Air Intake Placement – Recommendations From Years of Modeling Results

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Abstract:

General guidance regarding the design of ground level and upper level air intakes is provided in the context of different exhaust source locations. The exhaust source locations include rooftop, grade level, and sources on adjacent buildings. Different concepts that affect the level of dilution achieved at the intake are discussed, including intake protection, the effect of rooftop screen walls, and adjacent building effects. In each case, intake locations that may result in high re-entrainment impacts are identified and intake design recommendations are made to avoid these impacts.

1.0 INTRODUCTION

Optimal placement of outside air intakes is an important laboratory building design issue. In cases where the majority of exhaust sources are located at roof level, low level intakes may be advantageous. However, there can be instances when there are several contaminant sources at both roof and ground level. In these situations, the placement of outside air intakes with respect to air quality becomes more complex.

Localized air quality will benefit from an intake system design that provides protection of outside air intakes from direct line of sight impacts. This design strategy will reduce re-entrainment of building exhausts. Proper intake placement can also reduce the need for filtration at the intake with regard to odor, dust and other compounds.

The amount of protection provided by an intake location is difficult to quantify because it is dependent on several factors including building geometry (dimensions, corners, rooftop obstructions, setback from roof edge), exhaust type, exhaust location, and intake size. Both numerical and physical modeling methods are useful in assessing these factors. Using numerical and physical modeling, basic principles of outside air intake placement can be demonstrated with practical recommendations that can be applied to the design of building intake systems.

2.0 NUMERICAL AND PHYSICAL MODELING

Numerical modeling of rooftop exhausts can be complex because most numerical dispersion models were developed for tall isolated stacks. For rooftop exhaust stacks or other sources in close proximity to buildings, there is building generated turbulence and mixing that cannot be accounted for with the tall isolated stack model. However, Chapter 43 of the *ASHRAE Applications Handbook* (ASHRAE 1999)[1] outlines a numerical modeling technique that can be used to predict the flow re-circulation regions around a building. These re-circulation regions can be used to determine the effective exhaust stack height and the resultant dilution from a rooftop stack at a defined downwind distance. The ASHRAE method is based on wind tunnel data collected for simple building geometries and is most applicable to stacks and intakes located on the same rooftop.

The Gaussian dispersion equations can also be used to numerically predict exhaust dilutions at nearby elevated intake locations (although the equations do not account for building effects). As well, the Industrial Source Complex (ISC) model has a PRIME version which has the ability to include source and surrounding building effects in the dispersion calculations.

If the building geometry and surrounding site to be assessed are simple, these numerical methods will provide a conservative dilution prediction. However, if the building geometry or the site terrain is complex, numerical modeling may be too inaccurate to be of value. In these cases, physical wind tunnel modeling can be used to refine numerical predictions. Figure 1 illustrates a site with complex topography simulated in a boundary layer wind tunnel.

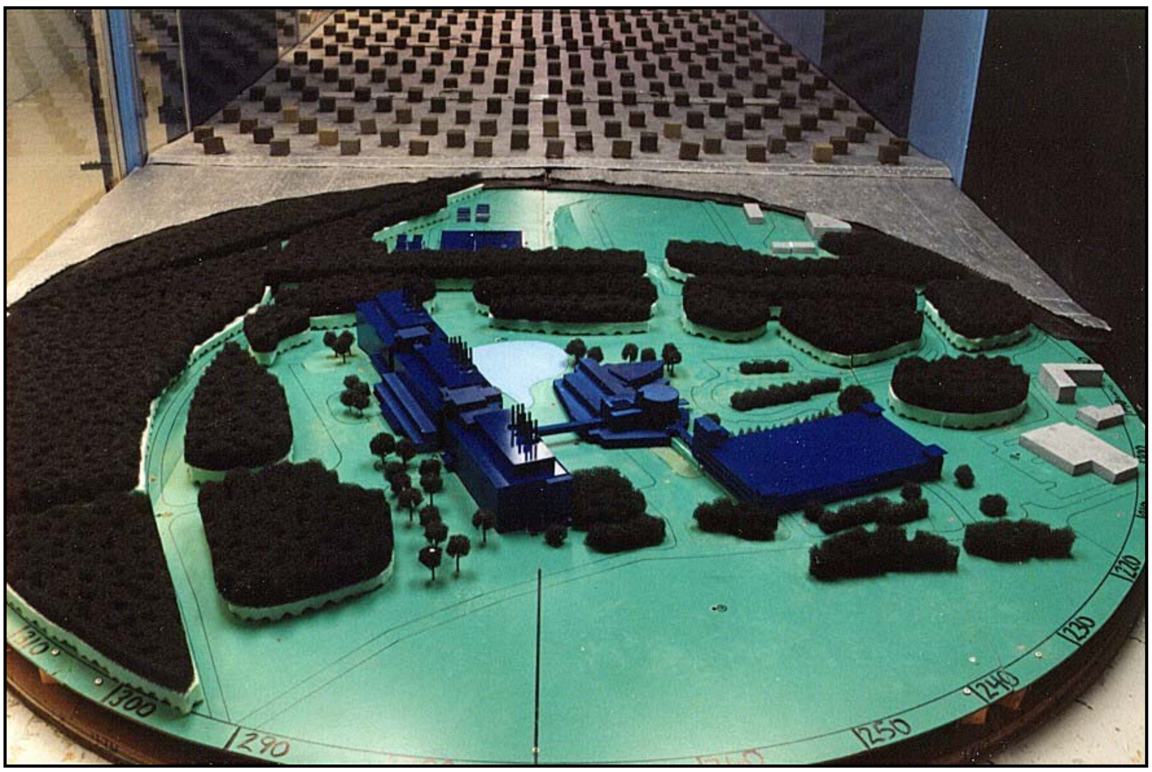

Figure 1: Exhaust Dispersion Model in Boundary Layer Wind Tunnel

Wind tunnel modeling is the most accurate method of predicting impacts from building exhausts because it simulates air flow patterns around complex building configurations. Wind tunnel modeling also accounts for the effect of surrounding structures, local topography and upwind velocity profiles created by surrounding terrain which cannot be simulated numerically. Wind tunnel data can be collected for several wind directions and wind speeds. This data can be used with hourly meteorological data to predict the expected frequency of impact for a particular source.

3.0 THE IMPORTANCE OF AIR INTAKE PLACEMENT AT THE INITIAL DESIGN PHASE

Optimal placement of outside air intakes is an important building design issue. Intake locations should be designed to minimize the probability of exhaust from nearby contaminant sources entering the building's air supply system. Typical exhaust sources of concern for re-entrainment include:

- laboratory fume hoods;
- animal holding rooms;
- cooling towers;
- emergency generators (diesel and natural gas);
- boilers (diesel and natural gas);
- incinerators;
- idling diesel vehicles (loading area and/or bus stop); and
- mobile vehicle traffic on roadways.

The air quality issues associated with these exhaust sources are both health and odor related. For example, there are occupational and ambient air quality standards that should be targeted to minimize the potential health effects associated with chemical emissions from laboratory fume hoods. There are also published odor thresholds for many of the same chemicals. In most cases, the amount of exhaust dilution required for the odor threshold is greater than that required for health limits. Odors are not a direct health concern but more of a nuisance issue. In some instances occasional odor events may be acceptable to the designers/owners of the building. As a minimum, air intakes should be located to meet applicable health criteria from all exhaust sources of concern.

In cases where there are limitations imposed on the design of building exhausts (i.e., visibility of exhaust equipment for aesthetics, maximum height for zoning, etc.) or there are nearby existing exhaust sources of concern that cannot be modified, the placement of outside air intakes with respect to air quality becomes complex. An assessment of the proposed air intake locations should be performed at the initial stages of the building design while there is flexibility in the mechanical system for recommended modifications. If the design of the mechanical system has progressed to the stage where the air intake locations cannot be modified, there are other options that can reduce exhaust re-entrainment concerns. Examples of these alternative mitigative strategies are listed below:

- exhaust controls (e.g., low-NO_x generators, change of fuel type for boilers);
- maintenance practices (e.g,, cooling tower chemical treatment programs); and
- intake filtration to target the removal of compounds related to health and odor concerns;

The above options can often result in increased capital, operational and maintenance costs that could be avoided with early assessment of the exhaust/intake design.

4.0 AIR INTAKE PLACEMENT GUIDELINES

There are different design issues associated with ground level and roof level intakes, which are dependent on the types of exhaust sources present at a particular site.

4.1 Ground Level Intakes

Ground level intakes are advantageous when the majority of exhaust sources are at roof level. However, in cases where there are nearby contaminant sources at ground level, ground level intake placement with respect to air quality becomes an important issue. Some sources that should be considered in placing ground level intakes include:

- loading docks;
- bus stops;
- emergency generators;
- lawnmowers;
- automobile traffic; and
- designated smoking areas.

When possible, the building itself should be used as protection from exhaust sources for ground level intakes (see Figure 2). This figure illustrates the use of the building as protection from ground level and nearby roof level exhaust sources. Assuming there are no other nearby buildings or grade level exhaust sources, the optimal intake location would be on the opposite side of the building. This location would result in the lowest impact from the exhaust source shown in the figure because it is fully protected by the building. Ground level intakes around the corner from the identified exhaust source are somewhat protected by the building and would result in a medium level impact. Depending on the type of exhaust source and the target criterion (whether it is health or odor related), a medium level impact may be acceptable.

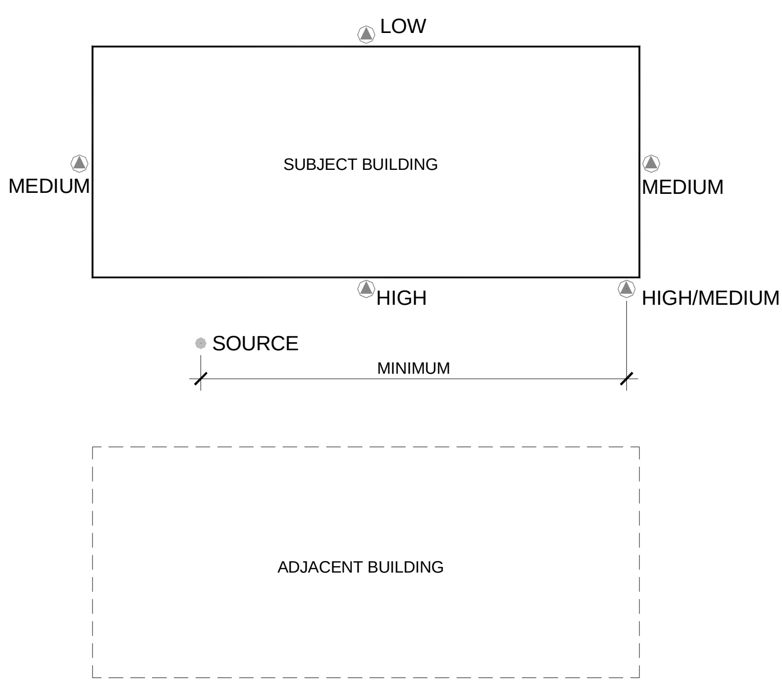

Figure 2: Ground Level Intake Protection (Plan View)

If it is not possible to use the building as protection from exhaust sources of concern, the location of the ground level air intake should maintain a minimum horizontal separation distance from the exhaust source. When there are no adjacent building effects, the level of impact at the intake will decrease with increasing separation distance from the source. The minimum required separation distance will depend on the source type and specific source parameters. The presence of an adjacent building facing the ground level exhaust source may result in a "valley effect". The inhibited lateral dispersion can greatly increase the required minimum distance from a source to an intake. In these cases, separation distance will provide little benefit and intakes within this "valley" should be avoided.

4.2 Upper Level (raised) Intakes

The main concern associated with the placement of upper level intakes is the presence of proposed upper level exhausts. However, ground level exhaust sources and sources on nearby surrounding buildings also play a part in the optimal placement of upper level air intakes. As with ground level sources, roof level intakes on the sidewall of the building should not be placed on the side of a building that faces ground level sources or surrounding buildings with upper level exhausts.

4.3 Rooftop Protection

Air quality at upper level intakes will benefit from a design that provides protection from direct line of sight impacts from rooftop exhausts. For rooftop air intakes, penthouses and other rooftop features should be used as protection from the rooftop exhaust sources. High re-entrainment impacts can occur at an unprotected rooftop intake location (see Figure 3).

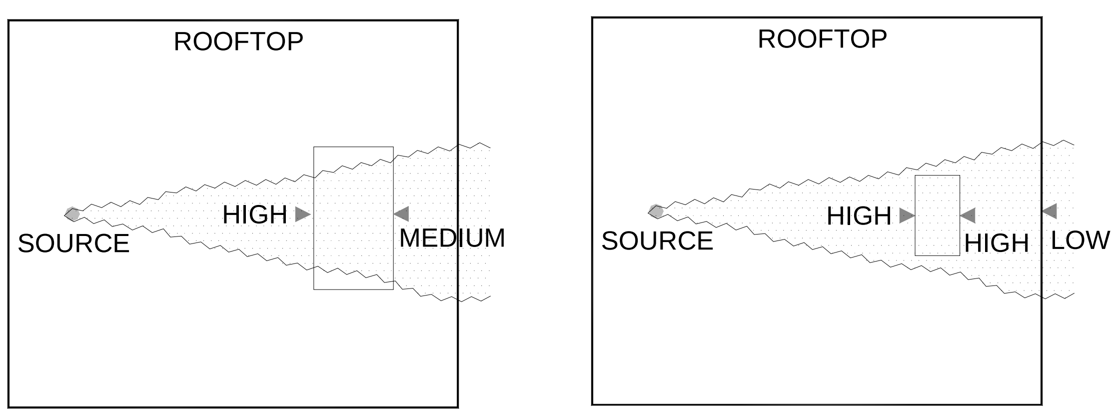

Figure 3: Rooftop Intake Protection (Plan View)

This figure illustrates how rooftop structures can be used to provide protection from exhausts. The amount of protection provided is dependent on the type of source and the size of the exhaust plume once it reaches the intake. The object providing protection must be at least as large as the exhaust plume impinging on it. This causes the plume to be mixed into the wake behind the object. This mixing reduces the peak impact at the plume centerline by combining it with low concentration air at the edge of the plume. An object significantly smaller than the size of the plume will have much less effect.

To estimate the level of protection provided by a rooftop obstruction, the size of the exhaust plume as it reaches the obstruction must be determined. The decrease in pollutant concentration from the centerline of the plume in the horizontal and vertical directions is a function of downwind separation distance (x direction). The decreased concentration is accompanied by a commensurate increase in plume dimension. This can be defined using the standard deviation(s) terms from the Gaussian Plume Model in the y and z directions. Typical values[2] of these are defined below for neutral stability conditions:

$$\sigma_y = 0.32x^{0.78}, \sigma_z = 0.22x^{0.78}$$

where σ_y = horizontal standard deviation from the plume centerline; (m)
σ_z = vertical standard deviation from the plume centerline (m); and
x = distance downwind (separation distance) (m)

As a general rule of thumb, the face area of a rooftop obstruction should be larger than the area of the exhaust plume to protect the intake from exhaust re-entrainment. The area of the exhaust plume at the rooftop obstruction can be estimated using the following relationship:

$$A = \left(4\sigma_y + \Phi\right)\left(4\sigma_z + \Phi\right)$$

where A = area of the exhaust plume (m^2);
σ_y = horizontal standard deviation from the plume centerline; (m)
σ_z = vertical standard deviation from the plume centerline (m); and
Φ= stack exit diameter (m)

The level of protection provided by a rooftop obstruction cannot be based on the face area alone. The aspect ratio between height and width of the rooftop obstruction must also be reasonable (i.e., a squat, long obstruction that meets the face area requirement may not constitute protection). Accordingly, if the face area of the obstruction is greater than or equal to the area of the exhaust plume (as defined above), the following constraints on the height and width of the rooftop obstruction must also be satisfied:

$$W \geq \frac{\left(4\sigma_y + \Phi\right)}{4}, H \geq \frac{\left(4\sigma_z + \Phi\right)}{4}$$

where W = width of the rooftop obstruction (m);
H = height of the rooftop obstruction (m);
σ_y = horizontal standard deviation from the plume centerline; (m)
σ_z =vertical standard deviation from the plume centerline (m); and
Φ = stack exit diameter (m)

In general, if the face area of a rooftop obstruction is greater than the area of the exhaust plume and the above constraints are met, an intake on the downwind side of the obstruction is protected from the exhaust plume (shown as a medium impact location in Figure 3). Two examples illustrate the effect.

First consider a 0.3m (1 ft) diameter exhaust stack, 10m (33 ft) from an air handler. Calculation of σ_z and σ_y gives us:

σ_z = 1.32 m (4.3 ft), $H = 4\sigma_z + \Phi$ = 5.6 m (18.4 ft)
σ_y = 1.93 m (6.3 ft), $W = 4\sigma_y + \Phi$ = 8.0 m (26.3 ft)

Therefore, if the air handler elevation area (height x crosswind dimension) is larger than 44.8 m^2 (482 ft^2) it will protect the intake. The unit could be 3 m (9.8 ft) tall and 14.9 m (49 ft) long to meet the requirement.

For a second example, consider a cooling tower fan 3 m (9.8 ft) in diameter and 10 m (33 ft) from the same air handler. The plume width and height would be:

σ_z = 1.32 m (4.3 ft), $H = 4\sigma_z + \Phi$ = 8.3 m (27.2 ft)
σ_y = 1.93 m (6.3 ft), $W = 4\sigma_y + \Phi$ = 10.7 m (35.2 ft)

The 3 m (9.8 ft) high air handler would have to be 29.6 m (97 ft) long to provide protection.

4.4 Architectural Screens

Roof top architectural screens are commonly used to hide equipment from view. However, they can have a negative impact on intakes when they enclose both exhausts and intakes. Figure 4 illustrates the considerations for roof level intake placement when there is a screen wall present.

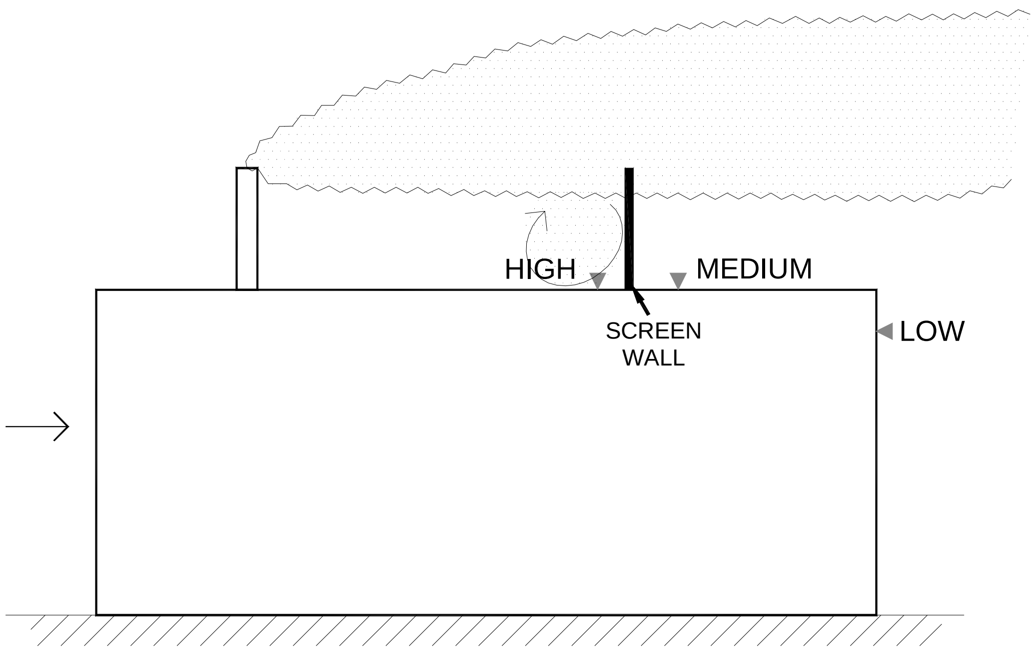

Figure 4: Effect of screen walls on rooftop intake placement

Intakes should not be located on the same side of the screen wall as an exhaust stack. The presence of the screen wall may prevent the exhaust plume from rising above the intake. In fact, if the initial plume rise from the exhaust stack does not clear the screen wall, the re-circulation region created by the screen wall can draw the exhaust down toward the rooftop intake. Conceptually, the "effective" height of the intake can be considered at an elevated point above the roof (possibly within the exhaust plume) due to the effect of the screen wall. Based on this concept, it is expected that with a solid screen wall, the contaminant concentration at the upper edge of the screen wall will be similar to the concentration at the intake. If the screen is significantly higher than the intake itself, then a significantly increased impact (i.e. lower dilution) can be expected. The effect of the screen wall decreases as the screen porosity increases. However, even with a highly porous screen wall, the better rooftop intake location with respect to air quality is outside of the screened area as far away as possible from the exhaust source.

4.5 Penthouse Setback

As mentioned previously, a design will benefit from a location that protects the intake from direct line of sight impacts from nearby sources. With regard to upper level intakes and rooftop sources, a well placed sidewall intake will provide significantly lower impacts than a rooftop intake location. Figure 5 illustrates the medium to low impact expected from a roof level source at a sidewall intake compared to a potentially high impact at the rooftop intake. It is also important to note that there is little exhaust dilution benefit provided by locating the sidewall intake further down the building face. This is because the contaminant concentration is relatively uniform within the leeward re-circulation region created by the building. The effect of a downwind building setback on an upper level sidewall intake is also shown in Figure 5. In some cases, a sidewall intake on a large setback will result in exhaust dilutions similar to those measured at a rooftop intake location. The effect that a setback will have on a sidewall intake is a function of the building geometry and the size of the setback. A small setback may have no effect on the sidewall intake benefit and a large setback may completely negate the positive features of the sidewall location. Whenever possible, the building intakes should be placed on the shear building face (illustrated as the low impact location in Figure 5) and not on a setback.

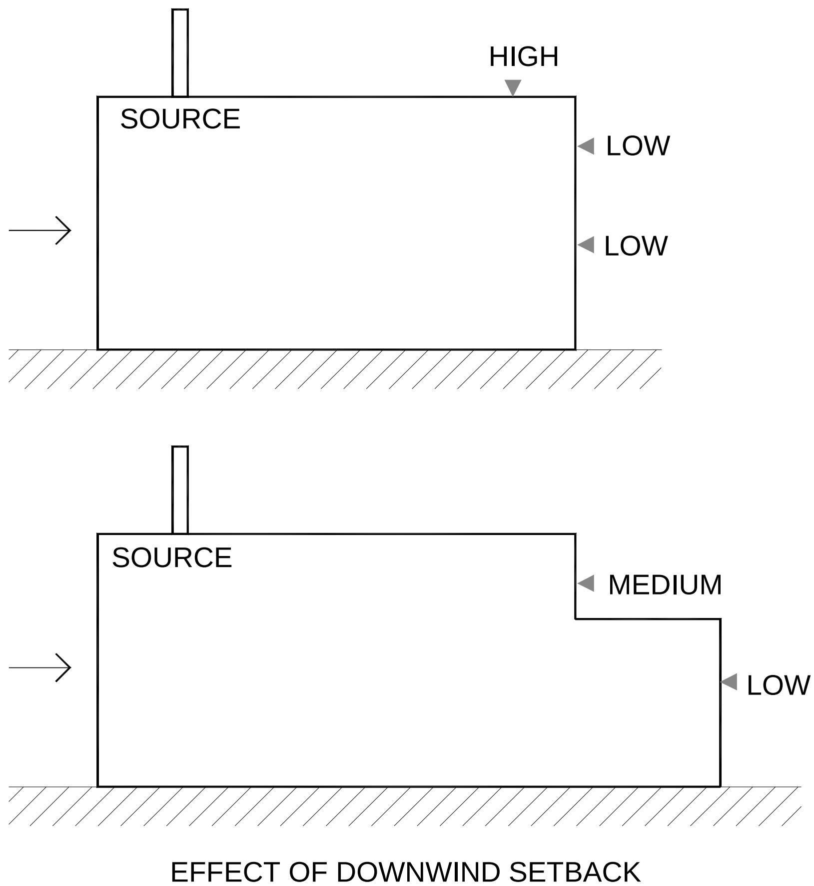

Figure 5: Rooftop and Raised Sidewall Intakes

4.6 Building Geometry

The protection afforded an upper level sidewall intake is also dependent on building geometry. Figure 6 illustrates a case where the building geometry is such that a sidewall intake at the penthouse level will not provide protection from a direct line of sight impact. This unprotected intake could result in high re-entrainment impacts. With complex building geometries it is important to keep in mind what constitutes protection of the intake (i.e., a sidewall intake will not provide protection if it is on a sidewall that faces an exhaust source). Using the same rationale, raised sidewall intakes should be avoided on any building face above a ground level exhaust source. As discussed for ground level intakes, the building itself should be used as protection from these low level sources.

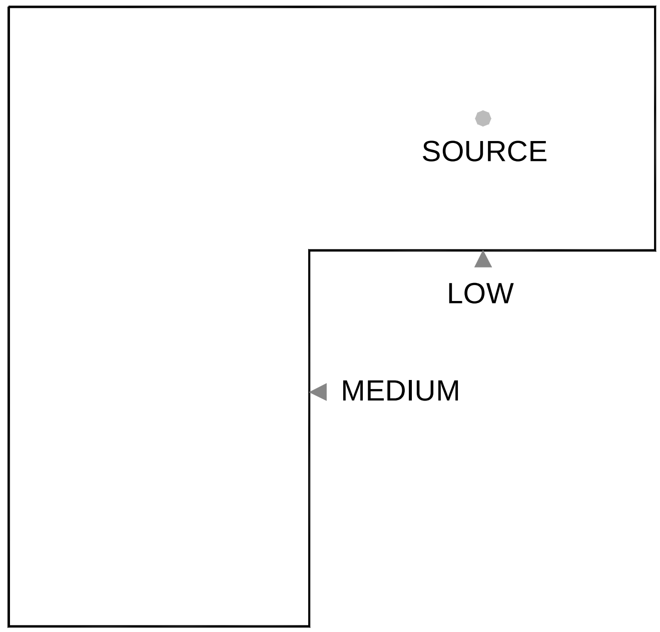

Figure 6: Raised Sidewall Intake Placement - Complex Building Geometry (Plan View)

4.7 Adjacent Buildings

Adjacent buildings play an important role in the design of building intake systems. The effect of adjacent buildings on local wind flow patterns can often dictate the best intake location. As well, adjacent building exhaust sources can have a significant impact on a poorly located intake. Figure 7 illustrates two basic concepts relating to adjacent building effects. Figure 7a shows the effect of a step-across roof on exhaust dilution (the gap between buildings is less than or equal to the building height).

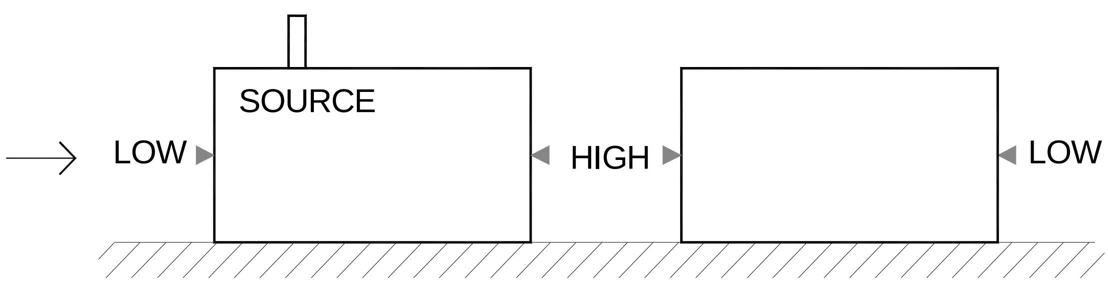

Figure 7a: Effect of adjacent building of similar elevation on sidewall intake placement

Based on studies performed by Wilson, *et al.* (1997)[3], the exhaust dilution expected in the gap between two buildings of the same height is similar to the dilution that would be expected at a rooftop intake if there were a continuous roof in place of the gap. For a step-across roof situation, the intakes should be placed on the sidewall of the upwind and downwind edges of the buildings (shown as low impact locations in Figure 7a) and not within the gap between them. This effect will diminish as the gap between the buildings increases.

Figure 7b illustrates the effect of an upwind emitting building on a taller downwind building. In many cases the exhaust stack design on the lower upwind building is such that the exhaust plume trajectory does not clear the downwind building.

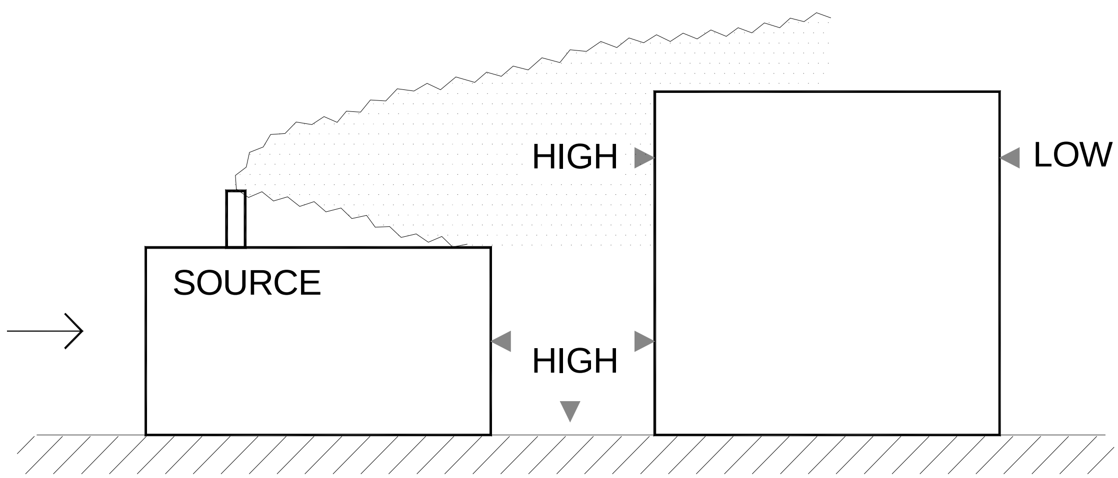

Figure 7b: Effect of lower upwind exhaust source on adjacent building intake placement

In these cases, the plume will directly impinge on the wall of the downwind building. Any intakes located on the upper portion of this wall will experience high re-entrainment impacts and should be avoided (as shown in Figure 7b). Intakes located in the gap between the buildings below the elevation of the upwind source may result in slightly lower impacts than the elevated intakes but this is still not a good location. The best design strategy from an air quality perspective is to use the building itself as protection from the exhaust source and locate the intakes around the corner, or on the opposite building face.

5.0 SUMMARY AND CONCLUSIONS

In an ideal design situation, building exhausts can be designed to minimize re-entrainment impacts at nearby intake locations. However, in many cases, there are limitations imposed on the design of building exhausts (i.e., visibility of exhaust equipment for aesthetics, maximum height for zoning, etc.), or there are nearby existing exhaust sources of concern that cannot be modified. In these cases, the placement of outside air intakes influences the level of air quality achieved.

Based on the above discussions, the following recommendations are offered for air intake placement under the different scenarios considered:

1. The proposed intake locations should be assessed at the initial stages of the building design.

Ground level intakes

2. The building should be used as protection from nearby exhaust sources. If this is not possible, a horizontal separation distance as large as possible should be maintained between the exhaust source and the ground level intake.

3. Ground level intakes should be avoided between two buildings where a “valley effect” may exist.

Upper level (raised intakes)

4. Raised sidewall intakes are preferred over rooftop intakes (careful consideration should be given to direct line of sight impacts for sidewall intakes with complex building geometries).

5. Raised sidewall intakes should not be placed on the side of a building that faces ground level sources or surrounding buildings with upper level exhausts.

6. Raised sidewall intakes on the shear building face are preferred over sidewall intakes on a setback

7. For rooftop air intakes, penthouses and other rooftop features should be used as protection from rooftop exhaust sources.

8. Rooftop intakes should not be located on the same side of an architectural screen wall as an exhaust source.

Adjacent Building Effects

9. For a step-across roof situation when the gap between buildings is less than or equal to the building height, intakes should not be placed within the gap.

10. In cases where there is a lower upwind emitting building, use the downwind building itself as protection from the exhaust source and locate the intakes around the corner or on the opposite building face.

References

1) ASHRAE. (1999) "Building Air Intake and Exhaust Design", Chapter 43 in 1999 ASHRAE Applications Handbook. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, Georgia.

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