Distributions of indoor and outdoor air pollutants in downtown Rio de Janeiro city, Brazil

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ABSTRACT

Indoor air quality (IAQ) has been a matter of public concern in Brazil. An IAQ survey was conducted in an office building and in a commercial bank in Rio de Janeiro, Brazil. Indoor and outdoor air of offices was analysed due to the possibility of causing adverse effect on the health of the occupants. Measurements were made in a day during working hours. Samples were collected for volatile organic compounds (VOCs), total volatile organic compounds (TVOCs), aldehydes, total particulate matter (TPM) and microbiological analysis. The concentrations of formaldehyde and acetaldehyde had been higher in indoor than outdoor air due to recent refurbishing of the office and the presence of carpets and cleaning materials. The TVOC concentrations ranged from 216.32 to 592.97 $\mu g/m^3$. The indoor levels of TVOCs were higher indoor than outdoor, indicating indoor sources of pollution, despite the office's location near street traffic. TVOC values exceeded the Brazilian Guidelines (500 $\mu g/m^3$). TPM values varied between 3.85–9.31 $\mu g/m^3$, in a commercial bank, and 12.36–16.31 $\mu g/m^3$, in an office building. These values do not exceed the Brazilian Guidelines (80 $\mu g/m^3$). The microbiological analysis showed that indoor air is good, because the values obtained varied between 35.7 and 121.4 cfu/m^3, below that suggested (750 cfu/m^3). The condensed water pans and the ducts were not working as primary and secondary sources of pollution. The characterization of indoor air pollutants allowed the suggestion of several remediation measures to improve air quality in the offices.

INDEX TERMS

Indoor Air Quality; VOCs; Aldehydes; GC-MS

INTRODUCTION

Air pollution is a major environmental health problem affecting developed and developing countries around the world. Increasing amounts of potentially harmful gases and particles are being emitted into the atmosphere on a global scale, resulting in damage to human health and the environment. It is damaging the resources needed for the long-term sustainable development of the planet (WHO, 2000). In developed societies, many people pass most of their time indoors. People, actually spend 88% of their day inside buildings, 7% in a vehicle, and only 5% spend their time outdoors. Therefore, indoor exposures will produce more harmful health effects, and the evidence is that indoor concentrations of many pollutants are often higher than those typically encountered outside (Jones, 1999).

In Brazil, there are some cases related to Indoor Air Quality (IAQ) and Sick Building Syndrome (SBS). In the past few years, there has been a tendency to select buildings based on various factors, e.g. architecture, climatization and low noise. This tendency probably will increase the number of SBS cases. The Government is alert, and the Ministry of Health already published the Portrait 3523, on August 28, 1998 and the National Agency of Sanitary Vigilance, decreed the Resolution 176, on October 24, 2000. Both suggested limits of many indoor pollutants, established cleaning methods for HVAC systems, indicated emission sources of pollutants, aiming to prevent risks to the health of the occupants. Since the last

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decade, some researchers have been studying IAQ in Brazil, with the objective of improving the quality of people's life and determining what kind of pollutants are commonly present here. Results of these studies indicated that the indoor air could be more polluted than the external air, especially for big cities. The pioneering works in Brazil had been initiated in 1992 with studies carried through in offices and restaurants in Rio de Janeiro and São Paulo (Miguel *et al.,* 1995; Santos *et al*., 1997). Many studies have been carried out during the last years in this area, where the researchers had evaluated air in bayside offices (Brickus *et al*., 1998a), dwellings (Almeida *et al* 2000), bank strong boxes (Carneiro and Aquino Neto, 2002) and printing facilities (Gioda and Aquino Neto, 2002), for example.

Important sources of chemical indoor pollutants include outdoor air, the human body and human activities, emissions from building materials, furnishings and appliances and use of consumer products. Microbial contamination is mostly related to the presence of humidity. The heating, ventilating and air-conditioning system can also act as a pollutant source, especially when it is not properly maintained. For example, improper care of filters can lead to re-emission of particulate contaminants. Biological contamination can proliferate in moist components of the system and be distributed throughout the building (WHO, 2000).

The goal of this study was to evaluate the indoor air quality in two offices situated at downtown Rio de Janeiro, one of them was recently refurbished, and to look for indoor sources of pollutants.

METHODS

Building Characteristics

The local climate in Rio de Janeiro is tropical with monthly mean temperatures varying between 21°C (June/July) and 29°C (January/February). Situated at latitude 22°54′S and longitude 43°10′W, the city of Rio de Janeiro experiences a climate with uniformly high temperatures, high humidity and abundant rainfall averaging 2381 mm per year. Samplings were carried out during a day of work, for each office, in June 2001 and February 2002, at the office building and commercial bank, respectively. Sampling locations were selected after evaluation of the human activities and the air conditioning systems, which cool these rooms. The chosen rooms were at office building: AL 01, AL 02, AL 03—indoor points, AL OD—outdoor point; at commercial bank: BB 01, BB 02, BB 03—indoor points, BB OD—outdoor point.

Sampling Strategy and Analytical measurements

Outside and inside measurements were taken simultaneously, for dry–wet bulb temperature and relative humidity, aldehydes, VOC, Total Particulate Matter (TPM) and fungi. Samplings were made for 8 h during daytime, with the office normally occupied. Complete sampling and analysis conditions were as given by Brickus *et al.* (1998a). The air samples for microbiological analysis are of four distinct types: Ambient air, Supply Air, Return Air and Mixer Air. The sampler used for these collections was a one stage CBI Air Sampler E01-S Impactor. Fungi analyses conditions were as described by Brickus *et al.* (1988b).

RESULTS

Environmental measurements, such as, temperature and relative humidity, TPM were made in all of the sampled points. Aldehydes and VOCs were collected only in office points, and microbiological analyses were performed only at the commercial bank. Figure 1 shows typical values for the physical parameters evaluated in this study.

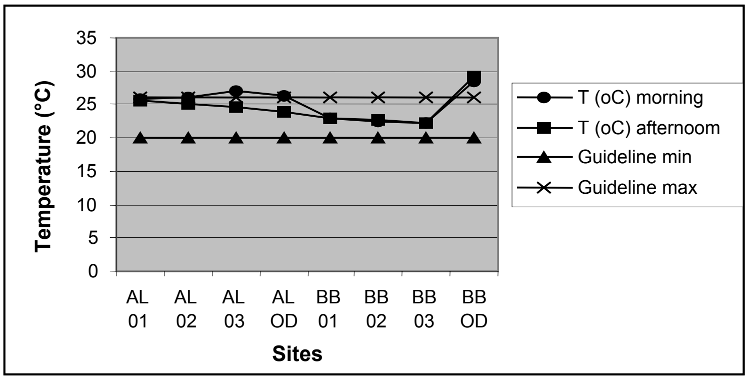

Figure 1 Relative humidity and temperature values for the strongbox sites.

ASHRAE recommends internal temperatures between 20–26°C, and Resolution No. 176 recommends 23–26°C for summer, once larger or smaller temperatures are uncomfortable to humans. ASHRAE recommends relative humidity of the indoor air in the range of 30–70% and Resolution No. 176 recommends 40–65%. It is known that low values of humidity of the air induces drying of skin, mouth and nasal mucous, while high values of humidity of the air can favour biological agents' proliferation.

TPM and Aldehydes

Figure 2 and Table 1 show the values found for TPM and aldehydes at office and bank points. This table lists I/O ratios which indicate the contributions for air quality. Figure 2 shows the results for TPM analysis, at the offices and the commercial bank.

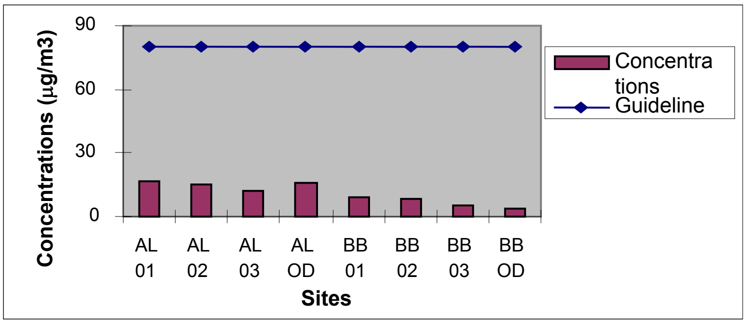

Figure 2 Indoor and outdoor values for TPM.

The formaldehyde and acetaldehyde results are summarized in Table 1. Formaldehyde concentrations ranged between 96.6 and 100.7 µg/m^3 for indoor air and 8.8 µg/m^3 for outdoor air, whereas the acetaldehyde levels were between not detected and 1.9 µg/m^3 for indoor, and not detected in outdoor air. The aldehyde concentrations are higher indoors, except at the AL 01 point for acetaldehyde, and indicate I/O ratios.

Table 1. Aldehyde concentrations, I/O ratios and TPM obtained at offices and commercial bank analysed

Samples	Formaldehyde conc. (µg/m^3)	I/O ratio	Acetaldehyde conc.(µg/m^3)	I/O ratio	TPM conc. (µg/m^3)
AL 01	110.0	12.5	ND	NA	16.31
AL 02	96.6	11	1.4	NA	15.10
AL 03	110.7	12.6	1.9	NA	12.36
AL OD	8.8	NA	ND	NA	15.85

Abbreviations: ND—Not detected; NA—not applied.

Volatile Organic Compounds (VOCs)
Seventy-two VOCs were identified and the mean concentrations of the main compounds measured, in micrograms per cubic meter, are listed in Table 2 and the average profile of distribution of VOCs by chemical class obtained in all the evaluated points, is shown in Figure 2. VOCs commonly detected can be divided into five categories. The largest classes are the aromatic and aliphatic hydrocarbons. The compounds in these two classes derive, for example, from petroleum distillate-type solvents. The terpenes constitute a class of odouriferous substances, which in the present sampling were detected only in indoor sites, and in low concentrations. They are probably related to cleaning products (Figure 3).

Table 2 Average of indoor and outdoor volatile organic compounds (μg/m^3) in the office building

Compounds	AL 01 (μg/m^3)	AL 02 (μg/m^3)	AL 03 (μg/m^3)	AL OD (μg/m^3)
Methyl pentanone	12.3	12.2	12.8	–
Toluene	120.9	118.7	118.4	2.4
Tetrachloroethene	6.5	6.4	36.1	–
Ethylbenzene	29.7	29.5	29.3	0.6
Xylenes	26.5	26.2	26.4	0.5
Butoxiethanol	90.8	164.4	17.6	–
Methylethylbenzene	18.2	18.1	18.5	1.3
Trimethylbenzene	21.3	21.2	21.1	–
Pentadecane	7.3	6.9	7.3	–
Trimethylcicloexen-2-one	15.6	16.2	15.3	–
Benzene	1.3	0.6	0.8	0.1
β-pinene	1.5	1.1	–	–
TVOCs	548.1	593.0	567.4	216.3

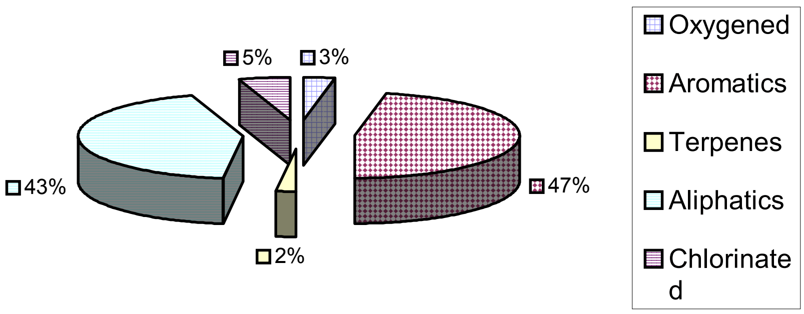

Figure 3 Average distribution of VOCs by chemical class for the indoor air at office.

Microbiological Analysis
The studied sites present airborne fungi levels below 750 cfu/m^3 and below a level obtained for the outdoor site (114.3 cfu/m^3). Table 3, shows the results obtained for microbiological analysis. Fourteen genera of fungi were identified in the sampled sites. Samples were collected in groups of four types for each studied room. The most common genera/types observed in sites include *Alternaria*, *Penicilium*, *Aspergillus sp* and *Cladosporium*. In outdoor air *Aspergillus sp*, *Cladosporium sp*, *Verticilium sp* and *Epicoccum sp* were observed. Fungi concentrations are shown in Table 3 and is larger than indoors. This source comes from outdoor fungi.

Table 3 Airborne fungi concentrations (cfu/m^3) found in the offices and bank sites

Sites	Mixer air	Supply air	Ambient air	Return air	Outdoor
System 1	35.7	78.6	50.0	100.0	114.3
System 2	35.7	85.7	57.1	121.4	–

DISCUSSION

Figure 1 shows that all measured values of temperature agreed with the specification of ASHRAE, but they disagreed with the specification of Resolution No. 176 for minimum temperature, all of them were under the limit except for outdoor BB and AL and indoor AL 03. The other points agreed with the specified values. Formaldehyde levels are a good indicator of the effect of the air-conditioning on indoor pollutant concentrations (Brickus *et al*., 1998). On the other hand, consistently higher indoor/outdoor levels of formaldehyde point to the importance of indoor over outdoor sources. Formaldehyde is a non-reactant phenolic resin used as a binder of plywood and particleboard (Sato *et al*., 2000).

All measured values for TPM agreed with the specification (80 μg/m^3)—Figure 2 and Table 1. None of these points surpassed the limit value, 80 μg/m^3 (Resolution No. 176). Formaldehyde concentrations range between 8.8 and 110.7 μg/m^3 for indoor air and 8.8 μg/m^3 for outdoor air and acetaldehyde range between 11.0 and 12.6 μg/m^3 for indoor air and there is no contribution of acetaldehyde outdoors (Table 1). The aldehyde concentrations are higher indoors; however, none of the sampled points surpassed the limit proposed for WHO (1988) and Aquino Neto and Brickus (1999), 100 μg/m^3. However, for especially sensitive groups showing hypersensitivity reactions without immunological signs, WHO recommends a maximum value of 10 μg/m^3 (WHO, 1988). The use of ethanol for cleaning surfaces (notably glass windows) in Brazil is very common, and this appears to be the major source of acetaldehyde indoors because acetaldehyde is a usual contaminant in commercial ethanol. In this study case, ethanol was not used for cleaning surfaces. This explains the minor acetaldehyde concentration in indoor air, contrary to values obtained in other typical indoor surveys (Brickus *et al*., 1998a; Santos *et al*., 1997). I/O ratios larger than one, for formaldehyde, indicate internal sources of pollution, probably due to recent reform suffered in this office. Common sources of formaldehyde are finishing materials, glues, furniture and sanitation products.

The distribution of VOC classes in the outdoor and indoor air varies due to their different emission sources. The absolute amounts of the compounds also varied widely between the offices. I/O ratios for VOC classes and TVOC were revealed discharges, amounting close to 53, which demonstrates that indoor air is much more polluted than the outdoor, with critical sources of pollution (Table 4). This fact indicates that the VOCs found in the indoor air originate mainly from indoor sources, possibly because of the materials used in reform.

Table 4 I/O ratios for VOCs and TVOCs obtained at sampled sites

Compounds	I/O (AL 01)	I/O (AL 02)	I/O (AL 03)
Toluene	50.4	49.5	49.3
Ethylbenzene	49.5	49.2	48.8
Xylenes	53	52.4	52.8
Methylethylbenzene	14	13.9	14.2
Benzene	2.2	6	8
TVOCs	2.5	2.7	2.6

In terms of the hydrocarbon fraction, a higher level of aromatic hydrocarbons was noted both in outdoor as well as indoor air. Saturated hydrocarbons can derive from a variety of consumer products and building materials, where they are present as solvents or thinners and in building composites (particleboard). Some may also arise from tobacco smoke and vehicular traffic (Santos *et al*., 1997). Among the sites studied methyl pentanone and trimethylcicloexen-2-one presented one of the highest mean concentration at the office. TVOC values are very useful in the assessment of the quality of indoor air. In 1996 Molhave and Clausen (1996) proposed the use of a target guideline of 300 $\mu g/m^3$ of TVOC as an indicator of health effects caused by a multicomponent air exposure to VOC at low concentrations. In Brazil, Aquino Neto and Brickus recommended, in 1999, a guideline for TVOC of 500 $\mu g/m^3$, and no single compound exceeding 50% of the total. These measurements demonstrated that values of TVOC concentrations in the evaluated sites are high enough, in light of Molhave's studies, to cause discomfort in occupants (especially sensitive individuals).

Microbiological analysis shows the presence of genera *Alternaria*, *Penicilium*, *Aspergillus sp* and *Cladosporium*, which were calculated to be significantly prevalent in all samples. Exposures to species of *Penicilium* and *Aspergillus sp* have been associated with occupational asthma and hypersensitive pneumonitis (Brickus *et al.,* 1998b).

CONCLUSION AND IMPLICATIONS

Our investigation suggests that better control of the indoor climate and reduction of airborne pollutants may result in appreciable improvement of the indoor comfort and air quality. Specific actions that can be taken to improve the indoor air quality at the offices and bank studied, could stand out for better monitoring of the air-conditioning system, in relation to temperature, relative humidity, and especially for air exchange rate to minimize the adverse effects to health caused by the aldehydes and VOCs present in the indoor air from the reform. Cleaning the ducts of the air-conditioning system, use of better filtration and preventive IAQ maintenance is also required.

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