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Personal Exposure to Carbon Monoxide in Underground Car Parks in Hong Kong

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Key Words
Car park
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Abstract
An extensive survey has been carried out in 52 underground car parks in Hong Kong focusing on carbon monoxide concentrations in the air. So far as short-term health effects are concerned this compound is generally regarded as the most important chemical species from car exhausts. Its presence can be used to quantify air pollution, and give an indicator of the air quality in car parks. The sites were sampled during peak hours. This report presents the results and analysis of the carbon monoxide levels measured. Of the 52 sites surveyed, 27 were rated as 'good', 7 'acceptable' and 18 'poor' according to our interpretation of recommended international health criteria. The findings also revealed that the utilisation rate of car parks varied significantly over time.

Introduction

There is an increasing demand in Hong Kong for car parks in the basements of buildings. To maintain an acceptable environment for people in these car parks mechanical ventilation is required to extract vehicular exhaust gases. Ventilation also reduces the possibilities of fire and explosion.

Under normal circumstances, exhaust from cars will disperse very quickly into the surrounding space, and harmful effects are thereby minimised due to the mixing and dilution of contaminants. However, in enclosed underground car parks, cross-ventilation is restricted. When there is insufficient air flow rate, exhaust from cars can accumulate and the concentration of contaminants can build up, with the increased potential for harmful effects on people. In the case of multi-storey and heavily utilised car parks this buildup of pollutants may be more acute.

The impact of car exhaust on the environment has long been a matter of interest [1]. In underground car parks car exhaust pollution may reach alarming levels. As a result of complaints received, such as poor air quality and smells from users of underground car parks, a survey was commissioned. The results showed that more than 34% of the car parks surveyed did not meet the World Health Organisation recommended criteria [2], or other appropriate standards for carbon monoxide (CO) levels (table 1).

Physiological Effects of CO

CO is the major pollutant in vehicle exhausts. It is a colourless, odourless and tasteless gas with a vapour density of 14, which makes it slightly less dense than air (14.45). Its presence in the exhaust results from incomplete combustion of the fuel. The effects on man of exposure to CO are well documented. Its acute health effects result from the formation of a strong co-ordination bond with the iron atom of the protohaem complex in haemoglobin to produce carboxyhaemoglobin. The oxygen carrying capacity of the blood is thus impaired. The affinity of haemoglobin for CO is roughly 240 times its affinity for oxygen [3].

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Table 1. Air quality guidelines for CO

Authority	Ceiling limits	15 min	1 h	8 h	Comments
ACGIH [19]		a		(29) 25[b]	TLV-TWA: this is a US guideline for industrial workplaces, not directly applicable to car parks
EPA [20]			(40) 35	(10) 9	
HKAQO [12]			(30) 27	(10) 9	aligns with EPA USA primary air standards; applies as a 'clean air' target; health effects of pollutant at elevated ambient levels: impairment of co-ordination, deleterious to pregnant women and those with heart and circulatory conditions
HSE [13]		(330) 300		(55) 50	8 h is revised to 15 min in 1994 issue
NIOSH [17]	(229) 200			(40) 35	health effects: cardiovascular effects
OSHA [8]	(229) 200			(40) 35[c]	proposed by the US Labor Department as an occupational safety and health standard
WHO [2]		(100)[d]	(30) 25	(10) 9	applies to the whole population

CO limits in $mg \cdot m^{-3}$ (in parentheses) and ppm for various time-weighted intervals.

[a] Replaced by Biological Exposure Index.

[b] Reduced from 50 ppm in 1992–93.

[c] Recently introduced. Transitional limit is 50 ppm.

[d] Exposure at these concentrations should be for no longer than the indicated times and should not be repeated within 8 h.

The degree of formation of carboxyhaemoglobin in humans is a combination of many factors including the variability of ambient CO levels, age, level of activity, personal susceptibility, whether the person is a smoker or non-smoker, etc. Those particularly at risk from its effects are people with diseases of the heart and the lungs, elderly, anaemic or postoperative patients. Coburn et al. [4] have correlated CO levels in the air and percentage of carboxyhaemoglobin in the blood. At 200 ppm CO in the atmosphere, 15 min exposure with heavy physical work would cause blood carboxyhaemoglobin to rise to 5.5%. At 35 ppm CO in the atmosphere, 8 h exposure with heavy physical work would result in a carboxyhaemoglobin level of 5.8%.

Although such results suggest that low concentrations of CO are not likely to cause any permanent effects or acute physical discomfort, this cannot be entirely discounted. Low concentrations of carboxyhaemoglobin resulting from exposure to ambient CO are usually not associated with immediate adverse health effects. However, patients with atherosclerotic plaques (deposition of cholesterol esters in blood vessels which narrow the lumen of the vessel and restrict blood flow), coronary diseases, diabetes, respiratory diseases and hypertension are potentially at increased risk because of their limited ability to increase blood flow in response to increased myocardial oxygen demand [5]. There is a possible risk of impairment of driving, and possible cardiovascular risk for this category of persons when inside underground car parks. From the evidence reported [5], the early onset of angina pectoris is consistently observed in patients with exertional angina at carboxyhaemoglobin levels from 2 to 4%. A report from Meyers et al. [6] has suggested that displacement of oxygen from the blood of drivers, with carboxyhaemoglobin levels of 5–20% after several hours exposure to CO, slightly impairs their capability to perform complex tasks.

Blood levels of carboxyhaemoglobin higher than 4% commonly occur in smokers [7] and can result from exposure to CO at levels within the occupational standards [5], e.g., 35 ppm for 8 h [8]. From a statistical report for 1995 [9], over 4.5% of patients (46,000) admitted to hospitals in Hong Kong were sufferers from various kinds of cardiovascular disease.

Since management companies cannot readily anticipate the CO levels in their car parks, it is possible that people in them who are carrying out mild physical work such as driving or carrying merchandise and who suffer from cardiovascular disease could experience carboxyhaemoglobin levels above 5%. A related factor is that there is no statutory regular health check for car park attendants, and most of these are smokers aged between 35 and 50. High levels of CO in car parks means that a lot of users and attendants are potentially at risk from its effects.

Methods

CO Monitoring

The equipment used for CO monitoring was an electrochemical Metrosonics Personal Gas Monitor pm-7700. The electrochemical sensor used has three electrodes, which are a sensing electrode, a counter electrode and a reference electrode separated by a thin layer of electrolyte. CO diffusing to the sensing electrode reacts at the surface of the electrode by oxidation. Reactions are catalysed by specially designed electrode materials. The indicated concentration is based on measurement of electrical current, the concentration detected being proportional to the magnitude of current produced. The redox reaction at the electrodes is expressed in equations (1), (2) and (3).

At the sensing electrode:

$$CO + H_2O \rightarrow CO_2 + 2H^+ + 2e \qquad (1)$$

At the counter electrode:

$$\frac{1}{2}O_2 + 2H^+ + 2e \rightarrow H_2O \qquad (2)$$

The overall cell reaction is therefore:

$$CO + \frac{1}{2}O_2 \rightarrow CO_2 \qquad (3)$$

The instrument was calibrated for zero and span before each measurement in accordance with manufacturer's recommendations. Zeroing was carried out every 2 or 3 h immediately before succeeding measurements. The sensor was used in conjunction with a data logger for continuous monitoring. The logger was programmed to store 1-min time-weighted average (TWA). The full scale range is 0–1,003 ppm, and the instrument has a response time for 90% reading of 35 s. Repeatability of the sensor as claimed by the manufacturer is 2%. The sampling rate of the logger was 4 samples per second. The logged data was down loaded onto the logger's storage unit via the Metrologger interface. The data was subsequently transferred to a personal computer for processing.

Field Measurements

In each car park, 4 locations were chosen for the monitoring of CO levels. At the up and down ramps, locations near exhaust grilles, and at 2 other randomly selected points: these were recorded as the profile of the car park. The sensor was placed 1.5 m from floor level as a simulation of sampling at the breathing zone [10]. To reflect true situations, no prior notice was given to any of the management offices concerned. The results represent the average levels of CO at the site at the time of measurement.

Because some large car parks might cover a vast area with different phases or blocks, the tests concentrated on underground levels. The locations being tested would represent the conditions of occupied areas in the car park. The outdoor and indoor air temperatures were also recorded using an electronic thermometer. The data collected were used to compare against the ambient conditions. Other data such as the car park usage, mean walking time from shroff or entrance point to parking stall, and number of cars in or out were also recorded to supplement the analysis.

Average CO emissions are higher at low engine speeds than high engine speeds [11]. Periods of rapid acceleration and retardation generally produce higher pollutant emission than those obtained when cruising. CO emissions are further increased when petrol engines run below their optimum temperature during a cold start. Under these conditions the engine works less efficiently and is often under choke condition. The readings of CO levels measured at the up and down ramp in underground car parks follow the above scheme. The CO levels were higher at the up and down ramps than elsewhere due to vehicles engaging low gear and queuing.

According to the WHO recommendations [2], the maximum permissible exposure level (MPEL) at any time is not allowed to exceed a 15-min TWA of 87 ppm; the Hong Kong Air Quality Objective standard [12] sets the level for 1 h exposure at 27 ppm and the level for 8 h at 9 ppm. At present there is no standard for air quality in car parks. Therefore, the WHO MPEL has been adopted as the major reference, and the 1-, 5-, 15-, 30-min and 1-hour concentrations have been used to assess the air quality test results.

The concentrations of CO measured were compiled to a 1-min maximum and 5-, 15-, 30-min, and 1-hour TWAs. Such figures allow a comparison with the various relevant standards such as those from the WHO [2] or HSE [13]. Three grades were given to represent the degree of acceptance of indoor air quality. 'Good' was given to those sets of readings which completely satisfied all recommended standards. 'Acceptable' was given to those which completely satisfied all recommended standards, but for which the maximum value fell between 50 and 200 ppm. 'Poor' was given to those which did not meet any one of the recommended standards. Detailed descriptions of the 52 car parks are shown in table 2.

Results

In the 52 underground car parks, the 1-min maximum CO concentration ranged from 9 ppm (site No. 40) to 667 ppm (site No. 50); the average concentration was 98 ppm. For the 5-min TWA, CO concentrations ranged from 6.4 ppm (site No. 38) to 506.6 ppm (site No. 37), with an average of 59 ppm. For the 15-min TWA, CO concentrations ranged from 3 ppm (site No. 38) to 361.6 ppm (site No. 37), with an average of 39 ppm. For the 30-min TWA, CO concentrations ranged from 2.7 ppm (site No. 38) to 255.1 ppm (site No. 37), with an average of 32 ppm. For the 1-hour TWA, CO concentration ranged from 2 ppm (site No. 38) to 153.8 ppm (site No. 37), with an average of 25 ppm. When compared with a survey of 17 locations

Table 2. Results of survey

Site	Volume of car park m³	CO concentration, ppm 1 min	5 min	15 min	30 min	1 h	Average exposure time, s[a]	Exposure risk index	Temper. difference °C	Cars in and out 0.5 h	Comment on air quality	Remark
1	1,358	*348*	156	*92*	70.4	*40.3*	27	156.6	0.9	10	poor	1, 2, 4, 5, 6
2	2,125	54	26.4	18.1	16.6	11.7	55	49.5	2.5	13	acceptable	
3	1,500	109	101	83	80	*61.4*	24	43.6	2.9	31	poor	4, 5, 6
4	21,600	24	12.1	9.9	7.9	6.3	50	20	0.5	27	good	
5	33,000	32	23.2	17.9	14.7	14.4	76	40.5	1.2	18	good	
6	9,923	42	35.8	33.7	30.1	*29*	48	33.6	3.5	26	poor	4, 5
7	34,081	*353*	256.8	*177*	165.7	*129*	120	*706*	1.5	122	poor	1, 2, 4, 5, 6
8	34,081	*225*	141.8	*107.2*	90	*73.3*	122	*457.5*	1.5	116	poor	1, 2, 4, 5, 6
9	79,200	54	30.4	19.6	15.1	13.8	86	77.4	1.7	54	acceptable	
10	23,970	20	15	14.7	14	13.6	115	38.3	1.9	54	good	
11	2,091	87	13	8	7	6	33	47.8	1.8	10	acceptable	
12	2,500	*232*	111	63	47.7	*37*	23	88.9	2.6	32	poor	1, 4, 5, 6
13	11,618	50	35.8	33.7	31.6	*26.2*	30	25	0.8	50	poor	4
14	3,000	23	15.4	13.5	12.6	10.3	15	5.75	2.2	5	good	
15	5,000	42	26.2	24	19.9	17.6	36	25.2	1.4	40	good	
16	1,485	42	36.8	33.3	33	*32.3*	27	18.9	0.3	6	poor	4, 5
17	10,000	84	56.2	51.6	39.9	*34.5*	46	64.4	2.1	26	poor	4, 5
18	69,000	27	5.5	5.3	5	5	36	16.2	0.5	19	good	
19	4,500	193	115	26.3	20.8	16.2	44	141.5	1.4	19	good	
20	7,142	67	41.6	34	28	*27.3*	56	62.5	1.2	23	poor	4, 5
21	7,314	109	102	34	30	24	50	90.8	1.2	25	good	
22	7,647	31	22	20	16.8	13.6	50	25.8	1.2	16	good	
23	21,600	12	10.8	9.6	8.5	5.1	55	11	0.9	3	good	
24	33,600	10	10	9.6	9	8.5	82	13.7	1.7	44	good	
25	1,843	151	123	36	29.3	*28.3*	48	120.8	3	20	poor	4, 5
26	14,000	*234*	173.4	84.4	46	*36.7*	82	*319.8*	3	27	poor	1, 4, 5, 6
27	17,664	45	19.8	17	10.6	16	71	53.3	2.6	16	good	
28	46,473	25	21.4	16.7	16.4	16	120	50	1.7	172	good	
29	9,500	40	34.8	31.9	28	24	82	54.7	1.2	13	good	
30	31,500	64	27.6	23.4	19.4	17.1	76	81.1	0.6	120	acceptable	
31	12,863	82	76.4	74.1	70.9	*66.8*	72	98.4	1.6	16	poor	4, 5, 6
32	4,950	99	57.4	29	16.6	11	60	99	4.4	10	acceptable	
33	16,000	47	8.4	8	6.8	6	35	27.4	2.2	5	good	
34	30,875	98	74.2	53.9	50	*45.1*	110	179.7	1.5	3	poor	4, 5, 6
35	2,250	27	19.6	17.1	15.6	12.6	59	26.6	2	6	good	
36	2,700	16	14.4	11.9	10.5	8.8	28	7.5	2.6	22	good	
37	17,496	*618*	506.6	*361.6*	255.1	*153.8*	74	*762.2*	2.5	54	poor	1, 2, 3, 4, 5, 6
38	25.200	29	6.4	3	2.7	2	79	38.2	1.4	14	good	
39	3,000	47	28	14.2	8.7	8.2	23	18	1	3	good	
40	138,600	9	8.6	7	6.5	6	134	20.1	3.1	12	good	
41	900	73	21	17	14.4	13.5	16	19.5	0.5	63	acceptable	
42	8,250	46	30.2	17.5	13.9	10.7	17	13	1	20	good	
43	9,036	100	54	45	41.3	*28*	25	41.7	0.2	14	poor	4, 5
44	21,796	12	9.6	9	7.7	6	61	12.2	2.2	127	good	
45	788	37	16.6	15.9	14	11.2	25	15.4	4.9	34	good	
46	1,688	34	31	27.8	25.7	23.2	10	5.7	4.7	15	good	
47	7,500	22	14.4	12	9.3	9	47	17.2	0.8	3	good	
48	27,109	46	43.4	41	35.2	*33*	61	46.8	2.6	60	poor	4, 5
49	11,200	101	47.2	32	23.6	20	76	127.9	0.8	6	acceptable	
50	30,550	*667*	150	69.5	45.4	*28.3*	105	*1,167.3*	1.9	76	poor	1, 4, 5
51	10,428	19	15.4	15	12.3	10.9	110	34.8	1.5	17	good	
52	5,040	34	20.2	12.7	12	9.7	52	29.5	1	9	good	
	Average	97.92	58.71	39.28	31.97	25.35	58.92	110.54	1.81	33.58		

Comment on air quality: good = meet all recommended standards; acceptable = meet all recommended standards, but the maximum value lies in between 50 and 200 ppm; poor = did not meet any one of the recommended standards.
Remarks: 1 = exceeded NIOSH and OSHA Ceiling limits (200 ppm); 2 = exceeded WHO 15-min TWA (87 ppm); 3 = exceeded HSE 15-min TWA (300 ppm); 4 = exceeded WHO 1-hour TWA (25 ppm); 5 = exceeded HKAQO 1-hour TWA (27 ppm); 6 = exceeded USEPA 1-hour TWA (35 ppm).

[a] It is the time taken from entrance point (ramp, stairwell or life lobby) to the parking stall. Average walking speed is assumed (0.75 m/s). Averaging also has been taken from dividing the car park into 6 areas and eventually arrive this value.

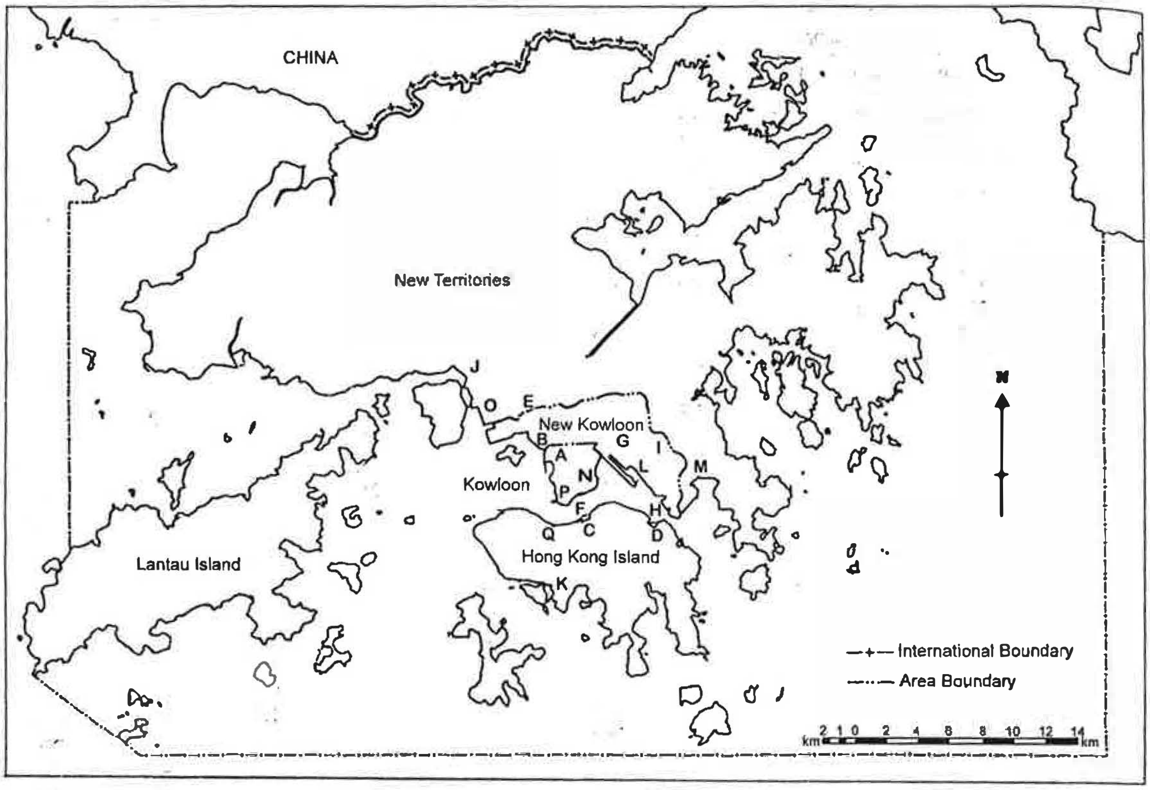

Fig. 1. Locations of on-street CO measurement.

(fig. 1) in Hong Kong's busy streets and open bustermin-us, the latter concentrations (table 3) were much lower than those in the enclosed car parks.

With reference to table 2, only 34 (65.5%) underground car parks completely satisfied all recommended criteria. Of these 27 car parks (52%) fell into the group 'good'; 7 car parks (13.5%) fell into the group 'acceptable'; 18 car parks (34.5%) fell into the group 'poor'. The situation deserves further investigation.

Statistical Analysis

The CO level was found to be dependent on the vehicle flow rate. Linear regression equations relating CO level to vehicle flow rate were derived using the method of least square fitting.

$$C_1 = m_1 \cdot f_1 \quad (1)$$
$$C_5 = m_5 \cdot f_5 \quad (2)$$
$$C_{15} = m_{15} \cdot f_{15} \quad (3)$$
$$C_{30} = m_{30} \cdot f_{30} \quad (4)$$
$$C_{60} = m_{60} \cdot f_{60} \quad (5)$$

where C_1, C_5, C_{15}, C_{30} and C_{60} are the resulting CO levels of measurements made for 1-, 5-, 15-, 30-min, and 1-hour TWA, respectively [1]. f_1, f_5, f_{15}, f_{30} and f_{60} are the vehicle count units in number per time interval of 1, 5, 15, 30 min, and 1 h, respectively. m_1, m_5, m_{15}, m_{30}, and m_{60} are the slope of equations of 1-, 5-, 15-, 30-min, and 1-hour TWA, respectively. A positive slope denotes an increase of CO concentration with a rising number of active cars. The regression fittings are shown in table 4.

The correlation coefficient between number of cars and the CO level was found to be good only at a 1-min count. The cars entering or leaving in a particular minute would create a sudden burden of pollutant. The ventilation system could not immediately purge this to the outdoors. A simple positive relationship of CO level versus number of active cars per minute is maintained. At the longer periods of time the effect of pollutant release is flattened or averaged. The cumulative number of cars counted at these periods was greater than 1 min, but the level of CO was negatively related due to the dilution effect over the period.

Exposure Risk

An average exposure time is defined as that taken by people exiting the parked vehicle and moving to the nearest exit or vice versa. The distance of each stall in a car

Table 3. CO levels in a busy street, at a bus terminus and in a vehicular tunnel

Location	Function	District	Average ppm	Maximum ppm
A	Roadside	Mongkok	4	8
B	Bus terminus	Cheung Sha Wan	5	17
C	Roadside	Wan Chai	5	10
D	Roadside	Shau Kei Wan	6	11
E	Roadside	Lai Chi Kok	5	12
F	Vehicular tunnel	Cross Harbour Tunnel	20	25
G	Vehicular tunnel	Tate's Cairn Tunnel	15	19
H	Vehicular tunnel	Eastern Harbour Crossing	12	16
I	Vehicular tunnel	Lion Rock Tunnel	12	15
J	Vehicular tunnel	Shing Mun Tunnel	7	10
K	Vehicular tunnel	Aberdeen Tunnel	6	11
L	Vehicular tunnel	Airport Tunnel	7	10
M	Vehicular tunnel	Tseung Kwan O Tunnel	12	12
N	Bus terminus	Hung Hom	2	8
O	Roadside	Prince Edward	4	6
P	Roadside	Tsim Sha Tsui	4	27
Q	Roadside	Central District	5	32

Table 4. Least square fitting equations

	Regression equation	Correlation coefficient (r)
1 min time-weighted	$C_1 = 31.4f_1$	0.6
5 min time-weighted	$C_5 = 3.3f_5$	0.25
15 min time-weighted	$C_{15} = 0.69f_{15}$	0.23
30 min time-weighted	$C_{30} = 0.31f_{30}$	0.27
1 h time-weighted	$C_{60} = 0.088f_{60}$	0.22

park was measured from a passenger exit or lift lobby and the average distance calculated. Architectural drawings were available for 17 of the sites. Principal dimensions of the other 35 sites were available but their detailed layout could not be obtained from the developers. The method of estimation for these sites was by dividing the whole area into 6 fictitious zones and proceeding as below.

A comparison was made between distances estimated by the 6 zones method (D_{6Z}/m) and that obtained from

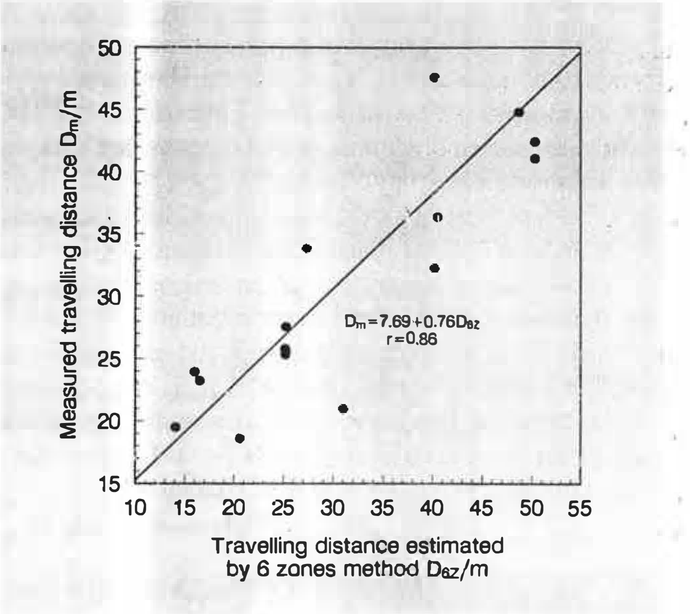

Fig. 2. Calibration curve for 6 zones estimation.

actual measurement (D_m/m) on the group of 17 sites. The average discrepancy was 17.6%. A calibration curve was constructed for extrapolation (fig. 2). The regression coefficient was 0.86. This method seems to be good enough as an engineering approach. The starting point was the exit or lift lobby to the centres of the fictitious areas. The accuracy of the 6 zones method depended on the configuration of the car park, the number of exit routes and the position of such exits or lift lobby. A rectangular shape and single exit route would yield values closer to those actually measured. An estimate of walking speed of 0.75 $m \cdot s^{-1}$ was made by asking 15 people to walk a distance of 50 m in a car park not carrying merchandise. The standard deviation from this sample size was very small.

People leave the car park when they pay the toll, take their car away or leave the underground level. The important exposure period is the time which the drivers spend exposed to the contaminated environment either parking or leaving the car park. On average over 52 car parks this was 59 s while the longest time was 134 s. The time spent at the shroff queue was not included in the average exposure time. If users were carrying goods, their actual time of stay could be longer than the average.

The average exposure time was used to assess the 'index of exposure risk'. It has been suggested that the amount of CO absorbed is proportional to time exposed and concentration of CO in the atmosphere [14, 15].

Based on this relationship, an index of exposure risk is defined here as the product of exposure time and concentration. The average stay in an underground level, estimated from the 52 car parks, was 1 min (table 2). With reference to the ceiling limits of CO, the maximum allowable value according to OSHA is 200 ppm [8]. This level for 1 min was therefore fixed as the threshold of the index, i.e. an index >200 was deemed to be unacceptable even for a short stay. This is a rough guideline for deciding whether there is a potential risk to health in underground car parks and better than the qualitative descriptors of 'good' or 'bad'.

The 'index of exposure risk' (I_{ex}) was defined as the average exposure time multiplied by 1-min TWA concentration of CO. The mathematical expression is:

$$I_{ex} = C_{1\,min} \cdot t \quad (6)$$

where is $C_{1\,min}$ is 1-min TWA of CO concentration in ppm and t is the exposure time in minutes.

Discussion

There are no existing building regulations to govern air quality in car parks. The sole statute is: 'There should be enough fresh air supplied to the premises' [18]. The phrase 'fresh air' is not defined and does not represent any compulsory statement. It is an abstraction which designers are not required to observe. In fact intake of 'fresh air' from street level might cause further degradation of air quality in an underground space. Legislative control of air quality in underground car parks is currently under consideration, but thousands of people who use them are daily exposed to the hazard of CO.

To qualitatively assess the car parks surveyed they were classified into 3 grades on the criteria of the acceptability of the air quality in them. 'Good' was awarded to those who completely satisfied our proposed health standards for CO. We believe that CO levels inside in these areas would not cause immediate or chronic effects to human beings based on current knowledge. 'Acceptable' was given to those who completely satisfied the health standards but which had maximum levels between 50 and 200 ppm. In these car parks it is unlikely that healthy occupants would experience harmful effects, but special attention should be given to susceptible persons. 'Poor' was given to those car parks which did not meet any one of the standards. In these places the CO levels represent a hazard to users or attendants.

To distinguish those car parks in which there was a potential risk to health an index of exposure risk which was a dimensionless number was used. This gives a measure of the likely risk of using that particular underground car park and is proportional to exposure time and exposure level. The greater the exposure risk index is, the greater the risk is. Those sites which had an index greater than 200 were considered as potentially harmful even if staying for a short while. It should be noted that this index is different from the grade given to each car park. The grade is based entirely on the levels of CO measured, while the index of exposure risk refers to people and is related to a short-term stay while parking and leaving the car park in which both the duration and level of exposure to CO are considered.

The CO levels measured at 15, 30 and 60 min were similar at sites: 2, 9, 11, 18, 19, 21, 25, 32, 33, 41, 49, 50. However, the values were much lower than the 1-min TWA for the reasons described above. Exhaust gases were quickly purged to the outdoors by the ventilation systems in these car parks which could efficiently control the pollutant to an acceptable level. This was not always the case at other sites and the effectiveness of a ventilation system could be assessed by comparing the measurements at different time points. It would be better if the higher CO levels at the up and down ramps were reduced through implementation of administrative controls. Provision of cleaner air specifically to these areas would be a good solution.

To have an estimate of the exposure risk inside underground car parks which affect the users and attendants an average exposure time was defined. Apart from activities such as queuing at shroff or car washing, drivers would spend at least 1 min in the contaminated environment and probably less than 5 min and so a 1-min maximum concentration of CO was chosen as a reference level. The 1-min maximum and 1-hour TWA of CO averaged over the 52 sites was 98 and 25 ppm, respectively. In 5 out of the 52 sites the exposure risk index exceeded the value of 200 which was judged to be acceptable. The highest index measured was 1,167. At such a level danger to users and particularly attendants exists. Since the working hours of car park attendants may be up to 10 h per shift and 6 days a week, the maximum permissible exposure should be lower than the 8-hour TWA in the recommended guidelines. Although there is no evidence that this group of workers are more or less healthy than the general population, including those aged between 35 and 50 who are smokers, the effect on their health through working under such conditions is a matter of concern.

No statutory requirements have been laid down governing the working conditions of attendants. This is in spite of the fact that they have long hours of exposure compared to users and are at higher risk from vitiated exhausts from vehicles. In their working week they might be working 10 h a shift, 6 days a week. Also, the activity levels of attendants may be very high at times, e.g. maintenance work, cleaning, etc. Since physical factors, such as a high temperature, can act adversely to increase the toxic response in a number of instances [16], any guidelines should be applied with caution when conditions deviate grossly from the normal situation. There is not enough information available to justify the standards outside a narrow range of ambient conditions. However, it is a general guideline that excursions over the limit should not occur but, if they do, they should be kept as low as possible [16]. Although provision for exhaust ventilation are often found in shroff offices, security counters or toll booths do not have a fresh air supply and air quality in these places remains a problem.

Overall this survey found that nearly 13.5% of car parks did not meet short-term exposure criteria to CO [8, 17]. Fortunately, the degree of exceedance was not serious. The WHO [2] published guidelines are designed to protect general populations and for occupational safety. These suggest that a 1-hour TWA to over 25 ppm of CO is harmful to human beings. This is an occupational standard and permissible values of exposure for workers are usually set higher than for the general population. In the survey, 34.6% of 52 sites exceeded WHO's 1-hour TWA [2]. This means that working or a long-term stay in those underground car parks could have an adverse effect on health.

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