Air Intake Contamination by Building Exhausts: Tracer Gas Investigation of Atmospheric Dispersion Models in the Urban Environment

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Background

The reintroduction of toxic gases emitted from roof stacks can significantly affect the quality of the air inside a building. The determination of a safe distance between the sources of pollution and the fresh air intakes is based on a complex exercise that must take into account several wind, physical and topographical factors. Estimates of maximum concentrations as a function of downwind distance from a stack can be obtained using empirical models provided by the American Society of Heating, Refrigerating and Air Conditioning Engineers [ASHRAE, 1997](1). However, this modeling approach has not been completely validated using field data. ASHRAE's formulas have mainly been evaluated by comparing their resulting dilution estimates to the wind tunnel data originating from some case studies, and the results of these comparisons have proven contradictory (2,3). Most previous field studies(4,5) were conducted using a limited number of samplers placed near the fresh air intakes. Consequently, the data obtained cannot be used for model validation since samplers were usually not on the plume center-line. In a comparative study conducted by Stathopoulos, Lazure and Saathoff(6), tracer gas experiments were conducted using a building in an urban environment. Air samples were collected at several locations on the roof of this building, and the emission concentration data were correlated with the meteorological data collected on the roof.

Dilution Models

A number of semi-empirical models exist for the evaluation of minimum dilution ($D_{min} = C_e/C_{max}$) of emissions originating from roof stacks, where C_e represents the concentration of the emissions, and C_{max} the maximum concentration at a specific sampling point for a given wind velocity. Two models included in the ASHRAE Fundamentals Handbook (1997) are the Halistsky model(9) and the Wilson-Chui-Lamb model(10,11,12) herein referred to as H and WCL respectively. These models are summarized in the Appendix.

Experimental Procedures

The test building is a 3-storey structure located in downtown Montreal that contains engineering laboratories and classrooms of Concordia University. Within 100 m of the building are several high-rise buildings that may have an effect on wind flow around the building. Preliminary tests carried out using a smoke source have demonstrated that the emissions from a laboratory stack could be directed towards the fresh air intake. Three tracer gas tests were carried out in autumn with winds from the west and northwest. The tracer gas, pure sulfur hexafluoride (SF_6), was injected into a laboratory hood and emitted from a 3 m stack on the roof. Air samples were collected using 15 samplers spread out over the roof. Wind data were obtained with a sonic anemometer on the roof. Locations of the stack, anemometer and samplers are shown in Figure 1. The samplers contained an automated sampling module designed and manufactured by the IRSST to sequentially sample up to 10 samples of air at a given interval of 15 minutes per bag. Tracer gas concentrations were determined using gas chromatography.

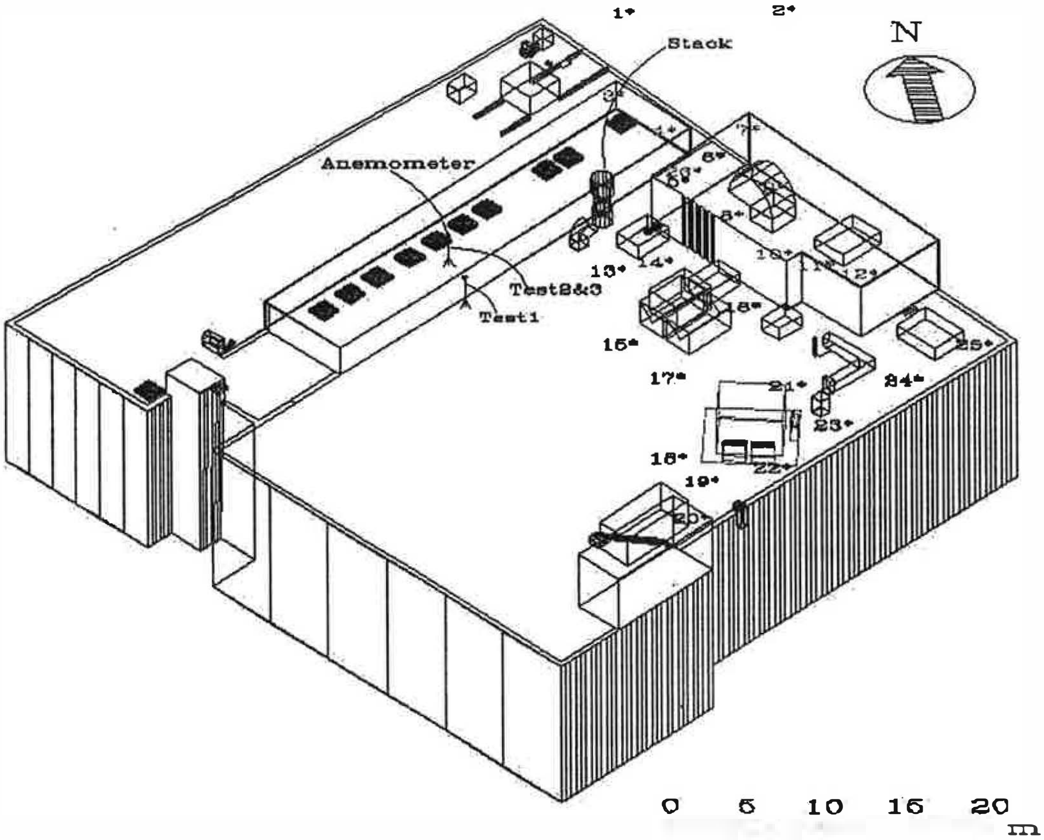

Figure 1. View of building showing relative heights of the stack and rooftop structures and location of samplers for all tests.

Results and Discussion

The wind speed, U_h, during the three tests varied from 2.0 to 4.5 m.s^{-1}. The average longitudinal turbulence intensity (Φ_u/U_h) at a height of 3 m above the exhaust level was 0.68. This is quite high, possibly due to the proximity of the neighboring buildings. The standard deviation related to wind direction (Φ_2), which is required for the WCL model, was estimated to be 30^o based on the large value of Φ_u/U. Figures 2 to 4 compare actual dilution values to the minimum dilution curves estimated from the H and the WCL models. The dilution levels for each of the samplers are plotted as a function of their distance from the emission source. It is important to remember that the WCL model was developed for roof-level stacks. Although the height of the stack is 3 m, its effective

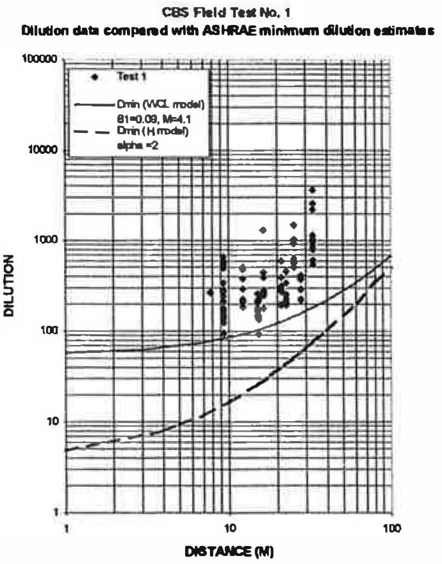

Figure 2. CBS Field Test No. 1 Dilution data compared with ASHRAE minimum dilution estimates

height is reduced due to the presence of rooftop structures (see Figure 1). Smoke tests revealed that plume makes intermittent contact with the roof very close to the stack. This plume downwash may be due to the influence of the rooftop structures.

In general, model H, provided very conservative estimates of D_{min}. Model WCL provided more accurate predictions of D_{min} but was unconservative in some cases. As observed in Figure 2, minimum dilution values measured during the first test at all locations were approximately 5 times greater than the values estimated by model H. On the other hand, D_{min} estimates obtained with the WCL model were generally within a factor of two of the data. This underestimation of D_{min} by the WCL model is in large part due to the significant plume rise as shown by the value of the exhaust momentum ratio ($M = w_s / U_h$) of 4.1, where w_s. is the exhaust velocity. In this test, it can be assumed that the plume center-line was usually above most of the samplers. The dilution data obtained in test 2 (M_{avg}= 1.8) are presented in Figure 3, as well as the dilution curves for models H and WCL. Model H underestimated D_{min} by a factor of at least 3. Model WCL underestimated D_{min} by a factor of at least 2 at most of the sampling points, except for a penthouse sampler near the stack (S = 4.7 m). At this location, the WCL D_{min} exceeded the measured value by a factor of 1.5. However, it is important to note that the conservative forecasts produced by the WCL at most locations are due to the lack of direct contact with the plume. Note also that the wind was usually not from the critical azimuth for most samplers.

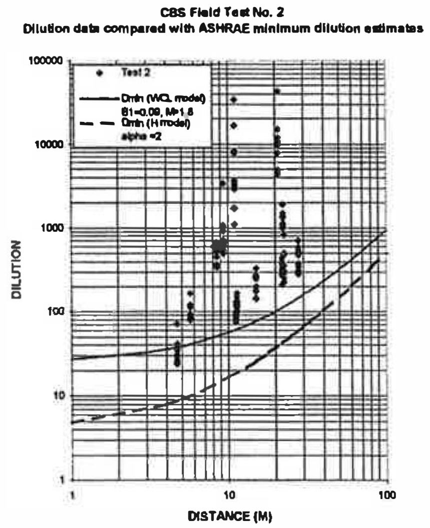

Figure 3. CBS Field Test No.2 dilution data Compared with ASHRAE minimum dilution estimates

The dilution data and the curves for test 3 (M_{avg}= 2.7) are presented in Figure 4. As in test 2, model H underestimates the actual dilution at all locations by a factor of at least 3. Model WCL also underestimates D_{min} at most locations.

However, the WCL model overestimates D_{min} by a factor of 2 at S = 11 m. The overestimation of D_{min} near the stack by the WCL model in tests 2 and 3 is likely due to the overestimation of initial dilution, D_o – see Appendix. The assigning of too large a value to the distance dilution parameter, B_1, could also explain the observed overestimation. However, considering the fact that the smallest dilution measured at S = 11 m is approximately 35 (a value practically equal to D_o), B_1 would have to be significantly reduced to fit the WCL curve to the data. Such a significant reduction in B_1 is rather unlikely, due to the fact that the turbulence in the upwind flow is higher than 50 %. Therefore, it is more likely that the initial dilution formula used by model WCL overestimates D_o.

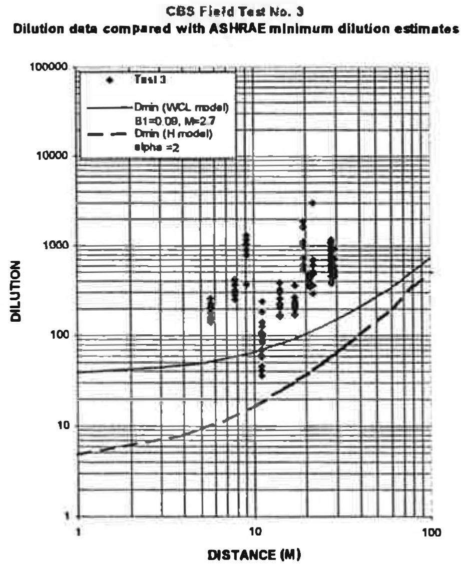

Figure 4. CBS Field Test No. 3 Dilution data compared with ASHRAE minimum dilution estimates

Conclusion

The results of the study show that the Halitsky (H) model gives a conservative estimate of the actual dilution, while the Wilson-Chui-Lamb (WCL) model generally give reasonable lower limits for the minimum dilution, even though the model overestimates certain data near the stack. The field experiments show that low dilution can occur even for high velocity stacks.

References

1. ASHRAE (1997) Chapter 15, Airflow around buildings, *ASHRAE handbook—1997 fundamentals*, American Society of Heating, Refrig. and Air-Cond. Eng. Inc., Atlanta.
2. Petersen, R.L. and Wilson, D.J. (1989) "Analytical versus wind tunnel determined concentrations due to laboratory exhaust", *ASHRAE Trans.*, vol. 95(2), pp. 729–736.
3. Schuyler, G.D. and Turner G.G., (1989) "Comparison of wind tunnel test results with empirical exhaust dilution factors" *ASHRAE Trans.*, vol. 95(2), pp. 729–736.
4. Lam, K.S. and Kot, S.C., (1993) "Field study of roof top dispersion in an urban area" 3rd Asia-Pacific Symposium on Wind Engineering, Dec13–15, Hong-Kong.
5. Georgakis, K., Smith, J., Goodfellow, H. and Pye, J. (1995) "Review and evaluation of models estimating the minimum atmospheric dilution of gases exhausted near buildings", *Journal of the Air and Waste Management Assoc.*, vol. 45, pp. 722–729.
6. Stathopoulos, T., Lazure, L. and Saathoff P. (1999) "Tracer Gas Investigation of Reingestion of Building Exhaust in an Urban Environment". Research report R-213, Série études et recherche, IRSST, February.
7. Halitsky, J. (1963) "Gas diffusion near buildings", *ASHRAE Trans*. vol. 69, pp.464–484.
8. Wilson, D.J. and Chui, E., (1985) "Influence of exhaust velocity and wind incidence angle on dilution from roof vents", *ASHRAE Trans.*, vol. 91(2B), pp. 1693–1706.
9. Wilson, D.J. and Chui, E., (1987) "Effect of Turbulence from Upwind Buildings on Dilution of Exhaust Gases", *ASHRAE Trans.*, vol 93(2), pp. 2186–2197.
10. Wilson, D.J. and Lamb, B., (1994) "Dispersion of exhaust gases from roof level stacks and vents on a laboratory building" *Atmospheric Environment*, vol. 28, pp. 3099–3111.

Appendix

Halitsky model (H) $D_{min} = [\forall + 0.11 (1 + 0.2\forall) S/A_s^{0.5}]^2$

Where : D_{min} = minimum dilution
$\forall$ = 2 (variable related to momemtum ratio, M)
M = exhaust velocity (w_s) / average wind velocity (U_h)
S = distance from emission source
A_s = exhaust area

Wilson/Chui/Lamb model (WCL) $D_{min} = (D_o^{0.5} + D_d^{0.5})^2$

Where : D_o (initial dilution at emission point) = $1 + 13\exists M$
D_d (dilution as function of distance) = $B_1 S^2 / MA_s$
$\exists$ = stack capping factor (1 for uncapped stack)
$B_1 = 0.027 + 0.0021\Phi_2$
Φ_2= standard deviation of fluctuations in the wind direction
S= distance from emission source