Designing integrated natural and forced ventilated car parks using wind tunnel and numerical modeling

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1 INTRODUCTION

Wind driven natural ventilation is frequently used to reduce the concentration of pollution in above ground multi-level car parks. Specifically, it is used to dilute the carbon monoxide (CO) generated by motor vehicles. Currently many code based approaches are available to evaluate whether a car park can be considered to be adequately naturally ventilated (AS1668.2:2002). Adequate natural ventilation can often be achieved when car spaces are located close to the open edges of the car park or when cross flow is present. However, situations commonly occur where car parks are partially enclosed and cannot be considered to be completely naturally ventilated. In these situations it is useful to identify the areas which are naturally ventilated and the wind directions for which this will occur. Mechanical systems can then be design to ventilate the remaining areas.

In this paper a combined wind tunnel - numerical modeling technique is outlined and details of the methodology and criteria provided. The application of this method to a car parking complex is discussed and an examples from a specific car parking area shown.

2 METHODOLOGY

2.1 *Outline*

The design of an integrated natural and forced ventilation system for a car park can be accomplished through the combination of wind tunnel and numerical modeling. The method proposed in this paper is outlined below:

1. A scale model of the development is constructed and pressure sensors are mounted at critical opening;
2. The model is tested in an atmospheric boundary layer wind tunnel and pressure measurements recorded;
3. The dominant flow patterns through and around the development are identified from the pressure measurements combined with local climate data;
4. The car park volume is modeled numerically using the pressure distributions measured from the wind tunnel as boundary conditions. CO produced by motor vehicles and ambient CO is also modeled.
5. Areas of high and low concentration of CO are identified for each of the wind directions modeled.
6. For areas where high levels of CO occur mechanical ventilation systems are introduced and the volume re-modelled.

This combined approach has several advantages over solely using either wind tunnel testing or numerical modeling. Naturally ventilated flows are driven by very small differentials in pressure created by wind and differences in air density. Therefore these flows can be very sensitive to small variations in pressure. The most accurate method to determine the wind driven component for complex building shapes is by measuring surface pressures on a physical model in a simulated atmospheric boundary layer wind tunnel. In addition wind tunnel modeling can accurately account for the effect of neighbouring buildings and local land topography. On the other hand, numerical modeling provides the capability to efficiently model buoyancy effects and also allows for the production of detailed distributions of CO concentration than would be easily accomplished through physical modelling.

2.2 *Wind Tunnel Measurements*

A detailed model of the carpark, the adjoining building and the neighbouring developments were constructed. This model also included topographic changes around and throughout the site and through site links. The car park areas under investigation were instrumented with pressure sensors along all of the openings and the sensors were aligned with the carpark balustrades.

The primary outputs from the wind tunnel testing were the pressure coefficients on the exterior of the development. These pressure coefficients have been combined with local metrological data to calculate the 50^{th} percentile wind pressures on the openings to the carpark. By analysing the pressure distributions several dominant flow patterns through and around the development were identified for each carpark area. In addition a calm - low wind scenario was investigated. This scenario was conservatively based on a 1^{st} percentile wind coming from the wind direction with the most shielding.

2.3 *Computational Methods*

The cars have been modeled as CO sources, with the number of cars and CO flow rates determined from the applicable standard (AS1668.2:2002). The car exhaust initial CO concentration and velocity was modeled using the results of a high resolution model of the flow of CO exiting the car of exhaust. The CO production rate was based on the maximum usage of the car park predicted by the applicable standard (AS1668.2:2002) and it was conservatively assumed that this rate would occur for at least an eight hour period. This production rate includes the CO produced when cars are first started as well as their movement around the car park. The movement of cars in dispersing the CO, creating a piston action, has also been considered.

The 50^{th} percentile pressure measurements from the wind tunnel testing have been used as boundary conditions on the openings. For each carpark area several different wind directions were modeled as well as the calm-low wind case. The concentrations of CO through out the carpark were compared against short and long term exposure standards.

2.4 *Carbon Monoxide Concentration Standards*

The simulated CO concentrations were compared against three criteria as specified in the Australian Standard (AS1668.2:2002): a peak CO concentration of 100ppm, a one hourly average concentration of 60ppm and an eight hour time weighted average of 30ppm. Based on an examination of the wind climate it was seen that winds may occur continuously from a given wind direction for one hour. However, in an eight hour period at least one change of wind direction is expected. As the cars were modeled as stationary CO sources, the CO concentrations were locally spatial averaged to account for their movement when the concentrations were compared against the one and eight hour criteria.

Based on these observations, for a region of a car park to be considered naturally ventilated all of the following criteria needed to be met:

- CO concentration does not exceed 100ppm for any wind cases
- Locally spatially averaged CO concentration does not exceed 60ppm for any wind case
- Time averaged and local spatially averaged CO concentration for the three most critical wind cases, including the calm case, does not exceed 30ppm

The application of these criteria may be considered to be overly conservative as it assumes a co-occurrence of the maximum usage of the car park as predicted by the applicable standard (AS1668.2:2002) with the worst natural ventilation wind conditions. However, it is suitable approximation without detailed car park usage modeling or monitoring.

3 APPLICATION TO A PARTIALLY ENCLOSED CARPARK

An integrated natural and forced ventilation study has been conducted for a multi-level carpark which adjoins a large development in a highly developed area of Sydney, Australia. The car park building is partially shielded by the adjoining main development, which is also larger in plan and higher than the car park building. The carpark is also partially shielded by neighboring buildings.

The overall multi-level carpark building is approximately 350m by 150m in plan and seven levels in height. Internally the carpark building is divided into separated car parking areas by impermeable walls. The different carpark areas have varying levels of exposure to the prevailing winds and vary in size between 30,000m^2 and 6,000m^2. The number of open edges on each of the car park areas varies between one and three sides.

The aim of the study was to determine the percentage of car parking spaces that could be considered to be naturally ventilated. It was a requirement of the planning authority that at least 25% of the enclosed car park areas be naturally ventilated. For the areas that were not naturally ventilated a forced ventilation system was tested and refined. The objective of this second phase was to target the forced ventilation in specific areas of the car park floor where natural ventilation was not satisfactorily achieved. This will rational the use of mechanical ventilation within this car parking complex.

3.1 *Description of the car park area*

In this paper one car park area that is representative of the approach taken in this study has be presented in detail. Figure 1 shows the outline of one of the partially enclosed carpark levels. The car park is approximately 70 by 120m in plan and is located on a middle level of the car park. The car park is enclosed on two sides and is well exposed to the prevailing winds on the opposing two sides. The car park is linked to other car parks by an opening on one of the edges (bottom edge).

3.2 *Wind Tunnel Measurements and Numerical Modeling*

The results from the analysis of the pressure measurements in combination with the local meteorological data show that there were six dominant wind flow patterns, including the low wind - calm case. These six cases have been modeled using numerical techniques.

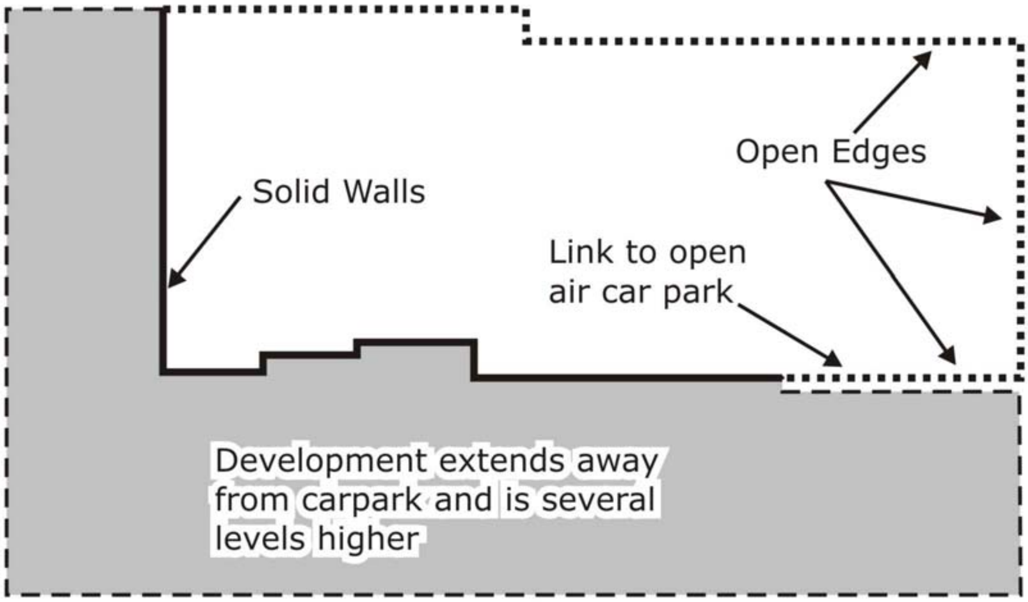

Figure 1.Layout of car park in relation to the surrounding developments

The carpark areas of the development have been modeled numerically using the Fluent 6.3 package. Turbulence was modeled using the re-normalization group (RNG) k-ε turbulence model. A meshing gradient function was used to increase the grid density nearby to the carbon-monoxide emissions sources as shown in Figure 2. The carbon monoxide movements and concentrations were modeled using the species transport module.

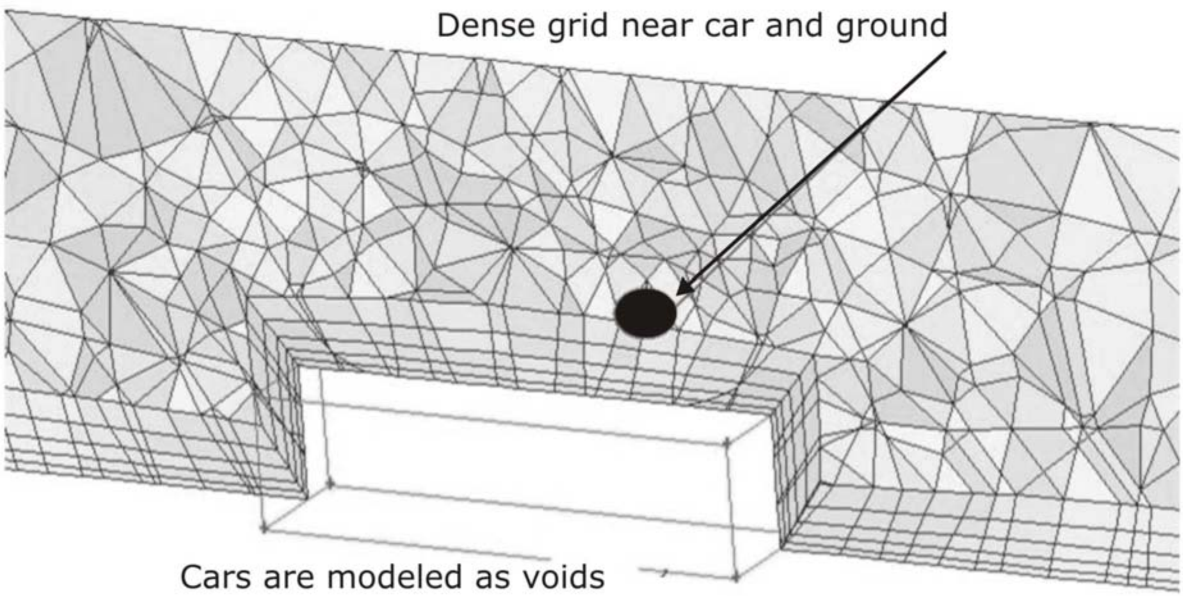

Figure2.Meshing example nearby to a car

The numerical model included CO production sites representing approximately 150 cars which were equi-spaced around the car parking area. The CO production rate was match with the applicable standard. Major internal features such as stair ways and car ramps were also modeled.

3.3 *Initial Computational Results*

Selected contours of CO for the various wind directions numerically modeled have been presented in the figures below. Figure 3 shows contours of CO concentration for wind normal to the largest open edge of the carpark, which occurs from approximately 20% of the year. The results from the pressure study for this case show that as expected the windward edge is positively pressurized relative to the side edge. The effect on the CO distribution can be seen, with the wind effectively moving the CO out of the car park. For this case the CO concentrations in the car park do not exceed the recommend levels and it is effectively naturally ventilated.

Figure 3. Contour of CO Concentration where natural ventilation is achieved.

Figure 4 shows contours of CO concentration for wind normal to the shortest solid wall of the carpark, which occurs from approximately 10% of the year. The results from the pressure study for this case show that due to the interaction between the wind and the surround buildings there is a pressure differential causing some cross flow. For this case the CO concentrations in the car park will exceed the maximum exposure levels nearby to the solid wall corners.

Figure 5 shows contours of CO concentration for wind normal to the longest solid wall of the carpark, which occurs from approximately 25% of the year. The results from the pressure study for this case show that there are only very slight pressure differential for this wind direction. For this case the CO concentrations in the car park will exceed the maximum exposure levels at the majority of locations.

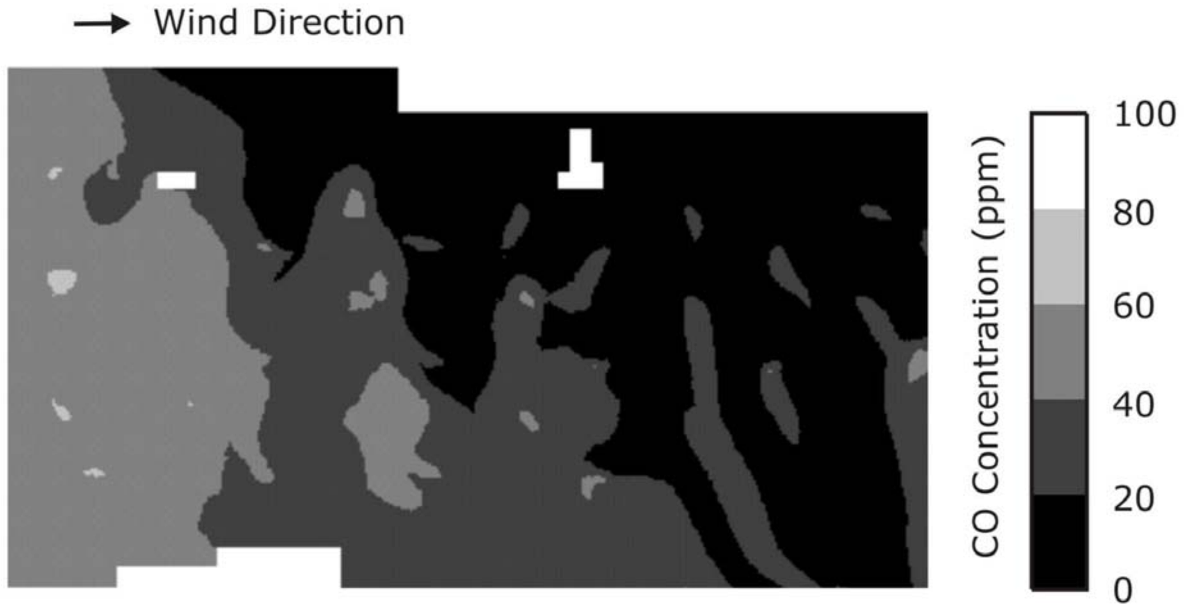

Figure 3. Contour of CO Concentration where natural ventilation is partially achieved

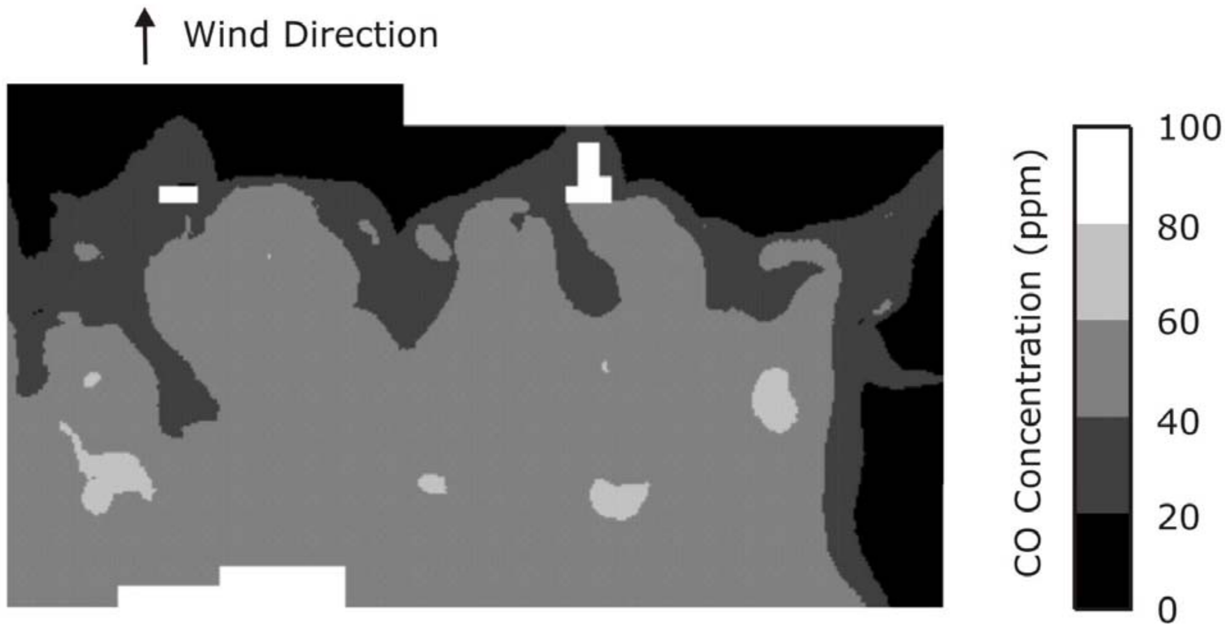

Figure 4. Contour of CO Concentration for case where natural ventilation is not achieved.

3.4 *Forced ventilation strategy and computational results*

The results of the numerical modeling for the various wind cases show that there are two general patterns in the spatial distribution of CO concentration. These are when high CO concentrations occur nearby to the solid wall corner which occurs for approximately 30% of the year and when high CO concentrations occur broadly over the carpark which occurs for approximately 50% of the year.

By recognizing these patterns an efficient forced ventilation system was designed that allowed for the forced ventilation of the corner area only and also the carpark more broadly. It is proposed that the mechanical systems be linked to CO sensors which will activate the system when specified CO thresholds are exceeded in either of these two areas. The system for this car park area used ceiling mounted jet fans and the final layout was based on a preliminary design by the mechanical consultant. Note that in other car park areas supply air was used as well as jet fan

Figure 6 shows the CO contours from the simulation of car park including the forced ventilation system. For this case only small areas associated with CO production sources exceed the eight hour CO concentration limit of 30ppm. These areas will be diluted by the movement of the cars.

Figure 6. Contour of CO Concentration for case where with forced ventilation.

3.5 *Observations about integrating forced ventilation systems with natural ventilation*

For the various car park scenarios tested we have generally found that ceiling mounted jet fans are useful in reducing regions of high CO concentration in areas where reasonable natural ventilation already occurred. In these cases the jet fans act to disperse the CO. However, in areas where there is an inherent lack of natural ventilation a more substantial forced ventilation system is required that may include supply and/or exhaust. In these cases jet fans on their own are of limited use.

4 CONCLUSIONS

This study suggests using a combination of wind tunnel and numerical modeling to draw on the respective strengths of the two techniques. The results of the wind tunnel study combined with the numerical modeling can be used to identify regions within a car park with high concentrations of CO and the frequency of these occurrences. The results are then used to design a forced ventilation control system that compliments inherent the natural ventilation of the carpark. Observations about the effectiveness of combined forced and natural ventilation have been made.

5 REFERENCES

Standards Australia, 2002. AS1668.2. The use of ventilation and air conditioning in buildings. Part 2: Ventilation design for indoor air contaminate control (excluding requires for the health aspects of tobacco some exposure)