MODELING NEAR FIELD AIR POLLUTION IN USM: EFFECTS OF DOWNWASH

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Abstract *Several research projects are currently being undertaken to pursue the goals stipulated in the Healthy Campus Program in Universiti Sains Malaysia One of the main concerns is the air pollution coming from the School of Chemical Sciences and its potential impact on the health of occupants in the surrounding buildings A previous study has concluded that the potential negative health impact is negligible The previous study has, however, ignored the effects of nearby buildings on the dispersion of air plumes When the distance between the stack and the target buildings is short, the target buildings will produce wake effects that may in turn cause an increase in the concentrations of plumes behind the building Hence the ability to simulate the effects of downwash due to the target buildings is desirable in order to provide a better estimation of the pollutant concentrations near the target buildings - Meteorological parameters such as wind conditions and atmospheric stability play an important role in the distributions of the plumes This paper will present a model analysis of air pollution including the effects of downwash due to near field buildings by using the ISC-AERMOD VIEW models Some results from the study will be presented to indicate that the air pollution levels will not pose a health hazard to the occupants despite the downwash*

1 Introduction

Air pollution has been an issue since fire was discovered (Godish, 1997) Nature was designed or has adapted itself to accommodate the pollutants until industrialization came along causing the breach of this inherent capability Constant monitoring on air pollution was therefore deemed necessary in USA by 1950 and 1960 (Eagleman, 1996) to provide baseline data Based upon these large data base, mathematical models were gradually developed to simulate the dispersion of air pollutants and to predict the potential adverse health effects Air pollution problems begin with the sources, transforms through atmospheric transport and dispersions and ends with the receptors (Schnelle and Brown, 2002). The USEPA (United States Environmental Protection Agency) models ISC3 on air pollution are based upon this path way concept The user friendly interface, ISC-AERMOD View which comprises of ISCST3 (Industrial Source Complex Short Term), ISC-PRIME (Industrial Source Complex-Plume Rise Model Enhancements) and AERMOD (American Meteorological Society/Environmental Protection Agency Regulatory Model) is an enhanced version of ISC3 models. This enhanced version will be used to simulate the air pollution problem in the study site of USM, with attention being focused on the area where the School of Chemical Sciences and the Science Complex are located. A previous study had been conducted in the same study site with the building wake effects being ignored. The focus then was to simulate the worst-case scenarios, to identify problem areas and to accertain that the environment was safe for occupants in and around the target areas The wake downwash effect will be considered in this paper in order to provide a better simulation of the problem.

2 Mathematical Model

The models in ISC-AERMOD View are based upon the steady-state Gaussian plume equations as follows

$$C = \frac{QKVD}{2\pi U_S \sigma_y \sigma_z} \exp\left[-0\ 5\,(y/\sigma_y)^2\right]$$

U_S = mean wind speed at release height (m/s)
σ_y, σ_z = standard deviation of lateral and vertical concentration distribution (m)
V = vertical term
D = decay term
K = a scaling coefficient for calculated concentrations conversion
Q = emission rate (g/s)

In the models, the above model is used to compute the concentrations of pollutant at designated receptors (USEPA, 1995). The concentration values are then plotted in contour forms to provide a better understanding on the dispersion of pollutants. It should be noted that AERMOD-PRIME predicts maximum concentrations that are very similar to ISC-PRIME for downwash dominated air pollution studies (USEPA, 2003). For maximum 1-hour cavity concentrations calculation, AERMOD provides the same predicted cavity concentrations as ISC-PRIME (USEPA, 2003)

Based upon data available, the prefered model used in this downwash-focused paper is ISC-PRIME ISC-PRIME performs better than ISC3 models in terms of a better building downwash simulation where ISC3 underestimates the downwash effects PRIME model is an enhanced version which is incorporated with better plume dispersion coefficients due to turbulent wake and plume rise reduction due to streamlines deflection and increased entrainment (Schulman et al , 1997). In the PRIME model, the concentrations of near and far wake of the buildings are considered separately (Schulman et al , 1998). The concentrations in near wake are given by the following equation

$$C_N = \frac{BFQ \exp\{(-1/2)(y/\sigma_{yc})^2\}}{(U_H H_C W'_B)}$$

H_C = height of the downwind recirculation cavity (m)
f = fraction of plume mass captured by the near wake
W'_B = building width scale through which the plume is mixed in the recirculation cavity (m)
σ_{yc} = horizontal dispersion coefficient for the downwind recirculation cavity (m)
B = empirical constant (recirculation factor for near wake concentration)
U_H = ambient wind speed at building height (m/s)

Near wake plume that was captured will reemit as a volume source that will contributes to the far wake. These far wake concentrations are given by the following equation

$$Cp = \frac{fQ\exp\{(-1/2)(y/\sigma_y)^2\}}{(\pi U_S \sigma_{zc} \sigma_{yc})}$$

σ_y = horizontal dispersion coefficient (m)
σ_{zc} = vertical dispersion coefficient for the downwind recirculation cavity (m)

Some of the primary plume might escape the near wake and thus contributes to the far wake These contributions are known as the second source and the following equation, which calculates the concentration contributed by the second source, is derived from the Gaussian plume equation

$$C_p = \frac{(1-f)Q\exp\{(-1/2)(H_p/\sigma_z)^2\}\exp\{(-1/2)(y/\sigma_y)^2\}}{(\pi \sigma_y \sigma_z U_s)}$$

H_p = plume height (m)

3 Source Input Parameters

The chemical dichloromethane is selected for study since it has the highest total emission rate (2 81 g/s) compared to other chemicals and earlier studies indicates that the dispersion pattern of the other chemicals and dichloromethane are similar. A total of 46 point sources with different emission rate and diameters is considered The emission rate and diameters for each of the stacks are different due to the simplification of 176 chimneys of the School of Chemicals Sciences into 46 equivalent point sources All 46 stacks are assumed to have the same height ot 16 2 m from ground level. The data in Table 1 were obtained from the previous study conducted by Gooi and Ooi (2003) and USM (2003) at the same site.

Table 1 Point Source Parameters Values

Point Source Parameters Values	Total Emission Rate of Dichloromethane Q (g/s)	2 81
	No. of Point Source Simulated	46
	Stack Height (m)	16.2
	Stack Exit Temperature (K)	305
	Exit Velocity (m/s)	13
	Stack Diameter (m)	0.2325

4 Building Downwash Parameters

The attributes of the buildings in the study site are obtained from the Development Department in USM The buildings projected widths and heights from each point source are needed for building downwash consideration. The Building Profile Input Program (BPIP) will convert the available building data to the projected widths and heights to be used by AERMOD and ISCST3. Another alternative to BPIP is the BPIP- PRIME which is used with ISC-PRIME and AERMOD-PRIME. PRIME model needs additional information on the buildings which are the vertical and horizontal distance from the stack to the center of the upwind face of the projected building with respect to the wind flow BPIP-PRIME provides these additional information of the buildings needed for the simulation of the PRIME model Both BPIP and BPIP-PRIME are available in the ISC-AERMOD View.

BPIP can process unlimited number of building tiers but BPIP-PRIME can only process 4 tiers per building (Thé et al , 2002) In order to use BPIP-PRIME, the building in the study site will be divided into sections Each sections is considered as an individual building in order to comply to the rule of 4 tiers per building. The details of the location and attributes of the buildings are transferred to ISC-AERMOD View by either importing the study site map in the form of Autocad or by insertion of the coordinates for each corners of the tiers. In this case study, the insertion of coordinates for the tiers is used.

In ISC-AERMOD View, the buildings simulated can be viewed in 2D and 3D form as shown in Figure 1. In Figure 1(a), the location of the origin point, (0, 0) is symbolized with a cross and the chimneys are indicated by dots. The coordinates system for the receptors and stacks location will be in accordance with the coordinates system used here. Each values in the coordinates are in meters. For 3D view, ISC-AERMOD View enable 360° rotation of the building in every direction for a better view as shown in Figure 1(b) and Figure 1(c). Furthermore, in ISC-AERMOD View, alterations on the wall colour and texture and roof colour of the buildings is possible 3D view of the location and size of the stacks are also shown in the 3D view of the buildings. Figure 2(a) and Figure 2(b) shows some of the stacks adjacent to the School of Chemical Sciences building from the interior and on top of the School of Chemical Sciences respectively.

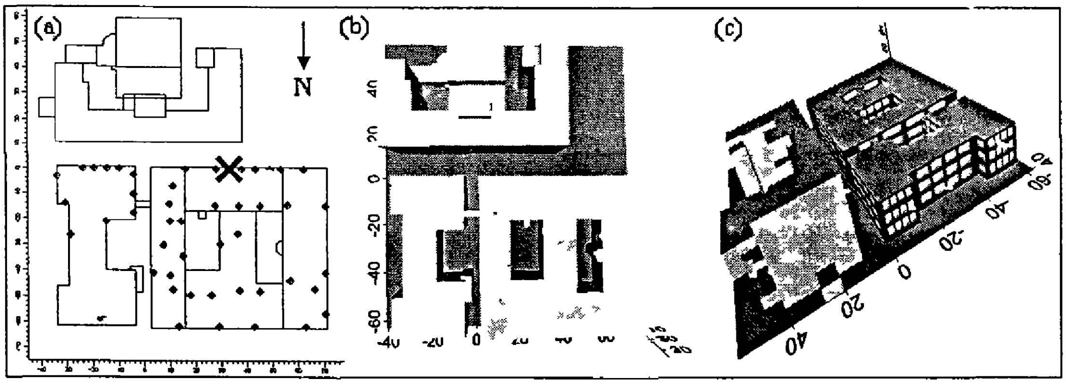

Figure 1 View of the buildings in (a) 2D with X=(0, 0), dots refer to chimneys (b) 3D from top and (c) 3D from sideway

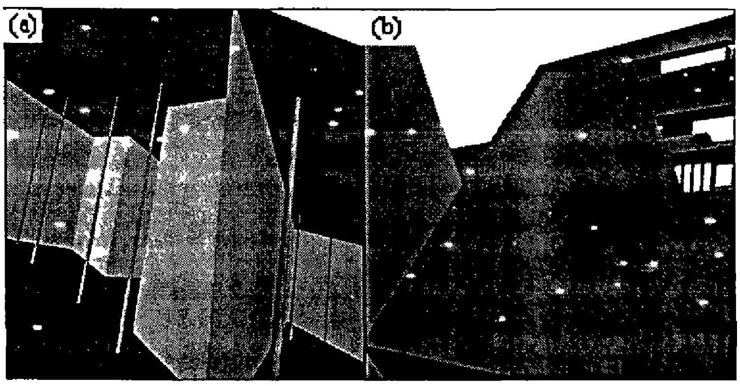

Figure 2 3D views of the stacks (a) from inside and (b) on top of the School of Chemical Sciences

5 Worst-case Scenario

5.1 Meteorological Parameters Values

Wind is assumed to be blowing south into the direction of the Science Complex in order to simulate a worst case scenario Stability class D is chosen as it represents a strong wind blowing all the time (Eagleman, 1996). Raw meterological data need to be processed by RAMMET since certain format is required before it can be used in ISC-PRIME or ISCST3 while AERMOD and AERMOD-PRIME need AERMET to process the meteorological data before it can be used in the models mentioned (Thé et al, 2002) Some of the meteorological data listed in Table 2 were obtained from a previous study conducted by Gooi and Ooi (2003) and USM (2003)

Table 2 Meteorological Parameters Values

Meteorological Parameters Values	Ambient Air Temperature (K)	300
	Wind Speed (m/s)	3.0
	Wind Direction	From North
	Stability Class	D
	Mixing Height (m)	100

5.2 Simulation Results

Results were shown in an averaging time of 1 hour. Figure 3 shows graphically the pollutant concentrations at ground level, 15 m and 25 m above ground level when subjected to building downwash. With a total emission rate of 2 81 g/s, the peaks of the concentration are 354.4 μg/m^3, 466.8 μg/m^3, and 1728.9 μg/m^3 at these three levels respectively. The peak concentration for ground level occurs at the coordinate (60, 10), which is around the southwest corner of the School of Chemical Sciences as shown in Figure 3(a). Furthermore, higner concentrations of dichloromethane at ground level tend to gather behind the Science Complex indicating the downwash effect of Science Complex as the plume is blown towards the building. The peak concentration for 15 m above ground level occurs at (65, 10) as shown in Figure 3(b) and the peak concentration occurs at (10, 0) for 25 m above ground level as shown in Figure 3(c)

The nearly identical height of 15 m above ground level and the stack height may have some contribution to the higher concentration at 15 m above ground level At 25 m above ground level, the peak concentration is the highest When referred to the plotfile output the range between the highest and second highest concentration is wide, approximately different by 1000 μg/m^3. This probably indicates that the peak concentration might only occur for a short time period. Eventually, in the averaging time of 1-hour, the highest concentration will be picked although it only occurs in a short period. The wide range between the highest concentration and other concentration values causes the range of colours used for contour plot to be not much different, thus it is harder to view the dispersion pattern displayed Therefore, the second highest concentration is used as the maximum values for the determination of colours of the contour plot as shown in Figure 3(c)

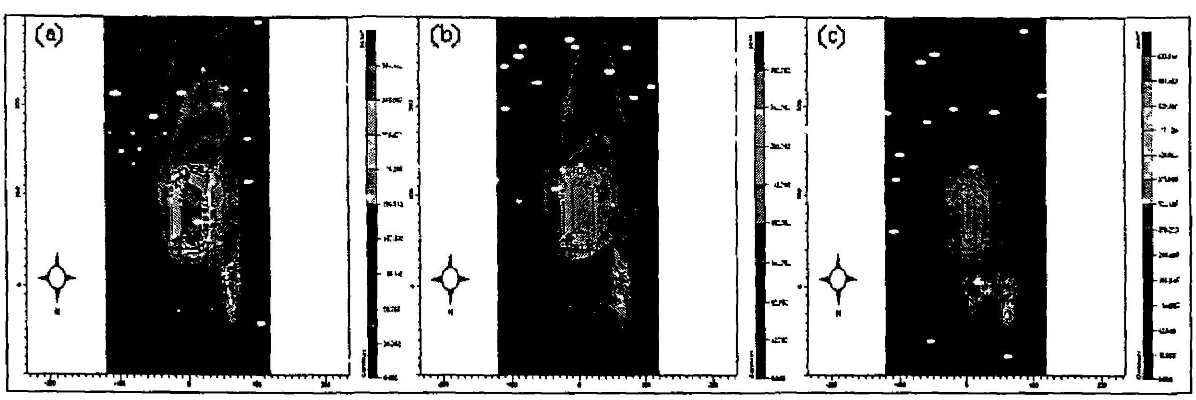

Figure 3 Pollutant concentrations at (a) 0 m, (b) 15 m and (c) 25 m above ground level

For a better understanding of the dispersion pattern of dichloromethane, the concentrations are plotted against the distance from the School of Chemical Sciences, which we refer to as the source as the stacks were located on top of it. From Figure 4, the concentration will increase then oscillate and later decrease at all three levels of receptor height This is consistent with the plume thickening then dispersing faster when it is further away from the source. Figure 4(a) and 4(b) shows that the concentration starts increasing at about 10 m from the source due to the presence of Science Complex. The presence of Science Complex induce the creation of eddies causing the thickening of the plume in the lee side of the building. Therefore, higher concentrations of dichloromethane gather behind the Science Complex In Figure 4(c), there were some fluctuations in the concentrations with respect to the distance indicating plumes from the stacks rising higher before it disperse vertically and horizontally

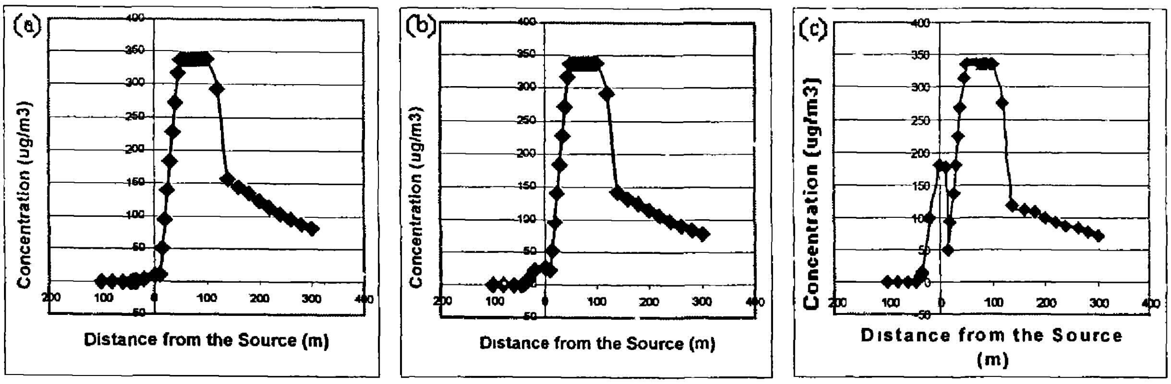

Figure 4 Pollutant concentrations at (a) 0 m, (b) 15 m and (c) 25 m above ground level versus the distance from the source

6 Actual Scenario

6.1 Meteorological Parameters Values

For an actual scenario simulation, the wind data are obtained from the Penang Bayan Lepas Airport 1968-1982 annual wind rose summary The wind rose indicates that the wind blowing from north dominates the other wind directions The data from the wind rose are then summarized for a 24 hour period where the selections of stability class are based upon wind speed, cloud cover and solar insolation These summarized meteorological parameter values are obtained from Gooi and Ooi (2003) and USM (2003). The meteorological data for the 24 hours are then plotted into a wind rose as shown in Figure 5 using the WRPLOT View available in ISC-AERMOD View. Mixing height is set as 100 m

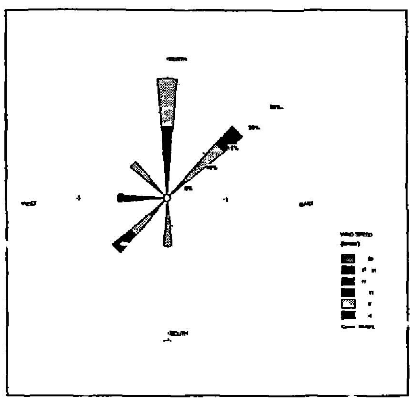

Figure 5 Wind Rose Summary plotted using WRPLOT View

6.2 Simulation Results

The dichloromethane peak concentration and the peak concentration location at ground level, 15 m above ground level and 25 m above ground level with 1-hour averaging time are 1001.7 μg/m^3 at (-20, 55), 1006 0 μg/m^3 at (-60, 95) and 33, 007.2 μg/m^3 at (15, -45) respectively. From Figure 6(a) and 6(b), the higher concentrations tend to accumulate at the left wing of the Science Complex. These conditions occur as the wind was mostly blowing from the north and northeast as indicated in the wind rose in Figure 5 As in the worst case, the peak concentration at 15 m above ground level is higher mainly because 15 m is nearer to the stacks height. At 25 m above ground level, the peak concentration is significantly higher than the other peak concentrations.

From the plotfile output, the range from the highest concentration, 33, 007 2 μg/m^3 to the second highest concentration, 5, 712.3 μg/m^3 is vast. Thus, the second highest concentration at 25 m above ground level is used as a maximum value in the colour range used for the contour plot as shown in Figure 6(c). The vast difference also indicates that the peak concentration value is picked, as it was the highest within the 1-hour averaging time although it might only occur for a short period of time. The rising of plume and some downwash effect by the Science Complex might have added to the result of higher peak concentration at 25 m above ground level

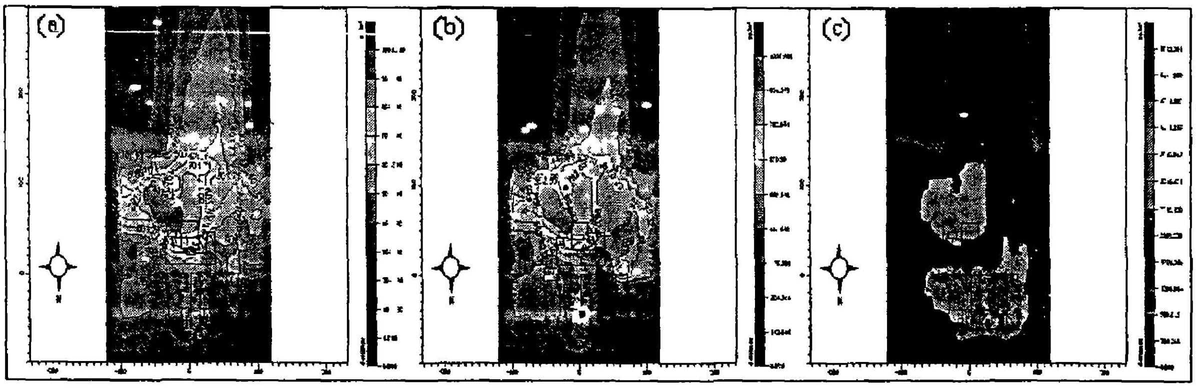

Figure 6 Pollutant concentrations at (a) 0 m, (b) 15 m and (c) 25 m above ground level

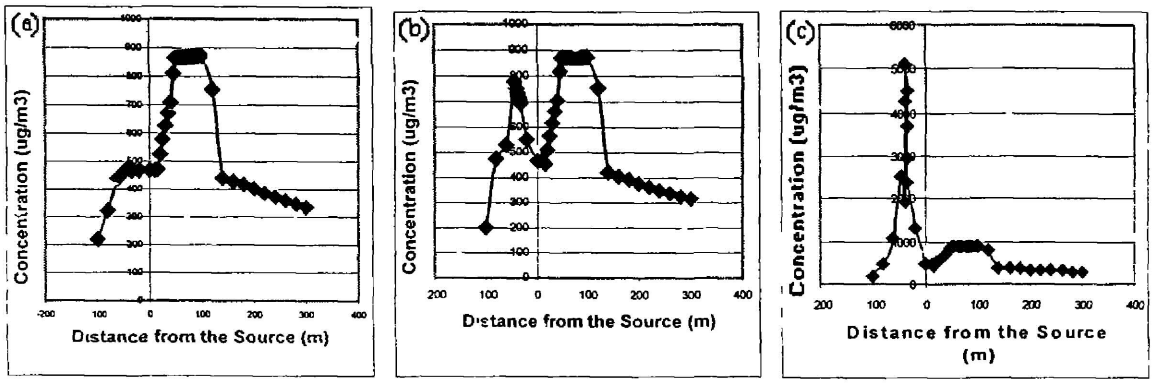

Figure 7 Pollutant concentrations at (a) 0 m, (b) 15 m and (c) 25 m above ground level versus the distance from the source

Figure 7 will give a better understanding concerning the dispersion pattern of dichloromethane at a certain distance from the source As shown in Figure 7, the concentration level fluctuates at first but still the pattern of plume dispersion still exists in which the concentration will eventually decrease as the distance increases. From Figure 7(a), the higher concentrations tend to gather near Science Complex as a result of the wake effect of Science Complex. Nearly identical height of 15 m and the stacks height produce increment of concentrations at the School of Chemical Sciences area at 15 m above ground level as shown in Figure 7(b) In Figure 7(c), the concentrations at the School of Chemical Sciences area increase significantly as the plume from the stacks rise to that height before dispersing vertically and horizontally. As the plume is "downwashed" to lower levels, there are lower concentrations at the Science Complex area at 25 m above ground level for that particular spot.

7 Discussion

The primary consideration for this research is the health of the occupants of the Science Complex Therefore, the worst case defines the worst health consequences to the occupants of the Science Complex when the wind is blowing the plume directly to the Science Complex. The actual scenario presented a better condition for the occupants of the Science Complex since the wind changes direction, the plumes will be able to disperse in other direction other than directly to the Science Complex. Hence, this explained the higher peak concentrations for actual scenario where the peak either occurs further from the Science Complex or the peak occurs at a particular spot near Science Complex where there are no occupants Summarizing the obtained results and comparing it with a suitable guideline will give an answer to whether the simulated scenario is detrimental to the health of the occupants in the studied buildings under a worst case scenario and actual scenario. Table 3 contains the comparison between the peak concentrations of the simulated cases and the Emergency Response Planning

Guidelines (ERPG) level of concern as published by the American Industrial Hygiene Association (AIHA) ERPG is used as the three levels for ERPG assume a 1-hour exposure to the chemical as in both cases simulated (USEPA, 1999). By expressing the simulation results in mg/m^3, the simulated peak concentrations can be converted to parts per million (ppm) for comparison with the ERPG levels as the ERPG levels is expressed in ppm. One mg/m^3 of dichloromethane is equivalent to 0.288 ppm (USEPA, 1994).

Table 3 Comparison of peak concentrations for both simulated cases with the ERPG for 1 hour averaging time

Height above ground level (m)	Worst Case Scenario			Actual Scenario			*Permissible Exposure Limit (ERPG) (ppm)		
	Peak Conc. (mg/m^3)	Peak Location	Peak Conc (ppm)	Peak Conc (mg/m^3)	Peak Location	Peak Conc. (ppm)	ERPG 1	ERPG 2	ERPG 3
0	0.35	(60, 10)	0.10	1.00	(-20, 55)	0.29			
15	0.47	(65, 10)	0.14	1.01	(-60, 95)	0.29	200	750	4, 000
25	1.73	(10, 0)	0.50	33.01	(15, -45)	9.51			

* nonregulatory values provided by the Government or other groups as advice

The three ERPG levels are defined as follows (AIHA, 2004; Nordin, 2002)

ERPG-1: The maximum airborne concentration below which most individuals could be exposed for up to one hour without experiencing anything other than mild transient adverse health effects or perceiving a clearly define objectionable odour.

ERPG-2: The maximum airborne concentration below which most individuals could be exposed for up to one hour without experiencing or developing irreversible or other serious health effects, or symptoms that could impair their ability to take protective action.

ERPG-3 The maximum airborne concentration below which most individuals could be exposed for up to one hour without experiencing or developing life-threatening health effects

In the worst case scenario, the peak concentrations at all level mostly occur near the School of Chemical Sciences building. Hence, the occupants in the Science Complex will not be much affected by it. For the occupant in the School of Chemical Sciences, the lower peak concentration at ground level and 15 m above ground level, which occurs near the corner of the building, does not pose a serious risk to the occupant in the School of Chemical Sciences. In the actual scenario, the peak concentrations at ground floor occur near the left wing of Science Complex, which is near the electrical room. This will not pose as a serious health threat since the electrical room has no occupant. The peak concentration at 15 m above ground level occurs far from the Science Complex and School of Chemical Sciences, thus, it will not cause any health hazard

The highest peak concentration for both the worst case scenario and actual scenario occurs at 25 m above ground level near the School of Chemical Sciences. Therefore, it does not pose as a serious risk to the occupants of the Science Complex. The School of Chemical Sciences is 16 m tall. As the peak occurs at higher level than the School of Chemical Sciences building, it will not endanger the occupants of the School of Chemical Sciences. Furthermore, evidently from Table 3, regardless of the location of the peak concentration, the peak concentrations in both cases at different heights of receptors are far lower than the permissible exposure limit of ERPG. These peak concentrations do not even come close to ERPG-1. Thus, it can be concluded that even with the consideration of the School of Chemical Sciences and Science Complex buildings wake effect, the concentrations of the dichloromethane released by the School of Chemical Sciences are well within the safety limits everywhere in the buildings concerned. A careful analysis also confirms that the concentration levels for all other chemicals concerned will not pose health hazards to the occupants as they are also well within safety limits even taking wake effects into consideration

8 Conclusion

Wake effects do significantly increase the concentrations of pollutants compared to those where downwash is not considered. Therefore, a better simulation can be performed by considering the effects of building downwash. After considering the downwash effects due to the School of Chemical Sciences Building and Science Complex Building, the concentrations of dichloromethane in the study site do not pose health hazards to the occupants of both the Science Complex and the School of Chemical Sciences as the simulated concentrations are well within the ERPG Guidelines. The simulated peak concentrations for the other volatile chemicals such as toluene, carbon tetrachloride, methanol and chloroform emitted by the School of Chemical Sciences are also well within the limits set by the ERPG Guidelines and hence they do not pose health hazards

9 Acknowledgement

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