The results were in agreement with the formula for roof exhaust near the exhaust but at greater distances (5 - 10 m; $S/\sqrt{A_c} > 150$) the formula gave minimum dilutions that were too high. One explanation for this might be the wind condition: the formula assumes wind blowing along the wall, whereas in the measurements the wind direction was partly around the corner of the building. This caused an alteration of the flow-field near the wall.

On the basis of cooking tests performed (3), up to 0.6 % of exhaust air can be permitted in the supply air. In accordance with the definition of this odour threshold, 50 % of the occupants do not observe any odour. The corresponding minimum dilution is 168. The value was determined in test conditions where herring were fried. Here it has been assumed that the exhaust air of the apartment does not contain any odour other than that caused by cooking. In this study 2-minute mean values obtained for the intake air were lower than the highest permitted value of 0.6 % (the highest 2-minute mean was 0.5 %).

The results concerned only one exhaust. However, it is possible that a number of families are eating herring on the same day. Accordingly, the summarizing effect of numerous exhausts should be studied.

CONCLUSIONS

The formula for minimum dilution in the ASHRAE Handbook (4) can be used for wall exhaust over short distances. For longer distances (5 - 10 m) the formula gave minimum dilutions that were too high.

The highest 2-minute mean intake air concentration was 0.5 % of the exhaust air concentration. This relative concentration was slightly smaller than the odour threshold value of 0.6 %.

The effect of the sampling time was found to have a considerable effect on the results.

On the basis of the tests performed so far, the wall exhaust system seems to be acceptable in residential buildings. The summarizing effect of numerous exhausts should be studied.

ACKNOWLEDGEMENTS

Helpful advice from Prof. D.J.Wilson, Alberta, Canada, before the start of this study is gratefully acknowledged. The study was supported by the Technology Development Centre (TEKES).

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ASSESSMENT OF HOOD STACK RE-ENTRAINMENT AS DETERMINED BY REAL-TIME TRACER GAS MEASUREMENTS

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ABSTRACT

A tracer dispersion study was performed to evaluate the dilution of exhaust stack emissions from chemical fume hood stacks on the rooftop of a laboratory building complex located on a United States midwestern university campus. Tests were designed to (1) experimentally verify dilution ratios at outdoor air intakes for emissions from existing chemical fume hood stacks on the building complex; (2) evaluate potential exposures to rooftop service personnel; (3) further characterize the airflow on the rooftop and the effect that turbulence might have on the dispersion of stack pollutants both instantaneously and averaged over time; and (4) evaluate the effects of increased stack heights as they relate to minimum and time weighted median stack dilution. Study results indicate that under normal operating conditions, vapors generated in the laboratories and emitted from the stacks were not expected to reach the outside air intakes in concentrations high enough to detrimentally impact the health of building occupants. However, odors of certain chemicals could be detected in some instances at the outside air intake and therefore could be sensed by occupants of the building and cause complaints about air quality.

INTRODUCTION

Environmental Health & Engineering (EH&E) performed a series of tracer gas tests to determine if the heights of currently-installed exhaust stacks provide acceptable exhaust dilution at a United States midwestern university building complex (hereafter, "the Building"). Since many of these stacks exhaust potentially hazardous substances, the dispersion of exhaust streams at the air intakes of the Building was of vital importance for the health and comfort of Building occupants. This study also provided the basis of evaluating the safety precautions that should be used by personnel who may be on the rooftop (i.e., to service equipment).

The study directly measured the amount of dilution that occurred on the rooftop from stacks of various heights, under varying wind conditions, and at various distances downwind of the source. This was accomplished by injecting tracer gas directly into an exhaust stack and monitoring the concentration of the tracer gas downwind on a real time basis using a computerized data acquisition system (DAS). These measurements were then assembled into frequency distributions to evaluate the percentage of time that the tracer dilution at the receptor was above a certain level. These measurements also serve as a check on calculated stack height requirements and outdoor air intake locations as based on a dispersion model study previously performed for these stacks and the Building's outdoor air intakes. Calculations were performed using a Gaussian Plume model for continuous sources to determine dilution ratios for planned and current stack locations, heights, and discharge velocities. The model used assumed steady-state flow conditions, and the results can best be related to the time-weighted median concentration of tracer (and dilution ratios) observed during the study. The effects of local turbulence were not included in these calculations.

METHODS

A tracer gas, sulfur hexaflouride (SF_6), was used to mark the air discharged from current and prototype stacks on the Building's rooftop. The tracer gas was delivered into the stack on the inlet side of the exhaust fan using an injection system designed to monitor and maintain a steady flowrate of tracer gas. Tracer flow was controlled by maintaining a constant delivery pressure

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across a glass capillary tube, whose output was connected to a Matheson Model 603 rotometer and then to the inlet side of the exhaust fan associated with the stack being tested. The flowmeter was calibrated in EH&E's laboratory using air. An appropriate correction factor was applied to account for the density difference between air and the tracer gas (SF_6). The total flowrate from the stack was measured and assumed to be constant throughout the test. Tracer was then detected using an ITI Model 505 Electron Capture Detector which was set up to monitor selected downwind receptors. The monitor was calibrated to detect SF_6 in the range between 10 to 750 PPB. The electrical signal from the detector was monitored every second by a PC Based data acquisition system, with the data stored on disk for later analysis. For purposes of this paper, the concentration of the tracer gas measured at the receptor locations monitored is expressed in terms of the dilution ratio, (DR), which is the stack concentration divided by the receptor concentration.

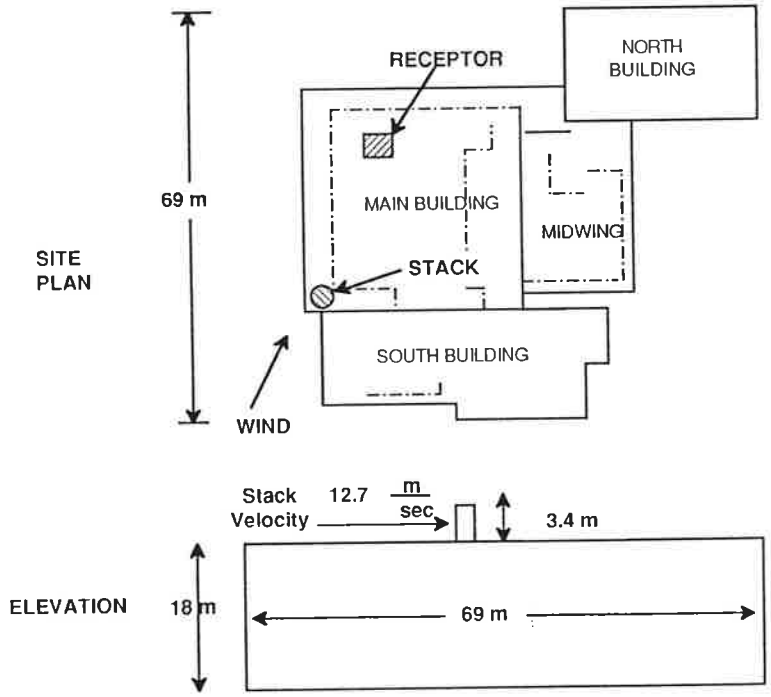

Figure 1. Schematic site plan and elevation showing location of receptor and stack on the rooftop of the building complex.

RESULTS

A total of 22 tracer tests were run over a period of four days on the top of the Building. During these tests, eight releases were made from 3.4 meter stacks, seven releases from 6.4 meter stacks, and seven releases from 7.9 meter stacks. Winds were persistently from the southwest ranging in velocity from 2.1 to 6.7 m/sec. Various down-wind distances were chosen on the Building rooftop to represent distance equivalent to that between the stack tested and the air intake. Figure 1 above illustrates the relative dimensions of the Building. Measurements were taken at downwind receptor locations on the roof ranging from 9.1 to 42.7 meters away from the stack. As can be seen from Table 1, the dilution ratios measured for all tests combined ranged from 377:1 to 4,268:1 for the 50th percentile, i.e., the minimum value for which 50% of the measurements were more diluted and 50% were less diluted out of all 22 tests was calculated to 377:1, whereas the maximum such value was calculated to be 4,268:1.

Table 1. Summary of results of 22 tracer re-entrainment tests. Results summarized by 50th and 10th percentile tracer concentrations and their corresponding dilution ratios.

Test	Date	Start Time	Stop Time	Stack Ht meters	Distance meters	Wind Speed m/sec	Tracer Concentration in PPB 50th %	Tracer Concentration in PPB 90th %	Dilution Ratio 50th %	Dilution Ratio 10th %
1	3/4/92	17:17	17:59	3.4	26.8	3.6	39	202	1,113	217
2	3/4/92	18:05	18:40	6.4	26.8	4.1	41	86	1,067	512
3	3/4/92	18:53	19:20	7.9	26.8	2.1	33	39	1,348	1,113
4	3/5/92	11:20	12:02	3.4	26.8	3.1	45	243	985	180
5	3/5/92	12:24	13:12	6.4	26.8	4.1	26	91	1,707	483
6	3/5/92	13:30	14:18	7.9	24.4	5.1	29	55	1,506	800
7	3/5/92	15:04	15:47	7.9	32.9	3.6	19	27	2,328	1,601
8	3/5/92	16:04	16:33	6.4	35.4	3.1	10	17	4,268	2,561
9	3/5/92	16:53	17:20	3.4	34.7	3.1	17	24	2,561	1,829
10	3/6/92	15:00	15:25	3.4	34.7	4.1	27	72	1,601	610
11	3/6/92	15:25	16:21	3.4	26.8	4.1	65	242	674	182
12	3/6/92	16:54	17:36	6.4	26.8	5.1	39	93	1,113	474
13	3/6/92	17:49	18:29	7.9	24.4	3.1	24	38	1,829	1,164
14	3/7/92	10:00	10:25	3.4	26.8	4.1	117	254	377	173
15	3/7/92	10:25	10:57	3.4	45.1	6.2	46	93	949	474
16	3/7/92	10:57	11:34	3.4	9.1	6.2	106	326	413	135
17	3/7/92	11:47	12:24	6.4	9.1	4.6	26	53	1,707	826
18	3/7/92	12:24	13:01	6.4	26.8	6.2	26	75	1,707	583
19	3/7/92	13:16	13:49	6.4	45.1	3.1	27	53	1,601	826
20	3/7/92	13:59	14:24	7.9	42.7	5.1	19	29	2,328	1,506
21	3/7/92	14:24	15:00	7.9	24.4	6.7	26	46	1,707	949
22	3/7/92	15:00	15:40	7.9	9.1	5.7	31	62	1,423	711
				Max	45.1	6.7	117	326	4,268	2,561
				Min	9.1	2.1	10	17	377	135
				Ave	27.7	4.6	38	101	1,560	814

The minimum dilution ratio calculated of all the tests for the 10th percentile, i.e., 90% of all values for that test were more diluted than this number was calculated to be 135:1 and the maximum dilution ratio was calculated to be 2,561:1.

Of the eight tests from 3.4 meter stacks, the dilution ratios ranged from 377:1 to 2,561:1 in the 50th percentile, and 135:1 to 1,829:1 in the 10th percentile. Of the seven tests from 6.4 meter stacks, the dilution ratios ranged from 1,067:1 to 4,268:1 for the 50th percentile, and from 474:1 to 2,561:1 for the 10th percentile. Of the seven tests from 7.9 meter stacks, the dilution ratios ranged from 1,348:1 to 2,328:1 in the 50th percentile, and from 711:1 to 1,601:1 for the 10th percentile. From these data, it can be seen that consistently more dilution can be achieved with increasingly higher stacks in the ranges which were tested.

To assess the relative effectiveness of different stack heights in diluting potential emissions, three tests that closely replicate each other in terms of wind speed and receptor distance, were chosen for comparison. In these tests, wind speeds ranged from 3.6 to 5.1 m/sec, and all measurements were taken at receptors 26.8 meters downwind from the source.

Figures 2 through 4 illustrate the typical characteristics of tracer concentrations versus time measured at fixed downwind receptors for 3.4, 6.4 and 7.9 meter tall stacks. In all cases, the tracer concentrations vary widely with time, suggesting that this exhaust plume was being entrained into a turbulent airstream. Tracer concentrations measured downwind of the 3.4 meter stack ranged from zero to 605 ppb with a time-weighted average of 88 ppb. Likewise, tracer concentrations measured downwind of the 6.4 meter stack ranged from zero to 305 ppb with a time-weighted average of 40 ppb, while those measured downwind of the 7.9 meter stack ranged from approximately zero to approximately 238 ppb with a time-weighted average of 34 ppb. When stack height is raised, there is a distinct dampening of peak amplitude and frequency of excursions.

Figures 5 through 7 show the cumulative percentage of time that the dilution ratio is less than a given amount for each of the three stack heights. 90% of the time the 3.4 meter tall stack had a dilution ration of greater than 217:1, while 50% of the time the dilution ratio was greater than 1,113:1 The 6.4 meter tall stack was shown to have a dilution ration of greater than 483:1 90% of the time, while 50% of the time the dilution ratio was greater than 1,707:1. The 7.9 meter tall stack had a dilution ration of greater than 800:1 90% of the time, while 50% of the time, the dilution ratio was greater than 1,506:1 . The tracer is detected from all three stack heights, but the percentage of time that concentrations exceed a given value (or the dilution ratios are less than a specific value) are lower for the higher stacks.

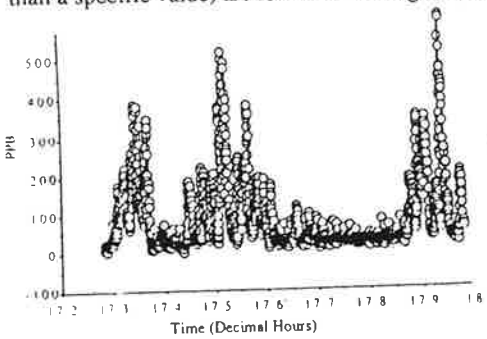

Figure 2. Results of tracer test #1 performed on 3/4/92. Tracer was released from an 3.4 meter stack, and monitored approx. 26.8 meters downwind. Winds from the southwest at approx. 3.6 m/sec.

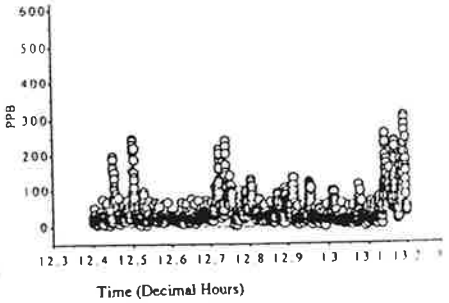

Figure 3. Results of tracer test #6 performed on 3/5/92. Tracer released from a 7.9 meter stack & monitored approx. 24.4 meters downwind. Winds from the southwest at approx. 5.1 m/sec.

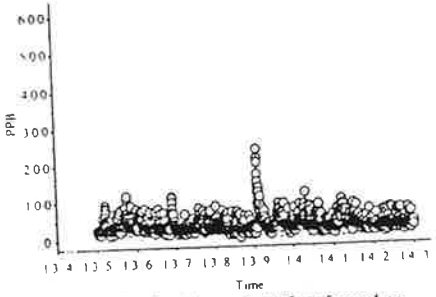

Figure 4. Results of tracer test #5 performed on 3/5/92 presented as cumulative percentage of time vs. receptor concentration. Tracer released from a 6.4 m stack, and monitored approx. 26.8 m downwind. Winds were from the southwest at approx. 4.1 m/sec.

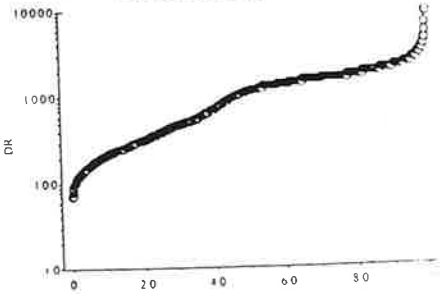

Figure 5. Results of tracer test #1 performed on 3/4/92 presented as cumulative percentage of time vs Dilution Ratio. Tracer was released from an 3.4 m stack, and monitored approx. 26.8 m downwind. Winds were from the southwest at approx. 3.6 m/sec

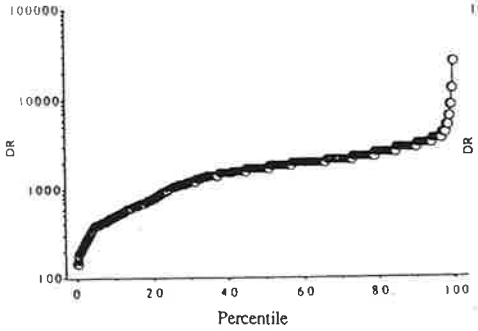

Figure 6. Results of tracer test #5 performed on 3/5/92 presented as cumulative percentage of time versus Dilution Ratio. Tracer released from an 6.4 m stack, and monitored approx. 26.8 m downwind. Winds were from the southwest at approx. 4.1 m/sec.

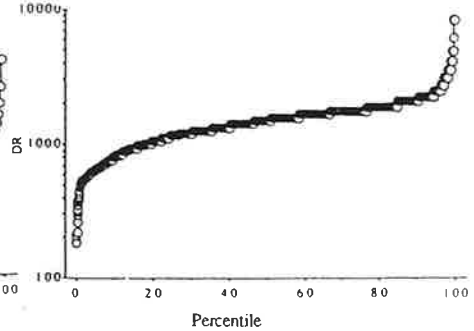

Figure 7. Results of tracer test #6 performed on 3/5/92 presented as cumulative percentage of time versus Dilution Ratio. Tracer was released from an 7.9 m stack, and monitored approx. 24.4 m downwind. Winds during this period were from the southwest at approximately 5.1 m/sec.

DISCUSSION

In summary, it can be seen from this series of figures both that the dilution achieved at a fixed receptor is greater for increased stack heights and that the variable effects of turbulence are decreased with higher stacks.

In Figures 8 through 13, measured tracer concentrations are plotted versus stack height, distance from source to receptor, and wind speed, for the 50th% tracer concentration and the 90th% tracer concentration for each of the 22 tests run.

Figures 8 and 9 show tracer concentration versus stack height for the 50th% tracer concentration and the 90th% tracer concentration. In both cases, it can be clearly seen that the spread in the ranges of concentrations observed decreases dramatically with increased stack height, and that although increased stack height does not necessarily seem to be correlated with the lowest measured concentrations, it is clearly correlated with consistently lower concentrations of tracer gas.

Figures 10 and 11 show tracer concentration versus distance from source to receptor for the 50th% tracer concentration and the 90th% tracer concentration, and Figures 12 and 13 show 50th% and 90th% tracer concentrations versus wind speed. In both cases, it can be seen that the spread in the ranges of concentrations observed decreases with increased source-receptor distance, though less dramatically than with increased stack height, and that increased source-receptor distance is not necessarily correlated with the lowest measured concentrations, but somewhat correlated with lower concentrations of tracer gas.

A review of the data collected in this study indicated that for certain used laboratory chemical odors may occasionally be detected on the rooftop and at the outside air intake of the Building. From this data, it was concluded that the occurrence of these odors will be intermittent in nature and of short duration and no direct health effects would be anticipated from these types of exposure. However, the sensing of an odor, although perhaps initially triggered by a relatively short duration exposure, can have a long-lasting impact on an individual.

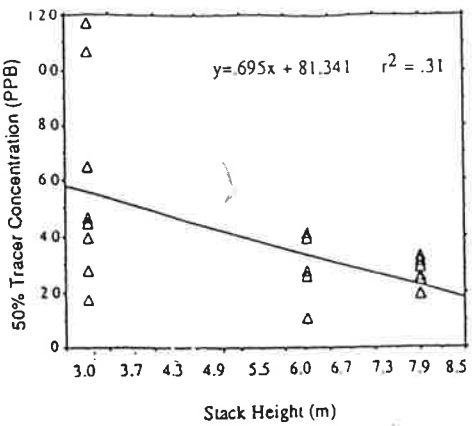

Figure 8. 50th %tile tracer concentration vs Stack Height for the 22 tracer tests performed.

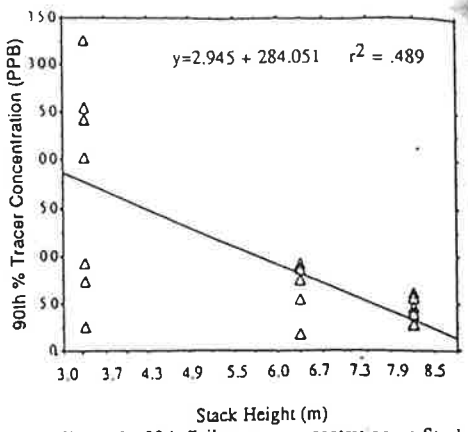

Figure 9. 90th %tile tracer concentration vs Stack Height for the 22 tracer tests performed.

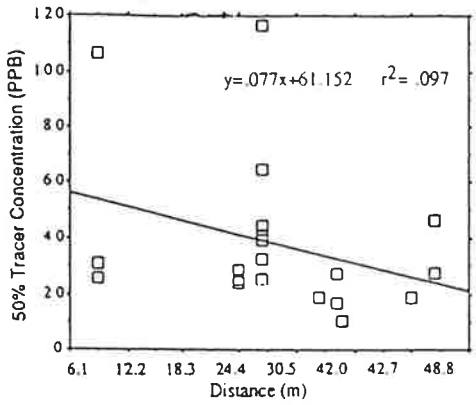

Figure 10. 50th %ile tracer concentration versus distance from source to receptor for the 22 tracer tests performed.

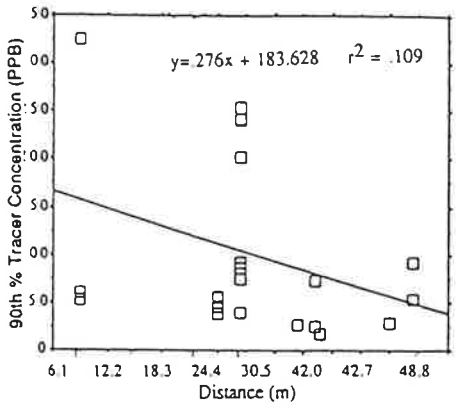

Figure 11. 90th %ile tracer concentration versus distance from source to receptor for the 22 tracer tests performed.

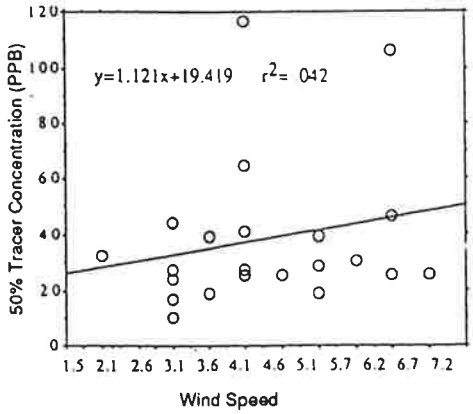

Figure 12. 50th %tile tracer concentration vs. wind speed for the 22 tracer tests performed.

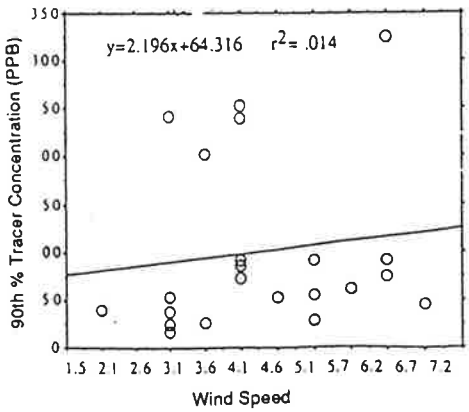

Figure 13. 90th %tile tracer concentration vs. wind speed for the 22 tracer tests performed.