HOW FRESH IS FRESH AIR?

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Ventilation designers must take care that make-up air is fresh, and not just reingested exhaust air. A common solution is to place air intakes upwind of exhaust vents for the prevailing winds. Scale model studies in a boundary-layer wind tunnel show that this is often not a solution on its own. Firstly, non-prevailing winds, although less frequent than the prevailing winds, can still occur frequently. Secondly, locally redirected flow can lead to reingestion of exhaust gas at an upwind intake. Scale model test data demonstrate the potential for relatively high levels of exhaust gas to be reingested at intakes located upwind for the prevailing winds, even when the intakes are at large distances from the exhausts.

INTRODUCTION

In the quest for cleaner indoor air, building designers have been pushing for more make-up (fresh) air. This has led to a growing concern about reingestion of building exhaust air into fresh-air intakes. Labs, hospitals and industrial buildings are a special concern, since their exhausts often contain toxic substances. In office buildings, the intrusion of odours from kitchens, truck loading docks and emergency generators has caused complaints by occupants and major retrofits by owners.

Scale model testing of reingestion from exhaust sources allows designers to safeguard the quality of incoming fresh air. This, in turn, can help reduce the quantity of fresh air required to avoid complaints. The scale model tests, conducted in a boundary-layer wind tunnel, provide both visual and quantitative information with which to develop properly designed exhaust vents and intake louvres.

This paper highlights some unexpected exhaust gas reingestion problems, uncovered by scale model tests. Although it may seem desirable to position exhaust vents downwind of fresh air intakes for the prevailing winds, tests have shown that this arrangement is not always as good as it seems. The reason is that, while the prevailing wind directions are dominant, other wind angles can also occur frequently. In addition, locally redirected wind flow on the leeward side of a penthouse or roof step can lead to reingestion at upwind intakes.

THE PREVAILING WIND

The term "prevailing winds" refers to the wind angles that occur most frequently at a site. A seemingly logical way of minimizing the potential for exhaust reingestion is to arrange the exhaust and intake vents so that the prevailing winds do not carry exhaust gases toward the intakes. If the site experiences one dominant wind direction, the goal is to place the exhaust vents downwind of the intakes for that direction. If the site experiences two dominant wind directions, opposite to each other, the goal is to place the exhausts and intakes across-wind of each other for those directions. In general, these techniques achieve a reduction in the potential for reingestion, but the reduction is often not as great as expected. As indicated by the following examples, non-prevailing winds can be more frequent than one thinks.

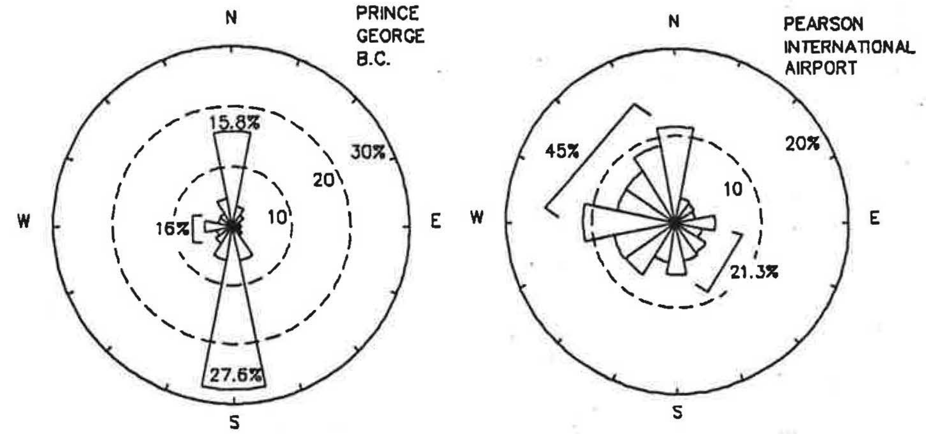

Figure 1 Wind Frequency Distributions

Figure 1 shows wind frequency distributions for Prince George, British Columbia and Pearson International Airport at Toronto, Ontario. The distributions are presented in the form of wind roses. Each wedge-shaped rose petal takes up a 22.5° wide sector of the compass. The length of the petal indicates how often the wind blows from within that sector. At Prince George, for example, winds from the south occur 27.6% of the time (about 2400 hours per year) and winds from the north occur 15.8% of the time.

The wind rose for Prince George shows that the prevailing winds come out of the south and out of the north, running parallel to the axis of the valley in which the city is located. In this situation, an engineer designing the mechanical system for a building would be inclined to place exhaust vents and fresh air intakes east and west of each other. As indicated by the wind rose, however, winds from westerly sectors (between southwest and northwest) occur 16% of the time (or about 1400 hours per year). Thus, cross-talk between an exhaust vent on the west side and an intake on the east side of the building might still be frequent.

The wind rose for Pearson International Airport shows that the prevailing winds at Toronto are less defined than at Prince George. The wind comes most frequently out of sectors between west and north (45% of the time). In this case, the engineer might tend to locate his exhaust vent on the southeast side of the building, downwind of the intakes for winds between west and north. The wind rose shows, however, that winds blowing in the opposite direction occur 21.3% of the time, or about 1900 hours per year.

REDIRECTED FLOWS

Wind flowing over a building can be locally redirected, especially downwind of a roof step, upwind of a roof step or on a roof that is lower than the roofs of surrounding buildings. In some cases, the local wind flow is directly opposite to the general wind flow, allowing an intake to reingest gases from an exhaust vent that appears to be located downwind. Often, the redirected flow occurs in a sheltered area where the wind has relatively little diluting effect on the exhaust gases. In a situation like this, placement of the intakes upwind of the exhausts for the prevailing wind may be the least desirable arrangement.

Figures 2 and 3 show actual examples of redirected flow leading to upwind reingestion.

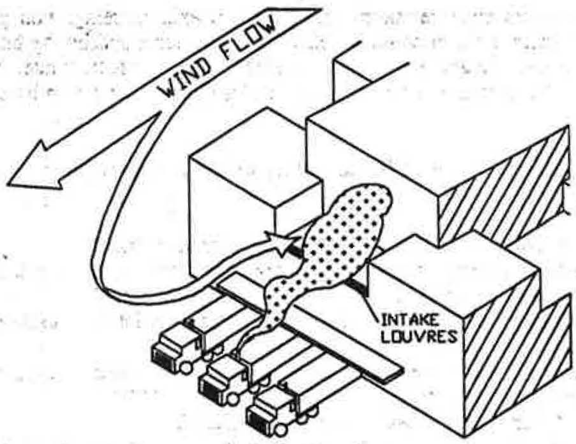

Figure 2 Isometric View of a Building with Loading Docks

The first case (Figure 2) occurred on the leeward side of a hospital building. Reverse flow directed diesel fumes from trucks at a loading bay into nearby intakes, causing complaints from the hospital staff. The second case occurred on the leeward side of a roof step, where exhaust air from a horizontal louvre was redirected toward some nearby fresh air intakes.

MEASURING REINGESTION ON SCALE MODELS

It is clear from the preceding discussions that, in addition to the direction of the

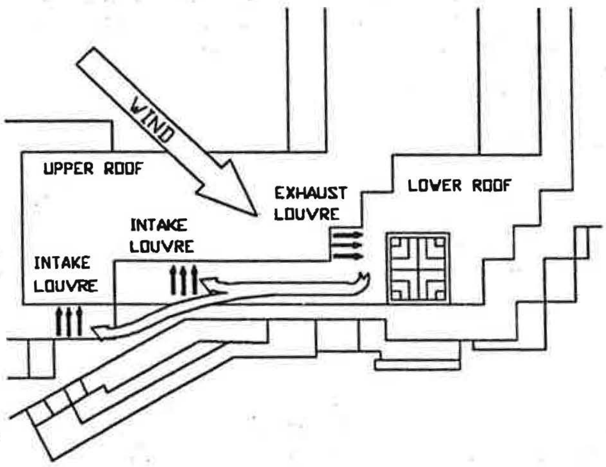

Figure 3 Plan View of Building Exhaust and Intake Louvres

prevailing wind, other factors must be taken into account if exhaust reingestion problems are to be avoided. These factors include: complicated wind flows generated by the building shape and surrounding terrain, stack height, exhaust exit velocity and exhaust flow rate. Scale model simulations provide a reliable method of accounting for all of these factors in assessing intake and exhaust vent designs.

There are several steps involved in simulating exhaust reingestion on a scale model, as summarized below:

(a) construct a scale model of the study building and its surroundings;
(b) subject the model to a wind simulation in a boundary-layer wind tunnel, examining a range of wind speeds and angles;
(c) during the wind simulation, emit smoke from an exhaust outlet and observe reingestion at fresh air intakes;
(d) replace the smoke with a tracer gas and quantify the reingestion by measuring the dilution of tracer gas reingested at the intakes;
(e) repeat (c) and (d) for each exhaust outlet to be studied;
(f) combine the wind tunnel results with wind statistics for the site in order to develop statistics on the level of reingestion.

A typical model is at a scale of 1:300 and includes all surroundings within about 350m of the study building. The wind simulation consists of reproducing at model scale the vertical profiles of mean wind speed and turbulence intensity, which depend on the roughness of the terrain surrounding the study site. The appropriate profiles are generated by a combination of the buildings and topography on the model and generalized roughness on the wind tunnel floor, upwind of the model. A detailed discussion of the principles of wind profile modelling can be found in Snyder (1981).

The exhaust gas flow characteristics at each model exhaust outlet are scaled to represent full scale, in accordance with the scaling principles described by Snyder (1981). During the tracer gas tests, air samples are drawn in at the intake locations and sent to a multichannel tracer gas monitoring system. Exhaust gas dilution ratios are then obtained by dividing the mean concentration of tracer gas measured at the intakes into the mean concentration of tracer gas emitted at the source. These dilution ratios indicate the extent to which an exhaust gas is diluted by the wind before being reingested at air intakes. A dilution of ratio of 1000:1, for example, means that each cubic metre of gas emitted at the exhaust vent is mixed with 1000 cubic metres of outside air on its way to the intake.

REINGESTION AT UPWIND INTAKES

Figure 4 shows an example of scale model dilution data. These data are for the hospital loading bay shown in Figure 2. Wind angle is given on the horizontal axis, with 0° representing wind blowing directly from the diesel exhausts toward the air intakes. Dilution of the reingested diesel fumes is given on the vertical axis. The figure shows data for three speeds of the general wind flow (referenced to 10m above grade in the open).

The least dilution (greatest reingestion) occurs in the reverse flow situation, when the intake is upwind of the diesel exhausts relative to the general flow. In this situation, the diluting effect of the wind is considerably less than when the intake is downwind of the exhausts. Line A in Figure 4 represents the dilution of diesel fumes at which approximately 20% of an exposed population will find the odour objectionable (5000:1). This value is an extrapolation of published odour panel data (Cernansky, 1981). The dilution of the diesel fumes reingested at the hospital intakes falls well below line A both when the intakes are upwind of the exhausts and when they are downwind. This finding is consistent with the history of odour complaints at the site.

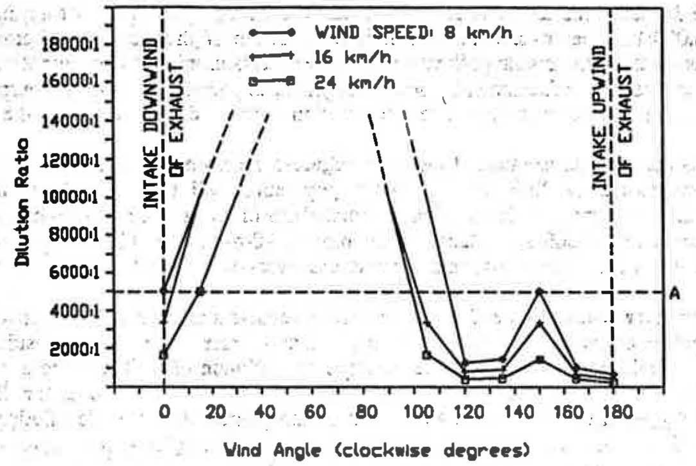

Figure 4 Scale Model Dilution Data for Diesel Fumes at the Loading Bay Shown in Figure 2

Figure 5 shows dilution data obtained from several scale model studies. Each data point represents an intake that was located upwind of the exhaust source for the prevailing winds. The horizontal axis of the plot represents the distance between the intake and the exhaust source, and the vertical axis represents the predicted 10-percentile dilution ratio. Dilution ratios remain below the 10-percentile value 10% of the time. For an exhaust source that runs 24 hours per day, 10% of the time represents 876 hours per year.

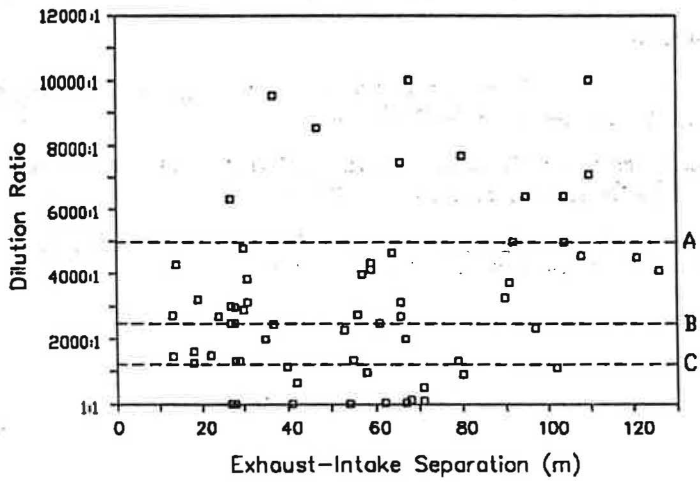

Figure 5 10-Percentile Dilution Ratios at Intakes Located Upwind of Exhaust Vents for the Prevailing Winds

The 10-percentile dilutions are widely scattered, ranging from almost no dilution (1:1) to over 10,000:1. The scatter in the data is a reflection of the variety of factors affecting exhaust gas reingestion (building shape, surrounding terrain, stack height, etc.). Since there is no distinct trend of increasing dilution with increasing intake-exhaust separation distance, it is not always possible to achieve a desired dilution ratio by simply increasing the separation.

Consider a diesel exhaust. Line A in Figure 5 represents the dilution of diesel fumes at which approximately 20% of an exposed population will find the odour objectionable (5000:1). Line B represents the dilution at which 50% of an exposed population will find the odour objectionable (2500:1). Many of the plotted 10-percentile dilutions fall below these lines, even when the exhaust and intake vents are over 100m apart.

As another example, line C represents the exhaust gas dilution (1250:1) at which strong odours would be avoided in the event that diethyl ether were spilled inside a typical fumehood. Weak odours would still be detected at a dilution of 5000:1. These values come from estimated evaporation rates for a spill and published odour thresholds for diethyl ether (Ruth, 1986). As with lines A and B, several of the plotted 10-percentile dilution ratios fall below line C.

These examples confirm that neither consideration of the prevailing wind nor large separation distances are sufficient means of avoiding exhaust reingestion in all cases.

CONCLUSION

Scale model studies conducted in a boundary-layer wind tunnel have been useful in the complicated task of identifying and avoiding exhaust reingestion problems. These techniques account for all of the site-specific factors responsible for reingestion problems. Through scale model studies, it has been shown that placement of fresh air intakes upwind of exhaust vents for the prevailing wind does not guarantee minimal reingestion and, in fact, can worsen it. Large separation distances between exhausts and intakes also do not ensure minimal reingestion. Other factors that must be taken into account include: building shape, surrounding terrain, stack height, exhaust exit velocity and exhaust flow rate.

REFERENCES

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