VA-89-10-4

#3617

Comparison of Wind Tunnel Test Results with Empirical Exhaust Dilution Factors

G.D. Schuyler, P.E.
Member ASHRAE

G.G. Turner

ABSTRACT

Dilution factors, obtained from scale-model tests in a boundary layer wind tunnel, were compared to empirical dilution factors obtained using the equations presented in the new (1989) chapter 14 of the ASHRAE Fundamentals Handbook. The use of this information in making design decisions is also discussed. The comparison illustrates the fact that while the empirical equations are useful in identifying a potential problem condition, building geometry can greatly alter the dilution. Consequently, a healthy level of conservatism should be maintained in setting stack heights or intake locations.

INTRODUCTION

Due to the complexity of airflows around buildings, it is extremely difficult to predict the amount of dilution that will occur between building exhausts and intakes. As discussed in chapter 14 of the ASHRAE Fundamentals Handbook, many situations are best assessed using wind tunnel testing of scale models. However, in many reasonably simple cases, an initial assessment of the potential for cross-contamination can be made. This chapter can be used in more than one way. Wherever possible, it can be used as a guide to the location and design of exhaust stacks and intakes. By maintaining exhaust locations well above the recirculation and high turbulence zones shown in Figure 1 (Figure 16 of the chapter), extremely low levels of cross-contamination can be achieved.

When it is found that exhaust and intake locations are within a recirculation and high-turbulence zone, the chapter can be used to estimate contamination levels. Whether or not a problem exists depends on the dilution level, the toxicity of the contaminant, and the concentration level of the contaminant in the exhaust effluent.

The methods described in chapter 14 can be used as an initial assessment of potential exhaust contamination to see if more detailed testing is required. This paper demonstrates the use of the chapter for this purpose. A test case is used as an illustration and was chosen from one of more than 60 similar tests performed in the past several years. The equations used

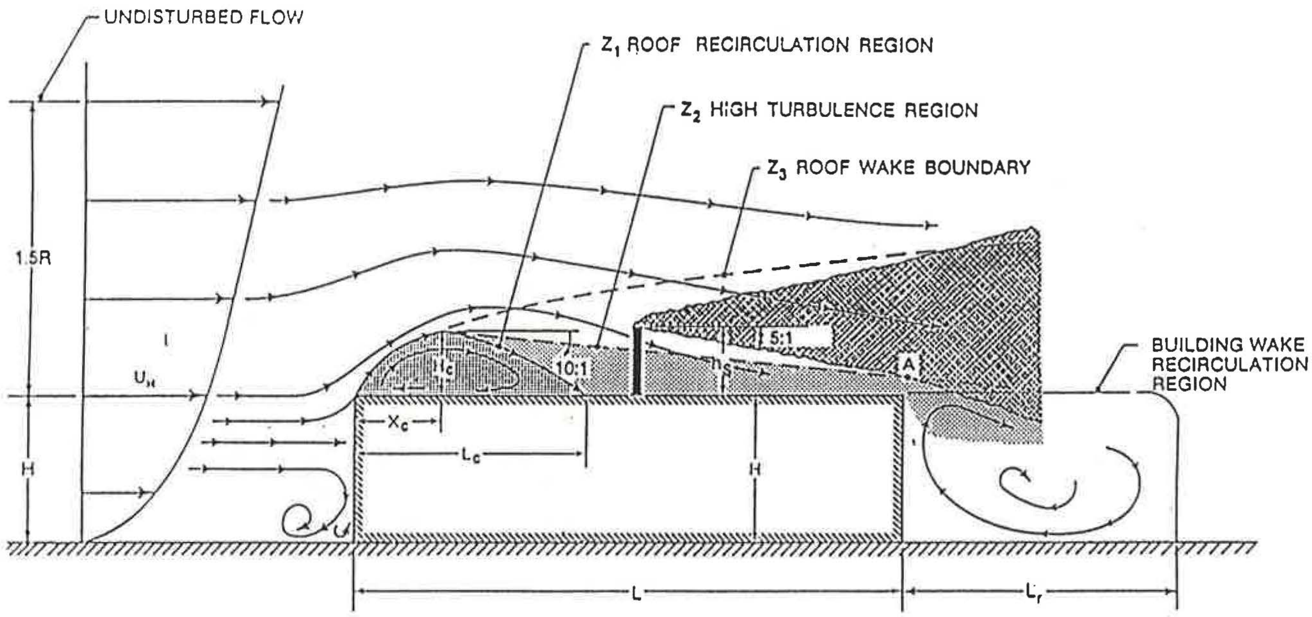


Figure 1 *Centerline wind and stack flow patterns.*

G.D. Schuyler is Principal and **G.G. Turner**, Project Coordinator, Rowan Williams Davies & Irwin Inc., Guelph, Ontario.

in this presentation are assigned the same equation numbers as in chapter 14 for easy reference.

CALCULATION OF DILUTION

The building, shown in Figures 2 and 3, is a laboratory building. The site plan of the study building is given in Figure 2. The surroundings are less than half the height of the study building and are located more than 100 m (328 ft) away from the building. The building has a simple shape. These two characteristics make it a good candidate for the calculation methods. The exhaust stacks are shown at locations A, B, and C on the penthouse roof. The full-scale exhaust characteristics are presented in Table 1. The intake locations that we will be dealing with are shown in Figure 1 as Receptors 1 and 2. Receptor 1 is located on the main roof of the building. Receptor 2 is located on the penthouse wall.

In the following discussion, the impact of exhaust sources A and B on Receptor 1 and the impact of source C on Receptor 2 are discussed.

Figure 3 shows the building in section. Using the building dimensions given in Figures 2 and 3, we can compute the height of the penthouse recirculation and wake zones using Equations 1 and 2. These zones are identified in Figure 3. We see that Receptor 1 and exhaust sources B and C will be within the calculated high-turbulence zone. Exhaust A protrudes slightly above the calculated high-turbulence zone. Some of the exhaust plume, however, will be drawn into the recirculation zone. Receptor 2 is located on the wall of the penthouse and would be within both the high-turbulence zone and penthouse wake recirculation region.

If we start out assuming that the stacks are flush with the roof, we can use Equations 19, 20, and 21 to compute the minimum dilution between exhaust and receptor location.

$$D_{min,0} = [D_0^{0.5} + D_s^{0.5}]^2 \qquad (19)$$

$$D_0 = 1 + 7.0\,\beta\,(V_e/U_H)^2 \qquad (20)$$

$$D_s = B_1\,(U_H/V_e)\,(S^2/A_e) \qquad (21)$$

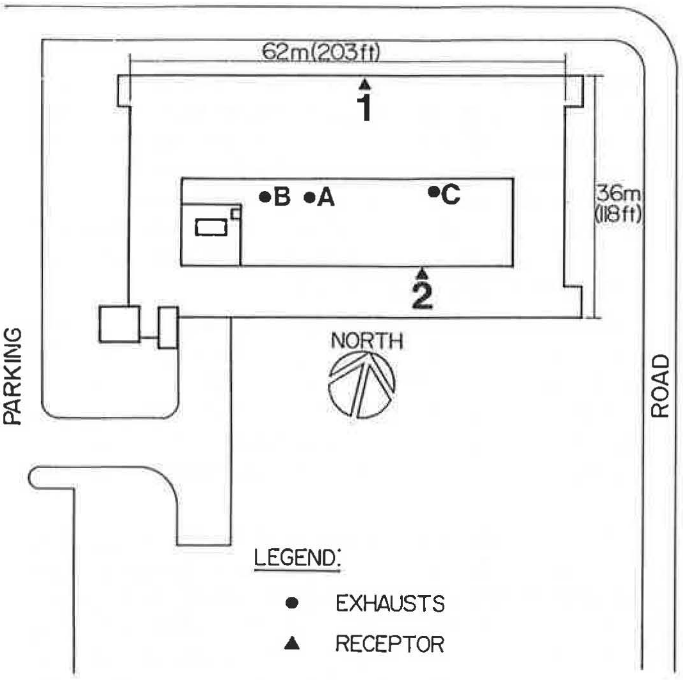


Figure 2 *Site plan of case study building.*

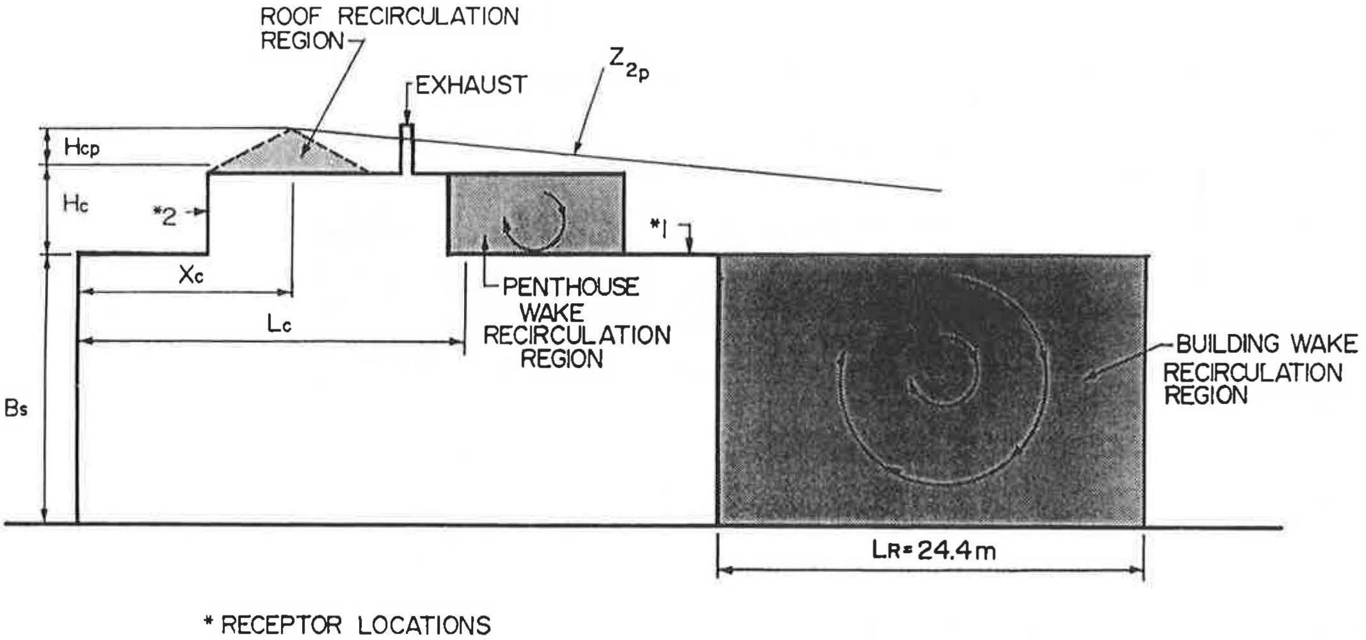


Figure 3 *Recirculation regions of case study building.*

where

$D_{min,0}$	=	minimum dilution for a roof-level exhaust
B_1	=	geometry and turbulence factor
β	=	1 for capped and 0 for uncapped exhausts
V_e	=	exhaust exit velocity
U_H	=	wind speed at roof height
S	=	stretched string distance from exhaust to intake
A_e	=	exhaust area

For uncapped exhausts, these equations give a minimum dilution, which, for any given geometrical situation, varies with wind speed, U_H. More important in providing an assessment of potential problems are the critical values of U and D, given in Equations 22 and 23. They represent the wind speed at which $D_{min,0}$ is the lowest. In the case of a capped exhaust, a minimum value occurs at $U_H = 0$ m/s.

$$U_{crit,0}/V_e = 2.9\, B_1^{-0.33}\, (S/A_e^{0.5})^{-0.67} \quad (22)$$

$$D_{crit,0} = 1 + 7.0\, B_1^{0.67}\, (S/A_e^{0.5})^{1.33} \quad (23)$$

These, as it mentions in the chapter, are approximations and the $D_{crit,0}$ approximation is good for $S/A_e^{0.5} > 5$.

In our case, the chapter mentions that the value of B_1, the distance dilution parameter, should be about .0625 for assessing concentrations at Receptor 1. For assessing concentrations at Receptor 2, the value of B_1 should be about 0.20, which is appropriate for roof exhausts with wall intakes. We can therefore compute these parameters using the physical parameters of this case study, so that

	Source A (at Receptor 1)	Source B (at Receptor 1)	Source C (at Receptor 2)
$D_{crit,0}$ =	456	575	504
$U_{crit,0}$ =	3.2 m/s (10.5 ft/s)	2.9 m/s (9.5 ft/s)	3.1 m/s (10.2 ft/s)

Since source A is capped, this is not a true minimum for that case. Figures 5, 6, and 7 show $D_{min,o}$ as a function of U_H/V_e for sources A, B, and C, respectively.

We would still like to take account of the exhaust stack height and can correct our critical values for stack height using Equations 24 and 25.

$$U_{crit,0}/U_{crit} = [12.6\,(h_s/S)^2 + 1]^{0.5} - 3.55\,(h_s/S) \quad (24)$$

$$D_{crit}/D_{crit,0} = (U_{crit}/U_{crit,0})\, \exp[12.6\,(h_s/S)^2 + 3.55\,(h_s/S) \times (12.6\,(h_s/S)^2 + 1)^{0.5}\,] \quad (25)$$

Using our case study parameters, we arrive at:

	Source A (at Receptor 1)	Source B (at Receptor 1)	Source C (at Receptor 2)
$U_{crit,0}/U_{crit}$ =	.67	.87	.76
$D_{crit}/D_{crit,0}$ =	2.7	1.4	1.9

Therefore,

	Source A (at Receptor 1)	Source B (at Receptor 1)	Source C (at Receptor 2)
D_{crit} =	1246	780	966
U_{crit} =	4.8 m/s (15.7 ft/s)	3.3 m/s (10.8 ft/s)	4.1 m/s (13.5 ft/s)

We need to know, however, how these numbers help us judge the performance of these exhausts and intakes. First, we must decide if these dilution levels would cause problems to occupants of the building. Second, we must decide how frequently, if ever, they will occur.

INTERPRETATION OF RESULTS

To decide if the dilution levels described above would pose a problem, we need to know what types and concentration levels of chemicals are being exhausted from the stacks.

In addition to the types and concentration levels, we also need to know at what concentration levels these chemicals pose a problem to health, comfort, or serviceability. We all recognize the first (health) as being of prime importance, but the other two can still cause considerable grief even when safety is not an issue. An example of this might be emergency diesel generator fumes entering an intake once every week when the generator is tested. Diesel odors are a common source of complaint and are worthy of further discussion.

TABLE 1

Full Scale Exhaust Details

Exhaust Source	Stretched String Distance		Stack Height		Stack Diameter		Exit Flow Rate		Exit Velocity		Temp.
	(m)	(ft)	(m)	(ft)	(mm)	(in)	(L/s)	(cfm)	(m/s)	(ft/s)	
A	21	69	2.4	7.9	254	10	472	1000	9.3	30.5	ambient
B	25	82	1.0	3.3	254	10	472	1000	9.3	30.5	ambient
C	13	43	1.0	3.3	254	10	472	1000	9.3	30.5	ambient

DIESEL ODORS

Diesel odors cause problems well below the level where they pose a health risk and are a very common source of complaint in many types of buildings. It is a difficult problem to handle due to the very low levels of diesel fumes needed to cause a problem. Generally, the concentration levels where problems occur are at least one order of magnitude lower than any safety criterion would require.

For guidance on the severity of diesel odors, one source of information is Cernansky (1983). Figure 4 is a composite of two figures presented in his review paper. It presents the human perception of diesel odor as a function of dilution ratio (C_o/C). At dilution levels of 500:1, approximately 90% of a normal population would find it objectionable. At a dilution level of 2500:1, the odor is considered fairly weak but still objectionable to about 55% of the population. If we extrapolate the results of this paper to the point where only 20% of the population find it objectionable, we find that we would require a dilution ratio of about 5000:1.

CHEMICAL THRESHOLDS

In many cases, owners and operators of facilities are unable to determine the chemicals that may be in use or the concentrations that may be exhausted. To help shed some light on this issue, however slight, we have prepared a list of some common chemicals and determined four different threshold values for each. Table 2 presents this list.

The column on the far right of Table 2, marked "odor thresholds," shows the values given for the low odor thresholds, which are the levels at which the chemicals would first be detectable to some people. The high odor threshold values are levels at which a large percentage of the population would find the odor objectionable.

The figures in the column of Table 2, which is marked NIOSH, are the eight-hour average occupational health and safety levels, published by the Occupational Safety and Health Administration as shown in the NIOSH Pocket Guide to Chemical Hazards 1987 (U.S. Department of Health and Human Services 1985). These are the levels above which it can be considered unsafe for workers. The legality and enforcement of these numbers are not our concern at present, since we simply wish to have a recognized safe working limit for demonstration. The left column gives the Ontario Ministry of Environment-proposed ambient air quality standards for Ontario. They represent a well-considered set of levels that can be used as an assessment guide. The Ministry of Environment levels are not safety limits. They are, rather, levels above which some noticeable effect on the environment can be detected when these concentrations are present in the air. The effects could be on plant or animal life as well as soil or

TABLE 2

Recommended Concentratioin Limits for Some Chemicals in Use in Typical Laboratories

	MOE Proposed Standard		NIOSH 8-h Avg.	ACGIH 15-min	Low & High Odor Thresholds
	(mg/m^3)	Avg. time	(mg/m^3)	(mg/m^3)	(mg/m^3)
Acetone	39.5	1-h	590	2375	47-1614
Benzene	3.3	24-h	0.32	7.5	4.5-270
Cresols	0.075	24-h	10	-	.0012-22
Ethyl Acetate	19	1-h	1400	-	.020-665
Ethylene Oxide	0.005	24-h	0.18	-	520-1400
Formaldehyde	0.065	1-h	0.12	3	1.5-74
Hydrogen Chloride	0.04	24-h	7	-	7-49
Mercury	0.002	24-h	0.05	-	-
Methyl Alcohol	28	24-h	260	-	13-26840
Methyl Chloroform	115	24-h	1900	2450	543-3800
Methylene Chloride	100	1-h	1738	1740	540-2160
Methyl Mercaptan	0.02	1-h	0.05*	-	.00004-.082
Nitric Acid	0.035	24-h	5	10	.75-2.5
Nitrogen Dioxide	0.20	24-h	9	10	2-10
Pentachlorophenol	0.02	24-h	0.5	-	-
Phenol	0.1	24-h	19	38	.18-22
Phosphoric Acid	0.1	24-h	1	3	-
Sulfur Doixide	0.275	24-h	1.3	10	1.18-13
Sulfur Acid	0.035	24-h	1	-	1.0-1.0
Toluene	2	24-h	376	560	8.0-150
Xylene	2.3	24-h	435	655	.35-174

MOE = Ontario Ministry of the Environment

NIOSH = National Insititute for Occupational Safety and Health (U.S. Department of Health and Human Services - ref. *Pocket Guide to Chemical Hazards*, Feb.1987)

ACGIH = American Conference of Governmental Industrial Hygienists (ref. *Threshold Limit Values and Biological Exposure Indices for 1986-1987*)

ODOR THRESHOLDS (ref. *American Industrial Hygienists Association Journal*, Vol. 47, March 1986, pp.A-142 to A-151)

*15-minute ceiling

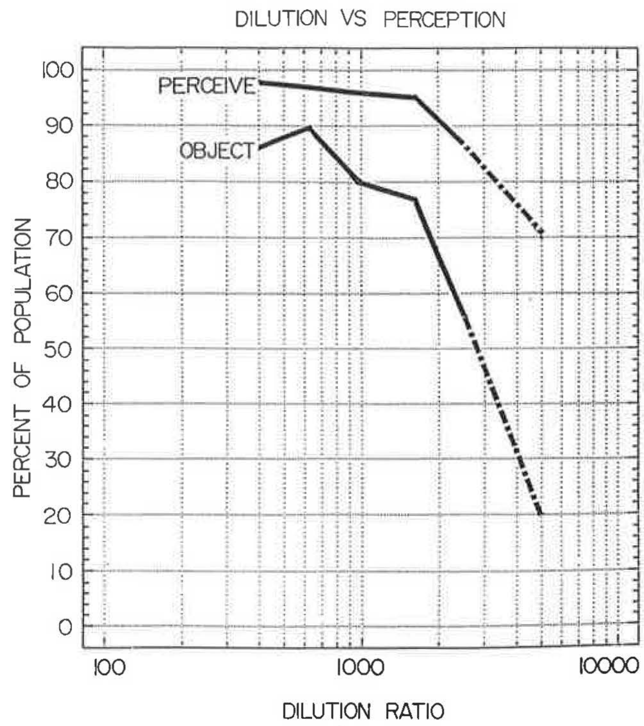


Figure 4 *Diesel odors—dilution vs perception.*

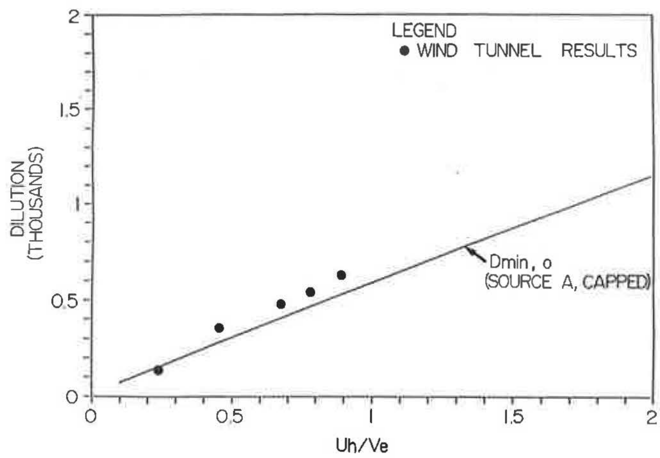


Figure 5 *Comparison of wind tunnel results with emprical dilution factors—Source A.*

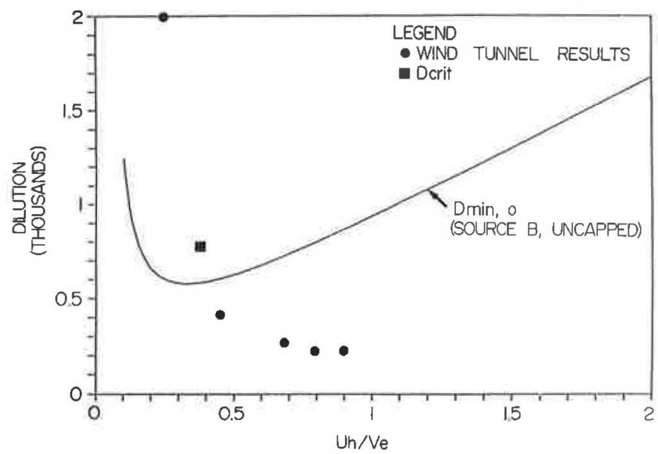


Figure 6 *Comparison of wind tunnel results with emprical dilution factors—Source B.*

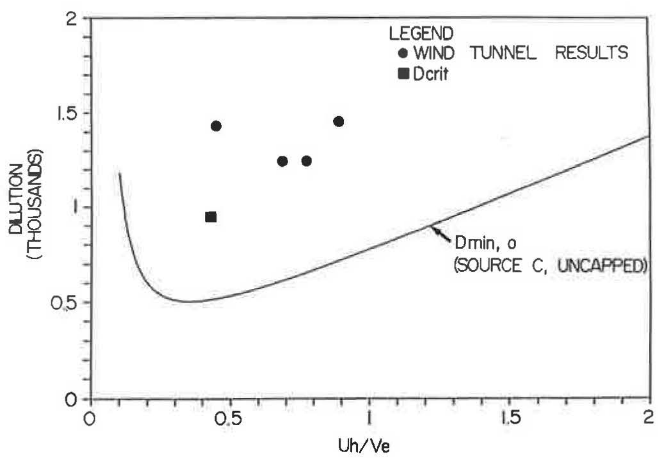


Figure 7 *Comparison of wind tunnel results with emprical dilution factors—Source C.*

property. They may include health, odor, soiling, surface damage, etc. For example, a chemical concentration that is safe for plants and animals but etches paint would not be acceptable.

The different levels can be used in different situations. For example, the design of a process exhaust on a factory roof would use the NIOSH criteria for its own intakes to protect its workers but would use the clean air criteria when dealing with a neighboring condominium. On a laboratory building, the NIOSH values may be used for general chemical use in fume hoods, but the 15-minute ACGIH levels may be used in considering spill scenarios.

With a list such as this, the minimum dilution can be used to calculate backwards to a maximum release rate from the stack. This, in many cases, is more useful information to the operator in assessing the potential for a problem.

FREQUENCY OF OCCURRENCE

The second issue in determining the adequacy of exhaust dilution is how often a problem will occur. In the case of highly toxic chemicals, once is too many, but in the case of strong odors, for example, the owner may be willing to accept a certain number of occurrences each year. Figures 5, 6, and 7 show the variation of $D_{min,0}$ with wind speed (solid line) for our case study for sources A, B, and C. We can see that for the uncapped conditions (Figures 6 and 7), there is a range of wind speeds where $D_{min,0}$ is nearly the same. The range of wind speeds that can cause a problem will be wider or narrower depending on the allowable amount of dilution. We need to determine the frequency of occurrence of wind speeds within the range that will cause a problem.

One source of wind speed information is the *Climatic Atlas of the United States* (U.S. Department of Commerce 1967). This atlas gives the average wind speed and the major wind directions as well as other weather data for many locations in the U.S. If the average wind speed is near the critical wind speed for the stack and the stack and intake are aligned with the prevailing wind direction, then one can expect that a problem condition could occur very frequently. Beyond this level of comparison, the analysis requires much more detailed information. Caution is required in using wind direction to limit cross-contamination. Building wakes and recirculation zones commonly produce upwind flows and greatly skewed wind patterns. The less prevailing winds can also cause problems for significant periods of time and thus should not be ignored. For study buildings in Canada, wind speed information is available from the Canadian Climate Normals, obtainable from Environment Canada. Sources of hourly weather data are cited in chapter 14.

If we assume that our case study building is in Toronto, then the alignment of the prevailing winds is shown in Figure 8. This figure shows the probability expressed as the percentage of time that wind will blow from a sector when the wind exceeds a certain wind speed threshold. From this figure, we can see that when all winds are considered, south (clockwise) through north and east are the most frequently occurring wind directions. As we can see from this figure, winds blow from stacks A and B to Receptor 1 approximately 20% of the time.

The average wind speed for the area (U_{ref}) is about 4.5 m/s (14.8 ft/s), 10 m (33 ft) above the ground. Since the roof height of the building is 15 m (49 ft), the following equation can be used to compute U_H, the velocity at roof height:

$$U_H = U_{ref} (H/H_{ref})^{\alpha} \qquad (26)$$

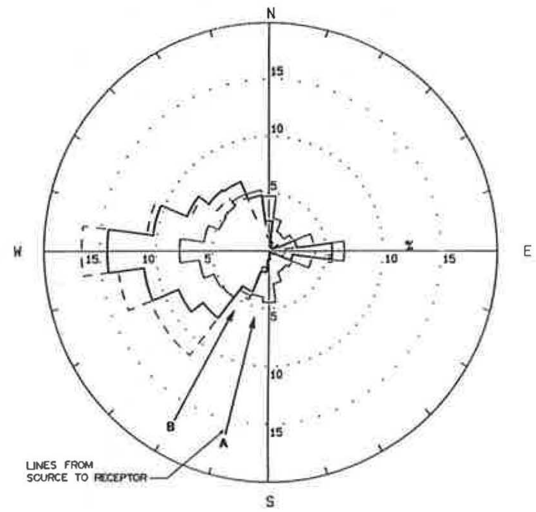
In this case study, the surroundings are considered suburban. The boundary layer is therefore characterized by a power law profile with an exponent of α = 0.25 and a free stream gradient height of 396 m (1300 ft). To compute U_H we must scale up to gradient height with the open airport profile and then down to 15 m (49 ft) using the suburban profile.

Therefore $U_H = 4.5\ (305/10)^{.15} \times (15/396)^{.28} = 3.0$ m/s (9.9 ft/s).

With a stack exit velocity of 9.3 m/s (30.5 ft/s), this results in an average value of U_H/V_E of about 0.3, which is below U_{crit} with D_{crit} values on the order of 1000.

This would constitute a diesel odor problem if this were a diesel exhaust stack. In fact the stacks are fume hood exhausts. Exhaust concentrations of more than 36 mg/m^3 formaldehyde could cause regular exceedances of the eight-hour average NIOSH limit for worker safety in the building.

The detailed wind tunnel results can be compared with these calculations to see if the same conclusion would be reached.



TORONTO, ONTARIO

—— > 0 m/s (ALL WINDS)
—— >10 m/s (33ft/s) (1 EVENT PER WEEK)
--- >13 m/s (43ft/s) (1 EVENT PER MONTH)

FREQUENCY OF OCCURRENCE IN %

TICK MARKS INDICATE FROM WHERE THE WIND IS DIRECTED
FREQUENCIES ARE FOR 15.0 DEGREE SECTORS OF THE COMPASS

Figure 8 *Directional distribution of winds 10 m (33 ft) above grade.*

WIND TUNNEL TEST METHODOLOGY

For the case study under consideration, a 1:200 scale model of the study building was tested in a boundary layer wind tunnel. The surrounding terrain and structures for a radius of 244 m (800 ft) were included on the model. The model was constructed on the turntable in the 2.4 m (8.0 ft) diameter working section of the tunnel, allowing the model to be rotated, thereby simulating the wind approaching the site from any wind direction. By adjusting the wind tunnel speed, the effect of wind speed on exhaust dispersion was studied.

The boundary layer wind tunnel used in the case study tests had a long working section with a roughened floor and specially designed turbulence generators at the upwind end. These enabled the mean wind speed profile and turbulence intensity of the wind approaching the modeled area to be correctly simulated. The mean wind speed at a given height is proportional to the ratio of that height to the height of the boundary layer raised to an exponent, as shown by the equation in the previous section. The value of the exponent depends on the terrain upwind of the site. For the case under consideration, the upwind terrain was classified as suburban for all wind directions. The corresponding value of the mean wind speed profile exponent used for testing was 0.25.

The tests were conducted utilizing a tracer gas technique in the wind tunnel. During the tests, a precisely metered mixture of air and carbon monoxide tracer gas was emitted from the exhaust sources in turn and the amount of tracer gas at the receptor location was measured using a continuous sampling technique.

The concentration data were reduced to the form of percent exhaust concentration ratios by the following equation:

$$C = (C_M / C_E) \times 100 \qquad (27)$$

where

C = percent concentration ratios

C_M = measured tracer gas concentration at receptor

C_E = concentration of tracer gas in exhaust

The value of C thus represents the percentage of the volume of the receptor air that originally came out of the exhaust. The dimensions and exhaust flow characteristics used in the tests are summarized in Table 1.

COMPARISON WITH WIND TUNNEL RESULTS

The model was tested in a boundary layer wind tunnel facility that was used to simulate the natural wind for 24 different wind directions at five different values of U_H / V_e. The different wind speeds were tested to show the effect of exhaust momentum on dilution. Table 3 provides the results for the exhaust sources A and B and Receptor 1 in the form of concentration ratios. Table 4 provides the results for exhaust source C and Receptor 2. The concentration ratios presented in Tables 3 and 4 were obtained by dividing the measured concentration of tracer gas at the receptor by the initially metered concentration exiting from the exhaust source. The wind speeds given in Tables 3 and 4 refer to a height of 10 m (33 ft) above ground level. The speed at the roof height of the building (i.e., U_H) would be approximately 11% higher. Thus, the 2.2 m/s (7.2 ft/s) would correspond to a U_H of about 2.5 m/s (8.2 ft/s). From Table 3 it can be seen that for source A and Receptor 1 the worst dilution ratio of 120.5 (i.e., a concentration ratio of 0.83%) occurs at a wind angle of 195° and a wind speed of 8 km/h.

The wind tunnel results are plotted in Figures 5, 6, and 7 for exhaust sources A, B, and C, respectively. We see that the measured results for source A, the capped case, compare well with the D_{min} value computed from Equations 24 and 25.

The value of D_{crit} and the curve of $D_{min,0}$ for source B, the uncapped case, do not agree as well. This may be due partly to the fact that the wind angle at which the source and receptor align is 50° from being perpendicular to the face of the building. On closer inspection of the geometry of the situation, it was concluded that air-handling units on the roof of the penthouse put source B into a wake region, which caused major changes in the dilution. This is probably why this par-

TABLE 3

Ratios of Concentration at Receptor 1 from Source (%)

Source*	Wind Speed (km/h)	Wind Direction(degrees) 150	165	180	195	210	255	240	255
A	8.	0.22	0.54	0.82	0.83	0.51	0.29	0.19	0.04
A	15.	0.09	0.26	0.31	0.28	0.24	0.14	0.10	0.02
A	23.	0.05	0.16	0.24	0.21	0.17	0.10	0.05	0.01
A	26.	0.05	0.15	0.18	0.18	0.14	0.09	0.06	0.01
A	30	0.04	0.13	0.17	0.15	0.14	0.07	0.04	0.01
B	8.	0.01	0.02	0.04	0.05	0.03	0.01		
B	15.	0.03	0.07	0.14	0.24	0.14	0.07	0.01	
B	23.	0.04	0.13	0.24	0.38	0.29	0.09	0.01	
B	26.	0.05	0.14	0.27	0.42	0.28	0.10	0.02	
B	30.	0.05	0.15	0.25	0.42	0.30	0.09	0.02	

*Source A capped; Source B uncapped

TABLE 4

Ratios of Concentration at Receptor 2 from Source (%)

Source	Wind Speed (km/h)	Wind Direction (degrees) 15	30	45	300	315	330	345	360
C	8.	0.02	0.01		0.01	0.03	0.01	0.02	0.02
C	15.	0.07	0.03	0.01	0.02	0.05	0.02	0.05	0.06
C	23.	0.08	0.03	0.01	0.03	0.05	0.02	0.06	0.07
C	26.	0.08	0.02	0.01	0.03	0.05	0.03	0.06	0.07
C	30.	0.07	0.03		0.03	0.04	0.02	0.06	0.08

ticular uncapped exhaust exhibited poorer performance than the neighboring capped exhaust, which was not influenced by the air-handling units upstream.

The results for source C and Receptor 2 show that the wind tunnel results are higher than the calculated dilution. This is what we would normally expect since the calculations are designed to give the minimum dilution level. In this case there were no complicating factors such as air-handling units upstream.

The comparison shows that the conclusions drawn based on the computation would still hold when considering the wind tunnel results. However, they do point out that a considerable variability can exist, especially due to upwind structures, which must be taken into account when making decisions based on these calculations. The simple reliance on the calculations to provide a minimum dilution can lead to erroneous results where cluttered rooftops or other flow obstructions are ignored.

When budget allows, a wind tunnel test can provide a great deal more detailed information. The results can be combined with detailed weather statistics to generate the number of occurrences per year of various dilution factors, as shown in Table 5. These tables make the decision process much easier by showing how frequently a particular problem may occur. For instance, if we are concerned with an accidental spill in a fume hood, we could estimate the combined probability of a spill occurring on a day when wind conditions would cause the spill to be dangerous. If, for example, we require that there be no more than a 1% chance of a dangerous spill in any one year and we expect five spills per year, the lowest dilution ratio that could be tolerated is that which would make the yearly probability equal to 1%. This can be calculated from the following equation:

$$P = 8766 \times N_1/8766 \times N_2/8766 \qquad (28)$$

where

P = yearly probability

N_1 = number of hours per year that a spill is expected

N_2 = number of hours per year when wind conditions would cause a problem

If we plug in P = .01 and N_1 = 5, then N_2 is 17.5 hours per year. We can see in Table 5 that the highest dilution factor that occurs less than 17.5 hours per year for source A at Receptor 1 is 100 and for source B and Receptor 1, it is 200. Should a chemical spill require a higher dilution ratio, then the stack would have to be moved or raised to maintain the 1% probability. The 1% probability in any one year was chosen because it is commonly used when designing for safety in structures.

CONCLUSION

In simple cases, the computations of chapter 14 can be used to check stack design. A margin of error is associated with the results of the calculation that must be considered when making decisions based on the results of the computations. One of the major sources of variability is building geometry. As illustrated with sources B and C, small upwind obstructions can greatly alter the dilution.

To make decisions on these results, more information is needed on wind climate and the particular chemicals being used. Some basic wind data, such as the prevailing wind directions and the average wind speed, are available that can help in the decision process.

The chapter is very useful in identifying a potential problem condition as a precursor to more detailed wind tunnel study. When using it on its own as a design tool, one should maintain a healthy level of conservatism in setting stack heights or intake locations.

REFERENCES

Cernansky, N.P. 1983. *Diesel exhaust odour and irritants: a review journal of the air pollution control association*, Vol. 33, No. 2, February.

Ontario Ministry of the Environment. Proposed ambient air quality standard.

U.S. Department of Commerce. 1967. *Climatic atlas of the United States.*

U.S. Department of Health and Human Services. 1985. Publication No. 85-114, "NIOSH pocket guide to chemical hazards."

TABLE 5

Average # of Hours/Year Below Dilution Factor at Receptor 1

	Dilution Factor							
Source	1000	500	333	250	200	143	100	67
A	1679.	856.	497.	382.	269.	100.	0.	0.
B	752.	429.	186.	68.	0.	0.	0.	0.