoke visualization tests. Major conclusions drawn from observations of the visualization tests are as follows:

1. Emissions from the stack on the SOM roof top do not appear to have much impact on the SOM itself. However, with a easterly wind there is some downwash into the larger of the two roof airhandler courtyards on the SOM. Some building downwash is also evident with a NE wind into the courtyard on the southern side of the SOM.

2. Emissions from the Research Bridge roof top tend to completely engulf any region downwind. Consequently there could be a considerable collection of pollutants from this source which may accumulate in regions where the air stagnates. The Plaza to the SE of the BRC being one such example.

3. There is some downwash of the exhaust vented from the BRC into the adjoining courtyard, especially for N,NW and SW wind directions. However, for the most part the fumes do not appear to have a strong effect upon the proposed BRC itself.

4. Vehicle emissions from Colorado Boulevard did have a considerable effect on the BRC. With wind coming from the N, the eddy in the wake of the BRC tends to draw the pollutants back into the BRC's SE courtyard. For winds coming from the NE, E, and SE directions, the auto emissions tend to impinge on the BRC, concentrating along its west and north sides. This results in high concentration on the intakes proposed for the west side of the building. But with winds coming from the SW and W directions, the vortices caused by the obstacle of the BRC

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building tends to sweep the traffic exhaust westward or away from the building, that would cause low concentration at the proposed intake locations.

Conclusions from concentration measurements. By maintaining flow similarity between model and field conditions, relative concentrations (χ/Q) for a given source configuration, building configuration and wind direction will be invariant. The wind tunnel relative concentration measurements for the UCHSC building complex will be the same as those that could be obtained during full-scale measurements under the same ambient conditions.

Variation of wind orientation produces a wide variance in sample concentrations. For the SOM Figure 3 shows concentrations measured at all the sampling locations from the three exhaust sources for the NE wind direction. Because the ETO stack is close to the intakes on the Hospital roof top and the exit velocity for the stack is large, the Maximum K concentration reaches a value as high as 6,000. Concentrations at the intakes on the Hospital roof top are always higher than the other locations sampled.

For the BRC Figure 4 indicates concentrations measured at the sampling points for a east wind direction for each exhaust source. Sampling point #19 detects the highest K concentration value measured during the entire test (13,000 from the traffic exhaust). This indicates that the traffic exhaust strongly effects the proposed intake locations. The wind coming from the E produces 20 times higher K coefficient than the wind coming from the west. This phenomenon was also shown during the visualization program.

Based on the concentration data acquired during this study, there were two recommendations as follows:

1. The intakes on the Hospital roof top should be closed and removed in order to avoid the highly hazardous ETO stack.

2. The best location for the potential intakes at the Biomedical Research Center should be on the roof top near the sampling point # 4 of that building to avoid the traffic exhaust.

References

1. ASHRAE, Handbook and Product Directory, 1989 Fundamentals, Chapter 14, (1989).
2. Hosker, R. P., Jr., "Flow and Diffusion Near Obstacles, "Atmospheric Science and Power Production, DOE/TIC-27601, pp. 241-326, (1984).
3. Meroney, R. N., "Turbulent Diffusion Near Buildings," Engineering Meteorology, Elsevier Publishing Co., New York, 1982, Chapter 11, pp. 481-521.
4. Tan, T.Z. and Meroney, R.N., "Fluid Modeling of Exhuast Gas Dispersion for the University of Colorado Health Sciences Center," Final Report for UCHSC, Denver, CER88-89TZT-RNM-17, 54 pp., (1989).
5. Tan, T.Z. and Meroney, R.N., "Wind-tunnel Studies to Mitigate Snowdrift into Rooftop Air-handling Courts on University of Colorado Health Sciences Center," Final Report for UCHSC, Denver, CER88-89TZT-RNM-15, 53 pp., (1989).
6. Snyder, W. H., "Guidelines for Fluid Modeling of Atmospheric Diffusion," EPA Report EPA-600/8-81-009, 185 pp., (1981).
7. Plate, E.J., "Wind-tunnel Modeling of Wind Effects in Engineering," Engineering Meteorology, Elsevier Publishing Company, New York, 1982, Chapter 13, pp. 573-639.
8. Meroney, R.N., "Guideline for Fluid Modeling of Liquefied Natural Gas Cloud Dispersion: Volume II: Technical Support Document," Gas Research Institute Report GRI 86/0102.2, xxx pp., (1986).
9. Golden, J., "Scale Model Techniques," M.S. Thesis, Dept. of Met. and Ocean., New York University, 42 pp., (1961).
10. Halitsky, J., "Gas Diffusion Near Buildings," Meteorology and Atomic Energy, 1968, editor D. H. Slade, Atomic Energy Commission, Ch. 5-5, pp. 221-256, (1968).

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5. Fan, T.J. and Meroney, R.N., "Wind-tunnel studies to Mitigate Reentry into Rooftop Air-handling Intakes on University of Colorado Health Sciences Center," Final Report for UCHSC, Denver, CER88-89TJF-RNM-15, 53 pp., (1989).
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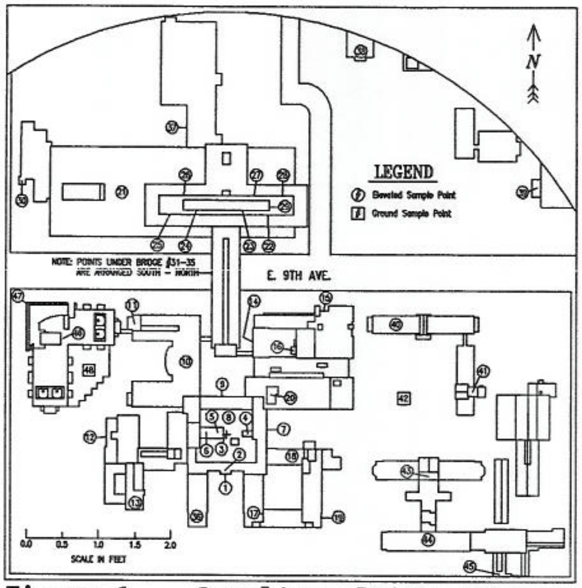

Figure 1 Sampling Point Diagram for the School of Medicine

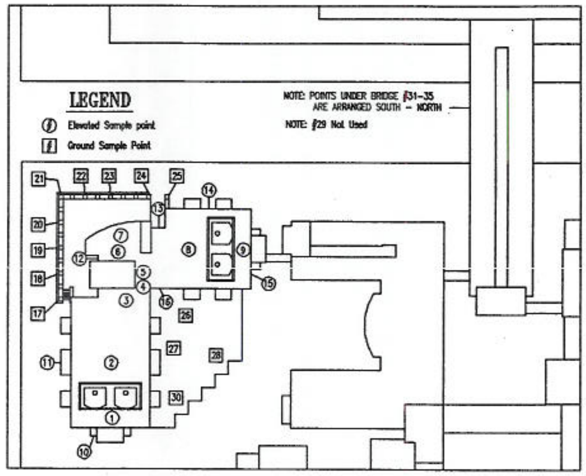

Figure 2 Sampling Point Diagram for the Biomedical Research Center

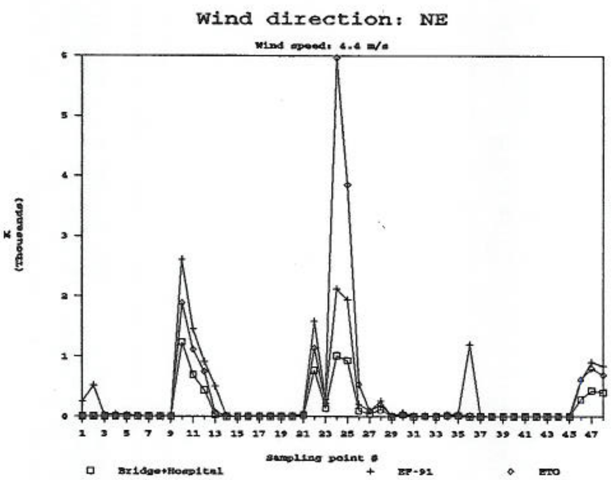

Figure 3 Concentration Level at NE Wind Direction for Low Speed Conditions

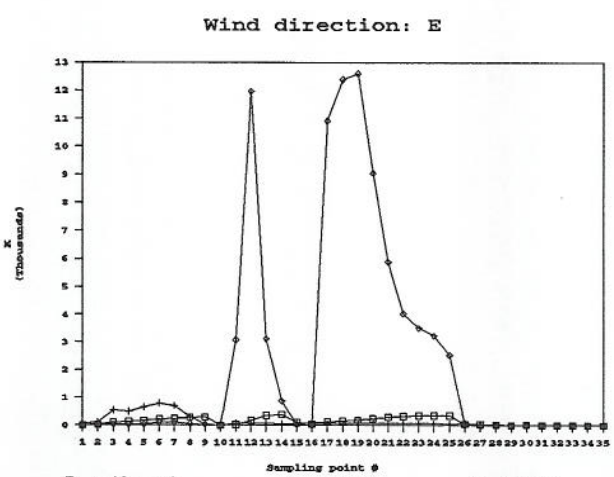

Figure 4 Concentration Level for East Wind Direction and Low Speed Conditions

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Figure 3 Concentration Level of NE Wind Direction for Low Speed Conditions

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