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Influence of Atmospheric Air Pollution on Indoor Air Quality: Comparison of Chemical Pollutants and Mutagenicity Levels in Santiago (Chile)

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Abstract

The influence of atmospheric pollution on indoor air quality (IAQ) was studied in downtown Santiago (Chile). Carbon monoxide (CO), nicotine, the mass of respirable particulate matter below 5 µm (PM_5 fraction) and total and carcinogenic polycyclic aromatic hydrocarbons (PAHs) were simultaneously monitored indoors and outdoors in restaurants, offices and other places. The levels of CO changed simultaneously outdoors and indoors (r = 0.89), especially during traffic rush hours, masking the contribution of other indoor sources and showing the importance of infiltration of outdoor air indoors. CO concentrations ranged from 1.0 to 73 ppm and 0.5 to 93 ppm for indoors and outdoors, respectively. The highest running 8-hour average levels measured were 16 and 18 ppm, respectively. These levels exceeded the Chilean 8-hour standard of 9 ppm to the extent of 178% indoors and by more than 200% outdoors. PM_5 concentrations were high and showed no significant differences ($p > 0.05$) between indoors and outdoors: levels in restaurants, offices and other places were not significantly different from each other. The concentrations of total and carcinogenic PAHs were also high indoors and outdoors, outdoor levels being higher than those indoors although no significant differences ($p > 0.05$) in indoor levels were found between restaurants and offices and between offices and other places. Nicotine levels showed significant differences ($p < 0.05$) between indoor and outdoor levels. In addition, great differences ($p < 0.05$) in indoor levels were also found between offices and restaurants, and offices and other places. Mutagenic response in *Salmonella typhimurium* by organic extracts from PM_5 collected in downtown Santiago in Bandera street and in a rural area showed that the extracts from the Santiago samples are highly mutagenic. These results suggest that in downtown Santiago, infiltration might be the main source of indoor pollution. Symptoms and health effects probably related to air pollution in people working in Bandera street and in Curacaví, a rural area located 45 km from Santiago were surveyed. This showed clearly that people working in downtown Santiago have greater frequency of eye complaints, sneezing attacks, cough, throat dryness and rhinitis.

Introduction

Many investigations have been carried out to examine the effects of atmospheric pollution on human health but it is easy to gain the impression that very few have dealt with the influence of outdoor air on the air quality inside buildings. Such an effect from outdoor air might be important as it produces problems in urban areas with high levels of atmospheric pollution, especially in developing countries.

Indoor air contains a large variety of pollutants which are released from several sources. Their concentrations usually vary in time and space depending on the diversity and intermittence of the sources and on the presence of

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absorbing materials. When ventilation systems are absent or operate badly, pollutants tend to accumulate and may reach levels which exceed standards, thus becoming potentially dangerous to human health. Investigations carried out over the past 15 years have shown that indoor air quality is frequently as bad or even worse than that outdoors [1]. However, little is known about how pollution indoors affects human health, especially during long-term exposures to low levels. Concern has concentrated mostly on the smoking habit, although other sources can release pollutants at levels much higher than those generated by cigarette smoke.

Indoor pollution particularly is a problem which can affect human health in Latin America. Millions of people may be affected as most of the population spends 75–90% of their time indoors [2]. This percentage can reach 100% among the most vulnerable groups such as: the elderly, pregnant women, persons affected by respiratory or cardiovascular diseases and the newborn. Health effects from indoor pollutants can be divided into two general categories: those associated with discomfort, allergies or acute illnesses and cancer. The pollutants related to the first group include micro-organisms, carbon dioxide, carbon monoxide, nitrogen oxides, sulphur oxides, formaldehyde, solvents and other volatile organic compounds (VOCs), while those of the second group include: amphibole asbestos, a large variety of organic chemical compounds including benzene, N-nitrosamines and some polycyclic aromatic hydrocarbons (PAHs) and possibly radon and heavy metals (Cd, Ni).

The most common sources of indoor pollutants are outdoor air and those from building and decorating materials (e.g. panels, false ceilings, paint, varnishes) or generated by a variety of activities (e.g. heating, cooling, humidification, cooking, smoking, the use of photocopiers).

Outdoor air enters a building through windows, doors, ventilation systems or points in the envelope which are not perfectly sealed. Among the factors which influence the presence and persistence of contaminants indoors, the most important are: the type of generating source , emission rate, ventilation conditions, air exchange rate, temperature, humidity and the presence of absorbing materials.

Combustion processes are the main source of air pollution indoors, these mainly generate particulate matter, PAHs, carbon monoxide, nitrogen oxides and sulphur oxides. Emissions depend on such factors as the nature of the fuel, the type of combustion device, the ventilation system and how well it is maintained. Generally, firewood and coal release larger amounts of pollutants than gas, kerosene and oil [3, 4].

Respirable particulate matter (PM_{10}), is a major indoor pollutant, as it can be deposited deep in the respiratory tract. Although these particles do not have a defined chemical composition (a large variety of organic compounds can be absorbed by and/or can condense on their surface), they can be very dangerous to human health, particularly if they have adsorbed or condensed on their surface irritating gases or carcinogens. The main sources of respirable particulate matter in the air of Santiago are both mobile (vehicles), fixed (industrial) and from soil erosion.

PAHs are among the most dangerous indoor pollutants to human health. These compounds, which are present both in the gaseous and in particulates phases, are combustion products and their distribution in both phases depends on their molecular weight. Two-ring PAHs are mainly found in the gaseous phase, while those with four or more rings are in the particulate material. A variety of such compounds are found indoors in relatively small concentrations ($ng \cdot m^{-3}$) but even so they are important, as many of them are mutagenic and or carcinogenic. Several PAHs have been classified by the WHO either as carcinogenic, pre-carcinogenic or co-carcinogenic agents. This organisation has postulated that there is no threshold dose for carcinogenic agents. Their toxic activity depends on factors such as: chemical structure, absorption, cellular transport, storage, metabolism and the level of endogenous and exogenous oncostatic compounds and other defence mechanisms.

Santiago de Chile, with 5.3 million inhabitants, is one of the most polluted cities of America [5, 6]. According to recent data from the Transport Ministry, in 1996 the total number of vehicles was 640,000 of which 34,500 were diesel (mainly buses and lorries) while the remaining 605,500 were mostly cars. The number of fixed sources was estimated at 3,200. The National Environment Commission (CONAMA) has estimated emissions in Santiago for 1997 as: PM_{10} 41,782; CO 643,500; and NO_x 39,000 t/year. Over the last years the annual average for PM_{10} has exceeded 100 $\mu g \cdot m^{-3}$. In 1995, the Chilean air quality standard (150 $\mu g \cdot m^{-3}$) was surpassed on 57 days during the year. Although PM_{10} levels are commonly measured, in this paper we chose to sample PM_5 because these smaller particles are more respirable, in that more of them can go deeper into the lungs, than PM_{10} and because the Chilean authorities are evaluating and trying to establish a standard for particles smaller than PM_{10}. The standards for CO (9 ppm for 8 h) and for ozone (160 $\mu g \cdot m^{-3}$) were surpassed 60 and 154 times respectively in the same year. Recently Santiago has been declared to be a zone saturated with ozone, PM_{10} and CO.

Recent studies carried out with organic extracts obtained from Santiago's airborne particles have shown that they have high levels of PAHs, are highly mutagenic and can cause chromosomal aberrations in human lymphocytes in culture, also when injected into rats they increase the content and activity of cytochrome CYP1A1, the enzyme which transforms pre-carcinogenic into carcinogenic agents [7–11].

In many countries, when pollutants in the outdoor air exceed set standards, the population is advised to remain indoors, but if infiltration occurs and indoor sources generating pollutants are being used, indoor air quality might be even worse than that outdoors. The goal of the present work was to evaluate the contribution of outdoor pollution to indoor air quality. The study was done in downtown Santiago. One particular street was chosen, Bandera street, because of high traffic levels (mainly buses with diesel motors) and a high density of offices and restaurants. Bandera street has the highest percentage of heavy vehicles flow (50.34%) and the highest noise level (92.9 dB[A]) among the streets in downtown Santiago [12].

Material and Methods

Sampling Places

The study was carried out on Bandera street, in downtown Santiago and in Curacaví (a rural area 45 km west of the capital) between July and September, 1994. Bandera street is one of the the most congested urban streets, with considerable vehicular traffic, mainly taxis and buses (100% of the latter use diesel engines). Samples were taken at 14 points: five were restaurants, six offices, two gambling places and one a hotel. The last three are mentioned together in this paper as 'other places'. Of the places sampled, three used a cooking stove every day and one an unvented heater. Air was conditioned in all the offices but in only one restaurant. As controls, six places at Curacaví were monitored (five restaurants and one office). Of these, one had a fireplace and all the restaurants used a cooking stove daily. None of the places had air conditioning but neither was any particularly exposed to vehicle exhaust, excepting one restaurant close to a bus terminal. Monitoring was carried out simultaneously indoors and outdoors at each place for CO, PM_5, temperature, humidity, total and carcinogenic PAHs and mutagenic activity of extracts of the PM_5.

Collection of Particulate Matter (PM_5) and Nicotine

PM_5 were collected using Teflon filters with a Flow Lite portable pump at a flow of 2 litres·min^{-1} for a total volume of 2.88 m^3. Nicotine was adsorbed using XAD-4 columns run at a flow of 1 ml·min^{-1}. Both PM_5 and nicotine were sampled for 24 h. The nicotine concentration in the air was determined using gas chromatography after Hammond et al. [13].

Carbon Monoxide Monitoring

Carbon monoxide was measured with a Langan portable battery-operated monitor equipped with an electrochemical sensor and a data storage system. The instruments allow one reading a minute, and thus 1,440 measurements were obtained in 24 h.

Polycyclic Aromatic Hydrocarbons

PAHs were extracted from PM_5 and determined by HPLC as described in Gil and Adonis [11]. The identified and quantified PAHs were the following: naphthalene, acenaphthene, acenaphthylene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, dibenzo[a,h]anthracene, benzo[g,h,i]perylene, indene[1,2,3 cd]pyrene and coronene. Standard compounds were purchased from Supelco, Inc. The coronene standard was kindly provided by the late Prof. R. Perry of Imperial College, UK.

Mutagenicity

Mutagenic activity of organic extracts from PM_5 was determined by the modified Ames test (pre-incubation and micro-suspension test), as described by Kado et al. [13] using *S. typhimurium*, strain TA98. The assays were done with and without an S9 metabolic activation fraction.

Statistical Analyses

For all the variables monitored, correlation coefficients were calculated (Student's t test) using Statview software. All the results were expressed as means ± SE.

Survey of Symptoms Related to Exposure to Air Pollutants

A survey of symptoms related to exposure to environmental pollutants (variable) was carried out among 181 persons working in the places monitored (107 cases, 74 controls). A case study (individuals working at the places monitored on Bandera street), and a control study (individuals working at the places monitored in Curacaví) were designed. To avoid the effect of smoking as a confounding variable, each variable was stratified for the smoking habit. The statistical analysis includes the χ^2 test for dichotomous variables and a Student t test for continuous variables. The relative risk was estimated (relationship between risk and exposure).

Results

Carbon Monoxide Levels

Figure 1 shows the 24-hour levels for CO recorded simultaneously outdoors and in an office without an air conditioning system. Over a 24-hour period an excellent correlation was observed between the indoor and outdoor levels (r = 0.890). Outdoors, the levels increase at the beginning and at the end of the working day, suggesting that they are related to traffic and these changes are mirrored almost simultaneously to produce an increase in indoor concentrations. The highest outdoor value measured was 23 ppm, at 20.04 h, 6 min later the same value was reached indoors. The average 24-hour concentrations

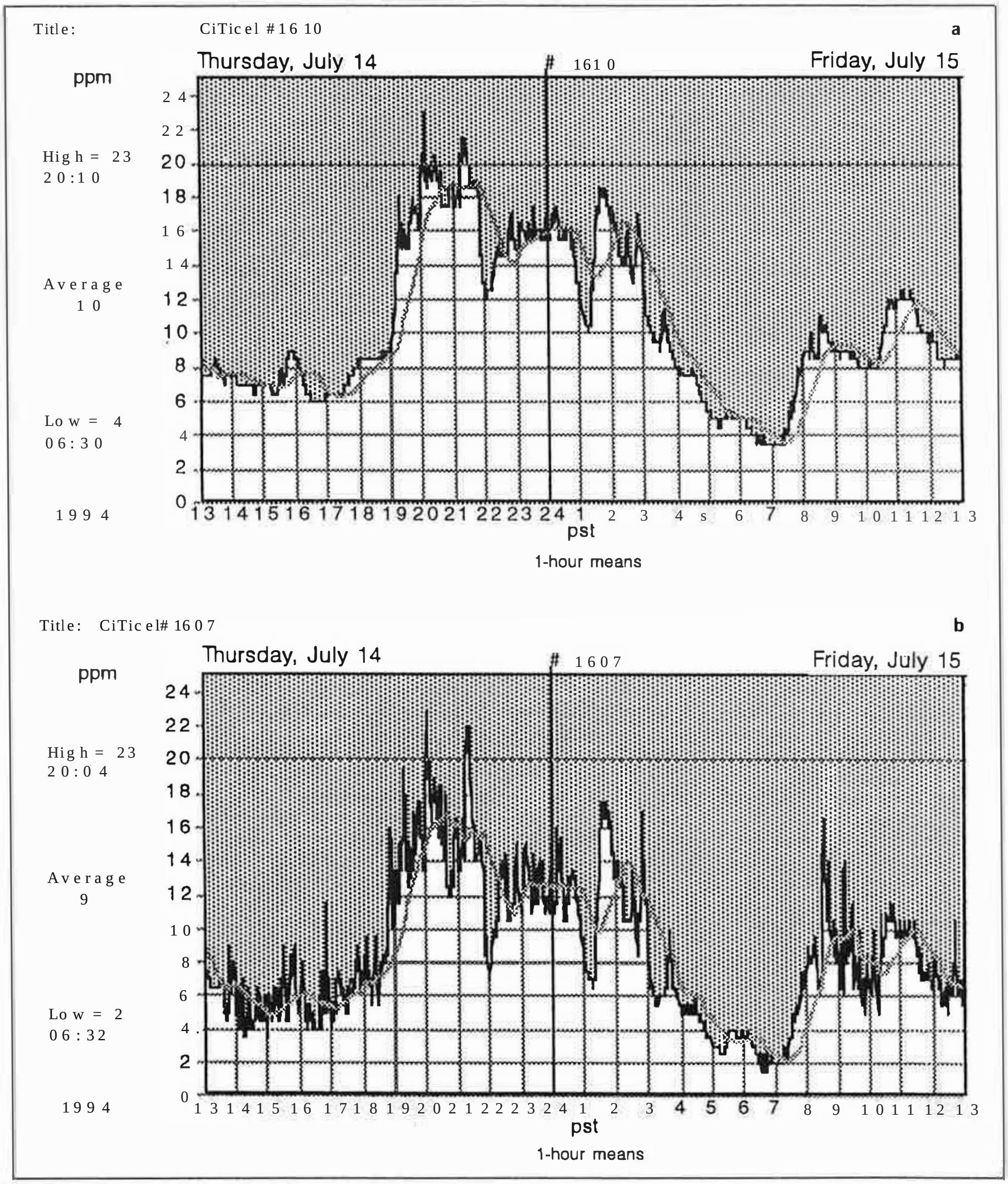

Fig. 1. Simultaneous real-time measurements of CO levels indoors and outdoors in Bandera Street. **a** Indoors. Mean 24-hour temperature, 23.86 °C. **b** Outdoors. Mean 24-hour temperature, 15.36 °C.

outdoors and indoors were 9 and 10 ppm, respectively, which is very close to the 8-hour standard for this pollutant. However, outdoors the hourly average (grey line) between 19.00 h and 21.00 h ranged between 9 and 16 ppm. Between 09.00 h and 13.00 h on the following day, the hourly average ranged between 10 and 16 ppm. Indoors, the hourly average between 19.00 h and 21.00 h ranged between 13.5 and 18.5 ppm. Levels below the 9 ppm standard were reached outdoors and indoors only at about 04.00 h. During the 24 h of sampling indoors, the running 8-hour mean exceeded the Chilean 8-hour standard of 9 ppm 12 times.

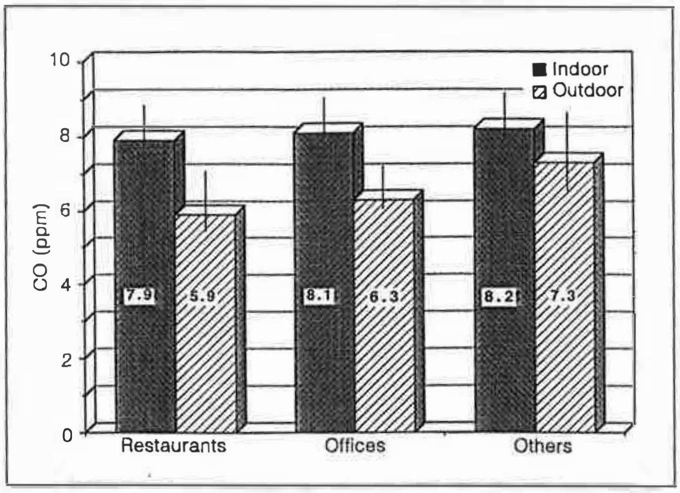

Fig. 2. Indoor and outdoor CO average concentrations (24 h) in different places of Bandera Street.

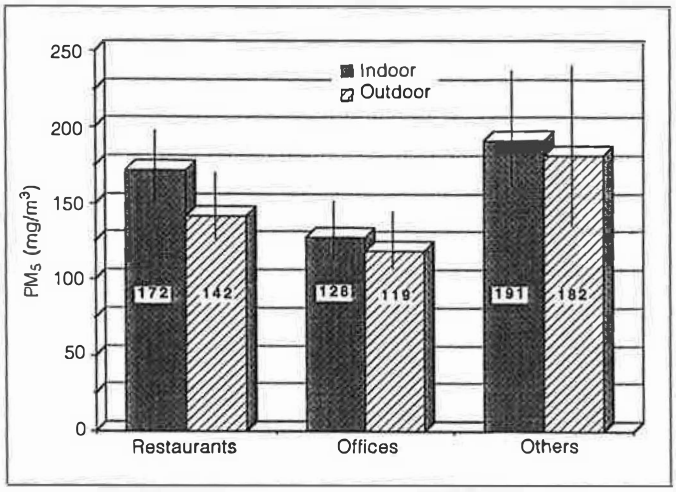

Fig. 3. Outdoor and indoor PM_5 average concentrations (24 h) in different places of Bandera Street.

Figure 2 shows the 24-hour average concentrations outdoor and indoor levels for CO obtained in restaurants, offices and other places. The indoor means in restaurants, offices and other places did not show statistically significant differences ($p > 0.05$). These values ranged between 7.9 and 8.2 ppm for indoors and between 5.9 and 7.3 ppm for outdoors. At the 14 places monitored, 24-hour concentrations were always higher indoors than outdoors with mean levels 33.8% higher in the case of restaurants, 27.1% for offices and 12.7% in other places. The highest indoor concentration was 73 ppm (811% higher than the standard) in a gambling place, but on the same day the highest outdoor concentration was 68.5 ppm. The highest outdoor concentration was 93 ppm (which is 1,033% higher than the standard).

During the 24-hour period, the CO values varied markedly, both indoors (1.5–73 ppm) and outdoors (2.0–93 ppm), suggesting variations in traffic density. Although indoor levels were always higher than outdoors, changes in outdoor concentrations almost simultaneously produced changes in indoor levels, particularly in places which were not equipped with air-conditioning systems. The correlation coefficients between CO indoors and outdoors were higher than 0.742.

Nicotine Levels

Table 1 shows the 24-hour indoor and outdoor levels for nicotine in restaurants, offices and other places. Indoor levels ranged between 0.3 and 3.3 $\mu g \cdot m^{-3}$ and outdoor levels between 0 and 0.8 $\mu g \cdot m^{-3}$. It can be seen that indoor mean levels significantly exceeded outdoor levels ($p < 0.05$). Indoor mean levels in restaurants and other places were similar but were 2.3 times higher in restaurants than those in offices ($p < 0.05$). These data show that people smoke more in restaurants and gambling places than in offices.

PM_5 Levels

Figure 3 shows the 24-hour indoor and outdoor levels for PM_5 obtained in restaurants, offices and other places. Indoor means in restaurants, offices and other places were not significantly different ($p > 0.05$). Average ratios between indoor and outdoor concentration were higher than or equal to 1 (1.36 for restaurants, 1.00 for offices and 1.17 for other places), showing that indoor mean levels were higher than or equal to outdoor levels. In some offices, restaurants and other places, indoor concentrations were much higher than outdoor levels, suggesting the presence of important indoor sources of particulate matter and/or accumulation of particles which had infiltrated from outdoors.

The highest PM_5 concentration obtained indoors was 260 $\mu g \cdot m^{-3}$ in a hotel, where the possible sources were stoves, 'califonts' and cigarettes, but on that same day a concentration of 280 $\mu g \cdot m^{-3}$ was reached outdoors, suggesting that infiltration of outdoor air is the main source of PM_5 indoors. This place is located at a corner, only a few metres from a bus stop and so emissions from the buses enter the building almost directly.

Table 1. Outdoor and indoor nicotine concentrations (means ± SE) in different places along Bandera street in downtown Santiago, Chile

Places	Nicotine, $\mu g \cdot m^{-3}$			Significance of inter-group relationships		
	indoors	outdoors	p value		p value (indoors)	p value (outdoors)
Restaurants (a)	2.20±0.48	0.40±0.15	0.0004	a/b	0.049	0.468
Offices (b)	0.95±0.31	0.33±0.10	0.0109	a/c	0.973	0.797
Others[1] (c)	2.17±0.90	0.37±0.19	0.0006	b/c	0.014	0.701

[1] 1 hotel and 2 gambling places.

Table 2. Outdoor and indoor total PAHs and carcinogenic PAH average concentrations in Bandera street, downtown Santiago, Chile

Place	Total PAHs			Carcinogenic PAHs		
	indoors	outdoors	I/O	indoors	outdoors	I/O
Restaurants (a)	236±65.60	225±54.39	1.05	37±13.97	35±12.62	1.06
Offices (b)	207±36.65	494±129.17	0.42	17±3.19	65±19.32	0.26
Others (c)	196±83.25	288±171.00	0.68	19±6.51	34±22.34	0.56

Significance of inter-group relationships

	p value, total PAHs		p value, carcinogenic PAHs	
	indoors	outdoors	indoors	outdoors
a/b	0.701	0.108	0.767	0.151
a/c	0.721	0.677	0.795	0.732
b/c	0.888	0.379	0.961	0.424

I/O = Indoors/outdoors. Total and carcinogenic PAHs were extracted from PM_5 and determined as described in Material and Methods. Results are concentrations for 24 h and are presented as mean ± SE.

Levels of Total and Carcinogenic PAHs

Table 2 shows the 24-hour indoor and outdoor levels for total and carcinogenic PAHs adsorbed in PM_5 particles collected in restaurants, offices and other places. No statistically significant differences ($p > 0.05$) between indoor means of total and carcinogenic PAHs in restaurants, offices and other places were obtained. Outdoor concentrations of total PAHs ranged between 54 and 978 $ng \cdot m^{-3}$, with an average of 354 $ng \cdot m^{-3}$. Indoor concentrations ranged between 36 and 405 $ng \cdot m^{-3}$, with a mean of 215 $ng \cdot m^{-3}$. For carcinogenic PAHs, outdoor concentrations ranged between 11 and 269 $ng \cdot m^{-3}$, with a mean of 83 $ng \cdot m^{-3}$. Indoor concentrations ranged between 12 and 95 $ng \cdot m^{-3}$, with a mean of 37 $ng \cdot m^{-3}$.

Table 3 shows the correlation coefficients between levels of some PAHs indoors in restaurants, offices and all the other places monitored and outdoors. Excellent correlation coefficients were obtained for restaurants: the highest coefficient between indoor and outdoor levels was for benzo[a]pyrene levels in restaurants (0.998).

Levels of Pollutants in Bandera Street and in Curacaví

Table 4 shows the levels of CO, PM_5 and total and carcinogenic PAHs in Bandera street and in a rural area (Curacaví). The levels for all the pollutants were considerably lower in the rural area.

Table 3. Correlation coefficients between PAHs indoors and outdoors in Bandera street, downtown Santiago, Chile

Indoor/outdoor	Total places (n = 14)	Restaurants (n = 6)	Offices (n = 6)
B(k)F/B(a)P	0.745	0.889	0.563
B(k)F/D(a,h)A	0.679	0.868	0.337
B(a)P/B(a)P	0.859	0.998	0.633
B(a)P/I(1,2,3 cd)	0.744	0.905	0.459
I(1,2,3 cd)/I(1,2,3 cd)	0.695	0.859	0.520
B(g,h,i)/B(g,h,i)	0.595	0.980	0.747
B(g,h,i)/B(a)P	0.830	0.930	0.622
B(g,h,i)/D(a,h)A	0.796	0.909	0.741
B(g,h,i)/I(1,2,3 cd)	0.874	0.991	0.866

B(k)F = Benzo[k]fluoranthene; D(a,h)A = dibenzo[a,h]anthracene; B(a)P = benzo[a]pyrene; I(1,2,3 cd) = indene[1,2,3 cd]pyrene; B(g,h,i) = benzo[g,h,i]perylene.

Mutagenic Response

The mutagenic response to organic extracts from PM_5 collected in Bandera street and in a rural area (Curacaví) in the presence and in the absence of S9 is shown in table 5. The extracts from Bandera street are highly mutagenic in the presence and in the absence of S9, suggesting the presence of direct and indirect mutagenic pollutants. The response of rural extracts was considerably lower especially in the absence of S9.

Survey of Symptoms and Signs Probably Related to Air Pollution in Urban and Rural Areas

A case control study was designed to compare people working on Bandera street (a highly polluted urban area) with people working in the rural area of Curacaví. Comparison was made by means of a survey of perceived symptoms and signs which could be related to the presence of air pollutants. The survey asked many questions including some about smoking habit and exposure to indoor pollution. Table 6 shows the percentages of affirmative replies regarding a series of symptoms and signs possibly associated with air pollution from people working at Bandera and at Curacaví. For all symptoms and signs asked about, a statistically significant difference ($p < 0.05$) was obtained, showing a greater frequency of symptoms and signs among people working on Bandera street, compared with those working at Curacaví, particularly with regard to eye complaints, sneezing attacks, coughs, throat dryness and rhinitis.

Discussion

In this work, the influence of outdoor pollution on indoor air quality has been studied. Concentrations of nicotine, PM_5 (respirable particulate matter) and total and carcinogenic PAHs have been studied simultaneously indoors in restaurants, offices, and other places and outdoors. The main sources of emissions of these pollutants indoors were: in the restaurants, fuel combustion (for heating, 'califonts' and kitchens) and cigarettes; in offices, fuels for heating and cigarettes; and in other places, mainly cigarette smoke, particularly in gambling places. All the offices had air-conditioning systems, although they were not always in optimum working condition. At all the places monitored, the other important indoor pollution source was through infiltration of outdoor air and its subsequent accumulation if the places were not equipped with good ventilation systems. At restaurants and gambling places, which usually have their doors and/or windows open, the infiltration of outdoor air was much greater than in offices.

Measurements of CO clearly shows the importance of infiltration of this gas from outdoors, as indoor concentrations fluctuated almost simultaneously with outdoor ones, and increased particularly at times when vehicular traffic was heaviest. This source was far in excess of that from other indoor sources such as cigarette smoke and fuel used for heating and cooking. This is confirmed by: the 24-hour average CO values, which did not show statistically significant differences ($p > 0.05$) between restaurants, offices and other places, in spite of the differences in indoor sources, and the excellent correlation coefficients obtained for indoor and outdoor measurements.

The greater indoor than outdoor concentration of CO can be explained by emissions due to combustion processes indoors adding to that from infiltration and accumulation of outdoor CO. In this study, it has not been possible to establish the contribution of each of the sources, however, the maximum indoor and outdoor levels at all the places monitored are found during the hours of heaviest vehicular traffic. This confirms that the main anthropogenic sources of CO in cities are vehicles and on Bandera street these are such as to affect the quality of indoor air substantially.

It is well known that high levels of CO decrease the blood's ability to carry oxygen to the tissues, as the CO displaces the oxygen from oxygenated haemoglobin, forming carboxyhaemoglobin. In an atmosphere containing CO, formation of carboxyhaemoglobin increases to reach an equilibrium at a rate depending on the level of exposure and the ventilation rate of the person.

Table 4. Average concentrations for CO, PM_5 and total and carcinogenic PAHs in Bandera street and in Curacaví (24 h)

Pollutant	Bandera street (n = 14)		Curacaví (n = 6)	
	mean	range	mean	range
CO, ppm	6.51	0.5–93.0	1.78	0.5–42.0
PM_5, $\mu g \cdot m^{-3}$	141.14	70.0–280.0	109.50	35.0–139.0
PAH, total, $ng \cdot m^{-3}$	354.0	54.0–978.0	102.0	59.0–214.0
PAHs, carcinogenic, $ng \cdot m^{-3}$	47.71	11.0–145.0	24.0	5.1–43.0
Temperature, °C	13.0	9.0–16.0	18.0	13.5–23.0

Table 5. Mutagenic response (revertants$\cdot m^{-3}$) induced in the strain TA 98 of *S. typhimurium* in the presence (+S9) and in the absence of S9 (–S9) organic extracts from PM_5 collected outdoors in Bandera street and in Curacaví

Place	Revertants$\cdot m^{-3}$		
	n	+S9	–S9
Bandera (a)	14	2,125	2,812
Curacaví (b)	6	536	88

+S9 a/b: $p < 0.01$; –S9 a/b: $p < 0.01$.

Table 6. Survey of symptoms and signs related to air pollution taken from individuals working in Bandera street and in Curacaví

Symptoms and signs	Positive answers, %	
	Bandera	Curacaví
Cough	36.2	12.6
Sneezing attacks	44.8	13.7
Expectoration	26.7	12.1
Wheezes	39.1	21.6
Bronchitis	45.7	28.4
Rhinitis	37.9	14.7
Eye irritation	75.0	20.3
Red eyes	64.7	14.7
Throat dryness	62.1	29.7
Permanent fatigue at work	20.7	13.5
Voice problems	31.0	16.2

Survey answered by people working in Bandera street and Curacaví (44.2% women and 55.8% men). Bandera street, n = 107; Curacaví, n = 74. All the responses (Bandera street/ Curacaví) were statistically significant at $p < 0.05$.

The CO standard for 8 h exposure established by the WHO, USA-NAAQS (National Air Quality Standard) and ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers) is 9 ppm, this level must not be exceeded more than once a year. Exposure to this concentration produces carboxyhaemoglobin plasma levels of 2.5% in 8 h. Levels higher than the standard affect perception, vision and alertness and produce dizziness, somnolence and headaches. They affect the central nervous system and can trigger changes in heart function. Studies by the WHO [15] suggest that people suffering from cardiovascular diseases could suffer a worsening of their symptoms if the carboxyhaemoglobin concentration in their blood rises to between 2.7 and 5.1%, and that changes in their performance at work can occur at carboxyhaemoglobin concentrations in the 2.5 to 5.1% range.

Average values and ranges found indoors in this study exceed substantially those obtained by other studies [16–20]. Likewise, average values and ranges obtained for CO outdoors were considerably higher than those obtained by other studies [16, 20–22]. It has been suggested that, assuming there is a reasonable air exchange, people may be exposed to concentrations which are generally lower than about 4 ppm, a figure of 2–3 ppm is considered reasonable in office and working places and 4–5 ppm at public functions or in restaurants. In this study, the average levels found were much higher: 8.1 ppm for offices and 7.9 ppm for restaurants, which suggests that the indoor air quality on Bandera street as regards CO concentration is very poor. Other studies report that the CO standard of 9 ppm for 8 h is rarely exceeded and usually this happens when there is limited air exchange, or the number of people gathered in an area is unusually high or when other sources, such as kitchens, heaters, cigarettes or vehicular emissions are nearby. In this study, the 9 ppm concentration was exceeded, on a 24-hour average, in four indoor sampling places (2 offices, 1 restaurant and 1 gambling place). In other places, concentrations exceeding 9 ppm were found for long periods of time although not as long as 8 h. CO binding to haemoglobin is slowly reversible (compared to oxygen) and after exposure the pigment dissociates to haemoglobin and CO which latter is eliminated by the lungs. However, it is important to ask what is the effect on human health after repeated exposure to high concentrations for periods shorter than those established by the standard. The high concentrations of CO found outdoors on Bandera street and the substantial influence of the air infiltrating indoors suggest that people working or living on that street are exposed to CO concentrations which exceed international standards many times during the year and that this could affect their health.

Nicotine is a derivative of pyridine and is released during the combustion of cigarettes. Tobacco is the only important source of this alkaloid and its presence is considered to be a 'tracer' for cigarette smoke [23]. The Occupational Safety and Health Association (OSHA) has established a standard for working places of 500 $\mu g \cdot m^{-3}$ of nicotine over 8 h. The standard for the short-term exposure limit is 1,500 $\mu g \cdot m^{-3}$ and the level considered dangerous by the National Institute for Occupational Safety and Health (NIOSH) is 35,000 $\mu g \cdot m^{-3}$. In restaurants in this study, the 24-hour average was only 2.2 $\mu g \cdot m^{-3}$, average values of 5.4, 5.1, 4.3 and 3.2 $\mu g \cdot m^{-3}$ have been found in other studies [24–27]. In the offices we studied, the average level was 0.95 $\mu g \cdot m^{-3}$ while other studies have found average levels of 1.1 $\mu g \cdot m^{-3}$ [28] and 4.8 $\mu g \cdot m^{-3}$ in offices where there were no restrictions on smoking [25]. Nicotine has a short half-life (6.5 min) indoors and higher levels may be obtained with shorter sampling times.

The main effects of particulate matter on human health are said to include changes in the defence mechanisms, damage to lung tissue, worsening of symptoms in people suffering from respiratory and cardiovascular diseases, carcinogenesis and premature death. The groups which are most sensitive are children, the elderly and those suffering from influenza, asthma, chronic pulmonary obstruction (COPD) and cardiovascular diseases. Most particulate matter found indoors comes from vehicular traffic, as well as from incinerators and other combustion processes vented through chimneys.

PM_5 average concentrations did not show any statistically significant differences ($p > 0.05$) between indoor and outdoor measurements and between restaurants, offices, and other places. However, taken individually in one gambling place and in one restaurant, indoor concentrations were greater than outdoor concentrations, probably reflecting the contribution of indoor combustion sources.

The average concentration of PM_5 in restaurants was 172 $\mu g \cdot m^{-3}$, which is much higher than the PM_{10} averages revealed by other studies carried out in restaurants by Oldaker et al. [25] (120 $\mu g \cdot m^{-3}$), Crouse and Carson [29] (111 $\mu g \cdot m^{-3}$), Odgen et al. [30] (111 $\mu g \cdot m^{-3}$). The PM_5 average for offices was 126 $\mu g \cdot m^{-3}$, which again is much higher than PM_{10} averages determined by other studies carried out in offices by Carson and Ericson [31] (44 $\mu g \cdot m^{-3}$), Crouse and Carson [29] (61 $\mu g \cdot m^{-3}$), but similar to those reported by Oldaker et al. [25] (126 $\mu g \cdot m^{-3}$).

In this study, 17 PAHs have been identified (including 6 carcinogens), which are referred through the text as total PAHs. However, it must be pointed out that there are other PAHs present which have not been identified or quantified and which have not been considered in the total. Moreover, the PAHs in the gaseous phase have not been determined.

The levels of both total and carcinogenic PAHs outdoors were generally higher than those indoors, particularly in the case of offices. This might be explained by the fact that indoors there were fewer combustion processes emitting PAHs and in offices lower infiltration because the windows were usually closed and they had air-conditioning. These results are confirmed by the indoor/outdoor ratios which, for total and carcinogenic PAHs were close to 1 for restaurants and lower than 0.7 for offices and other places. In spite of the different sources of indoor emissions, there were no statistically significant differences between indoor concentrations in restaurants, offices and other places ($p > 0.05$). No significant differences ($p > 0.05$) were found for these compounds between smoking and non-smoking places.

The most abundant of the total PAHs, in decreasing order of indoor concentrations were: acenaphthylene, pyrene and naphthalene. Outdoors, they were: pyrene, naphthalene and acenaphthylene. Indoor concentrations were lower on average than those outdoors (215 $ng \cdot m^{-3}$). Average outdoor concentrations of PAHs were 354 $ng \cdot m^{-3}$ which is 61% higher than those reported in a study carried out in Ohio [32], which found an average of 220 $ng \cdot m^{-3}$ and measured the same PAHs, except for fluorene and dibenzo[a,h]anthracene.

The carcinogenic PAHs determined were: benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, dibenzo[a,h]anthracene, indene[1,2,3 cd]pyrene and benzo[a] anthracene. Outdoor concentrations were, on average, 83 $ng \cdot m^{-3}$, 40 times higher than those found in the study by Chuang et al. [32], which measured the same carcinogens, with the exception of dibenzo[a,h]anthracene, and found an average of 2.1 $ng \cdot m^{-3}$. Indoor concentrations averaged 25 ng·m^{-3}. The most abundant carcinogenic PAHs, in decreasing order of concentration, both indoors and outdoors, were: benzo[a]anthracene, benzo[b]fluoranthene and benzo[a]pyrene. The most potent carcinogens are benzo[a]anthracene and benzo[a]pyrene. The average indoor and outdoor levels for benzo[a]anthracene were 7.9 and 19.8 ng·m^{-3}, and for benzo[a]pyrene 4.8 and 7.8 ng·m^{-3}, respectively. Indoor concentrations in restaurants of benzo[a]anthracene and benzo[a-]pyrene were almost twice as high as in offices and other places, values which must be explained not only by outdoor infiltration, but also by the use of fuels for cooking and, to a degree, cigarette smoke. The contribution of cigarettes as source of PAHs in restaurants is not considered significant, since although average concentrations of nicotine (as a tracer for cigarette smoke) in restaurants and other places were 2.3 times higher than in offices, the average levels of carcinogenic PAHs did not increase significantly in the former. This seems to suggest that cigarettes are not the main source of these PAHs, because all the restaurants monitored work with open doors, Thus, PAHs enter from outdoors and if the air circulation is not good, they will accumulate. This is clearly seen, by comparison of the indoor and outdoor average concentrations for coronene (a tracer for vehicular traffic), which were very similar (9.2 μg·m^{-3} indoors and 8.7 μg·m^{-3} outdoors).

The results presented in this study show that the main source of PAHs indoors in Bandera street is outdoor infiltration. This is supported by two facts: the indoor and outdoor concentrations of coronene overall and coronene concentrations in restaurants and other places which work with windows and door open which were almost double those in offices and secondly in restaurants (where there should be more internal generation of PAHs), a correlation coefficient of 0.987 was found for carcinogenic PAH concentrations indoors and outdoors.

Moreover, the survey of symptoms and effects on health which are probably related to air pollution, excluding smoking as a confounding factor, clearly shows that persons working on Bandera street have a greater probability of experiencing symptoms such as eye complaints, dry throats, cough, rhinitis and sneezing attacks than persons who work in the rural area and breathe air which is much less polluted.

If we stratify these data taking into account smoking, replies showed that for smokers there is an increased risk for coughs, bronchitis and dry throats. However, in the case of non-smokers, there is an increased risk of wheezing, sneezing attacks and rhinitis. This could be explained by a greater sensitivity of non-smokers to environmental pollutants, as the respiratory epithelium of the smoker is adapted to a greater extent.

The difference between symptoms and signs in the two monitored areas, without taking smoking into account, could be due to the presence of atmospheric pollutants. The levels of CO, PM_5 particles and total and carcinogenic PAHs were 3.43, 1.24, 3.42 and 3.25 times greater, respectively, on Bandera street than at Curacaví (table 4). However, the risk to persons working on Bandera street does not only refer to reversible symptoms or effects which could disappear if exposure were to cease, but also to long-term effects which could be irreversible, such as possible damage to genetic material.

Mutagenicity assays in the *S. typhimurium* TA 98 strain, showed that the Bandera samples were highly mutagenic in the presence and in the absence of an activating system, revealing the presence of direct and indirect mutagenic agents. In the case of Curacaví, mutagenicity was found to be 4 times lower in the presence of an activating system, and little direct mutagenic activity was detected.

Toxicity in the presence of an activating system could be explained by high concentrations of carcinogenic PAHs and indirect mutagenicity by the presence of nitroarenes. The latter have been considered to belong to the most powerful mutagenic agents. These compounds are produced either by reactions between PAHs, ozone, NO_2 and peroxyacetyl nitrate (PAN) or by emissions, particularly those of diesel engines. The small direct mutagenicity in the rural area could be due to lower emissions from diesel engines and because atmospheric conditions, or concentrations of pollutants are not enough to produce detectable amounts of nitroarenes. Also, there is possibly a higher mineral (soil) contribution to PM_5 in the rural area with proportionally lower carbon and PAH levels. It must be pointed out that the presence of direct mutagens represents a higher risk to human health, since they do not need biotransformation to express their mutagenic activity.

The main source of emissions of respirable particulate matter and PAHs with mutagenic and carcinogenic properties are diesel engines [33] which, for the city, implicates the many buses in Bandera street. We believe the authorities must take all the necessary actions to reduce these emissions, by restricting the number of buses in circulation, improving emission control and imposing appropriate fines on bus companies whose buses do not meet the emission standards. Furthermore, the health of people working on Bandera street must be protected by improving indoor air quality. Outdoor infiltration must be reduced and systems for purifying and recirculating air must be found. This is economically very important in view of the fact that productivity at work is lower in environments which cause discomfort.

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