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Indoor Environmental Quality: Sampling in One of the São Carlos' Public Buses

Fernanda S. Peiter, Wiclef D. Marra Júnior

Departamento de Hidráulica e Saneamento, Escola de Engenharia de São Carlos, Universidade de São Paulo, São Paulo, Brazil
Email: peiterfs@gmail.com

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Abstract

For twenty random days between August and December 2013 the environmental quality inside one of the buses of the public transportation system in São Carlos city (São Paulo—Brazil) was monitored. The levels of temperature, relative humidity, noise, monoxide carbon (CO), dioxide carbon (CO_2) and particulate matter ($PM_{2.5}$ and PM_{10}) were measured. The values established by Brazilian Standards NR-15, NR-17, NHO 01, CONAMA 03/90 and ANVISA 09/03 and the World's Health Organization were taken as references for environmental quality investigation. The Heat Index, parameter used by the United States National Weather Service, was calculated for the verification of the thermal sensation. The results show that the levels of temperature (17˚C - 38˚C), relative humidity (19% - 87%) and Heat Index (69˚F - 104˚F) were not in accordance with the adopted reference values. The particulate matter was higher than the World's Health Organization standards ($PM_{2.5}$: 24 - 48 μg/m^3, PM_{10}: 47 - 109 μg/m^3). The levels of noise measured (68 dB(A) - 92 dB(A)) may cause damage to the health of the bus workers like auditory fatigue or hearing loss. However, the concentrations of monoxide carbon and dioxide carbon inside the bus were not significant. The results show that the air quality inside the bus can be harmful especially to collectors and drivers, who work in this environment many hours during the day.

Keywords

Indoor Environmental Quality, Public Transport, Air Quality Standards

Subject Areas: **Atmospheric Sciences**

1. Introduction

Some authors have addressed the air quality in vehicles and measured different types of pollutants [1]-[8]. In general, they have reported that the means of transportation, vehicle route, traffic emissions, passenger activities,

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ventilation system and type of fuel may influence the concentration of pollutants in this environment. Chan *et al*. [9] found that the global average level in PM_{10} concentrations in roadway transport without air conditioning is usually the highest, followed by marine and roadway transport with air-conditioning in Beijing, China. In the same city, Pang and Mu [10] monitored the carbonyl compound rates in taxis, buses and subways and showed that the leakage of exhaust emissions from internal material, photochemical formation and infiltration of outside air are the main sources of pollutants in vehicles. Gómez-Perales *et al*. [11] concluded that metro is the mode of transport of lower $PM_{2.5}$, CO and benzene concentrations, in comparison with buses and minibuses in Mexico City.

Many factors can influence the presence of pollutants inside vehicles; therefore the monitoring of air quality in such environments must be maintained.

Among automobiles, buses have drawn a plenty of attention due to the large movement of people and convenient access within urban areas. Moreover, bus drivers have suffered from high exposure to pollutants during their longtime work inside the vehicle. An example is the occupational risk caused by noise, because some motors are located in the front of the bus, beside the driver [1] [3] [5].

This study examined one of the buses of the public transport fleet of São Carlos city, in São Paulo.

São Carlos (1136 km² and approximately 222,000 inhabitants) is located in São Paulo state, at least 200 km from the capital [12]. Its public transport system is composed of 140 buses that cover 58 routes. The bus drivers and collectors work approximately eight hours per day. On workdays, almost 60,000 passengers use buses. This research checked temperature and relative humidity, noise, particulate matter (PM_{10} and $PM_{2.5}$), CO and CO_2 inside the vehicle so as to verify its amount of pollutants and the environmental quality for users of the bus.

2. Experimental Design

2.1. Sampling Design

The study analyze done of the routes traveled by the São Carlos' public transport company. Line 04 is traveled by approximately 900 passengers daily. It connects two extreme neighborhoods, Vila São José and Redenção. The bus passes the bus station and the downtown area, characterized by trade and great movement of people and vehicles. It is noteworthy the bus is not air-conditioned and the natural ventilation is provided through its side windows. There are frequent stops and door openings.

The sampling was carried out on twenty random days from Monday to Friday, between August 28 and December 3, 2013. Some equipment was stored in a metal support box with side entries for air inlet. The installation point (at the height of an adult's respiratory system, approximately 1.5 m) inside the bus was determined to not interfere with the movement of passengers. The box-support was hung on a partition structure next to the turnstile (**Figure 1**).

On the days of the data collection, the support box was placed in the bus, at 8:10 a.m. and withdrawn at 4:10 p.m. Measurements were taken for eight consecutive hours so as to represent the exposure time of drivers and conductors to that atmosphere.

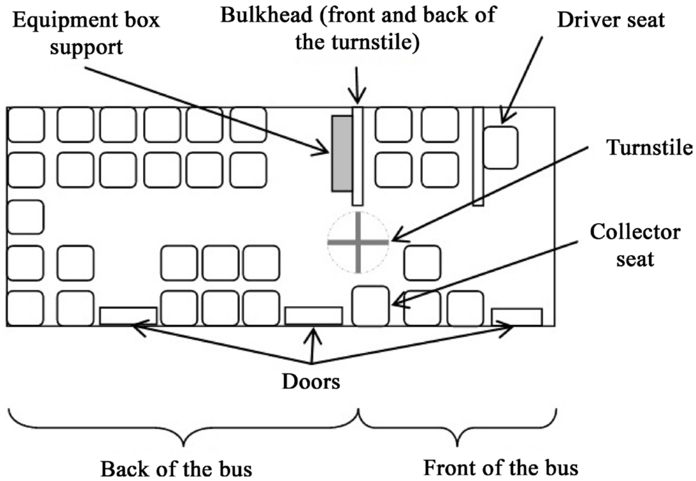

Figure 1. Location of the equipment.

2.2. Equipment

HOBO U12-11, an electronic indoor data logger produced by Onset, was used for the simultaneous monitoring of temperature and relative humidity. Data were recorded every 5 min.

A portable noise dosimeter DOS-500, by Instrutherm, measured the noise level in the environment. The device has an attached microphone and takes measurements in the 30 - 140 dB range with weighting frequency in amperes (A). Data were recorded every minute.

The carbon monoxide and carbon dioxide concentrations were measured by a MultiRAE IR multi-gas monitor produced by RAE Systems. The device measured intervals of 0 - 20,000 ppm for CO_2 and 0 - 500 ppm for CO. Levels of gas were measured every minute.

Two personal samplers (Personal Environmental Monitor—PEM) of SKC, models 761 - 200 B and 761 - 203 B, for $PM_{2.5}$ and PM_{10}, respectively, were used to determine the breathable fraction of suspended particulate matter. They were connected to digital vacuum pumps, SKC—Legacy Leland Model 100 - 3000, programmed for sampling at 10 L/min flow rate. The PEM operates with a Pall Corporation membrane of polytetrafluoroethylene (PTFE) of 37 mm diameter and pores of 2 micrometers. At the end of each collection day the membranes were raised in the laboratory for the determination of the concentration of particulate matter by gravimetric analysis. Prior to each weighing, they were stored in a desiccator for approximately 24 hours for a reduction in the interference of humidity. In the gravimetric tests a scale of 0.1 μg precision, model XP2U and Mettler Toledo brand, and an electrode were used for the removal of electrostatic charges present in the material.

3. Data Analysis

Air quality standards are created to prevent individuals from suffering adverse effects of pollution. They establish values for the reduction or elimination of contaminants in an atmosphere that can be hazardous to the health and welfare [13].

The next standards were taken as references of acceptable values for the health and comfort of individuals in the environment:

- Temperature: Maximum 30˚C (NR-15 Brazilian Regulatory Norm—Unhealthy activities and operations [14]);
- Relative humidity: Minimum 40% (NR-17 Brazilian Regulatory Norm—Ergonomics [15]);
- Noise: Maximum 85 dB(A) (NR-15 e NHO 01 Brazilian Occupational Hygiene Norm [16]);
- Carbon monoxide: Maximum 9 ppm (CONAMA 03/90 Brazilian Resolution—National Council on the Environment [17]);
- Carbon dioxide: Maximum 1000 ppm (ANVISA 09/03 Brazilian Resolution—National Health Surveillance Agency [18]);
- $PM_{2.5}$: Maximum 25 μg/m³ (World Health Organization [19]);
- PM_{10}: Maximum 50 μg/m³ (World Health Organization [19]).

3.1. Calculation of the Heat Index

Besides the direct verification of temperature and relative humidity measured, the Heat Index was calculated to observe the thermal sensation on the bus.

Steadman [20] proposed the Heat Index based on the interrelation between temperature and relative humidity. It has been used by the US National Weather Service to corroborate the "apparent temperature" and can be calculated in Fahrenheit degrees, as showed by Equation (1) [21]. Its effects are shown in **Table 1**.

$$\begin{aligned} HI = & -42.379 + 2.04901523 \times T + 10.14333127 \times RH - 0,22475541 \times T \times RH \\ & - 6.83783 \times 10^{-3} \times T^2 - 5.481717 \times 10^2 \times RH^2 + 1.22874 \times 10^{-3} \times T^2 \times RH \\ & + 8.5282 \times 10^{-4} \times T \times RH^2 - 1.99 \times 10^{-6} \times T^2 \times RH^2 \end{aligned} \quad (1)$$

3.2. Calculation of the Occupational Level of Exposure to Noise

According to Brazilian standards NR-15 and NHO 01, levels of noise above 85 dB(A) are inadequate and require immediate corrective actions. The daily noise dose must be calculated according to Equation (2), of NHO 01, for the determination of the workers' level of exposure.

Table 1. Effects to health associated with heat index.

Heat Index	Alert level	Possible heat disorder
80˚F - 90˚F	Caution	Fatigue is possible with prolonged exposure and activity
90˚F - 105˚F	Extreme caution	Sunstroke, heat cramps and heat exhaustion
105˚F - 130˚F	Danger	Sunstroke, heat cramps and heat exhaustion likely, and heat stroke
130˚F or greater	Extreme danger	High heat stroke by continuous exposure

[22].

$$LE = 10\log\left[\frac{1}{n}\left(d_1 \times 10^{0,1S_1} + d_2 \times 10^{0,1S_2} + \cdots + d_i \times 10^{0.1S_i} + \cdots + n_n \times 10^{0.1S_n}\right)\right] \quad (2)$$

LE = Level of Exposure to noise (dB(A));
d = Total number [including data below 80 dB(A)];
d_i = Total number of data at the same level;
S_i = Sound pressure level (dB(A)) [data below 80 dB(A) are not included].

However, the level of exposure (LE) must be turned into a normalized specific exposure level (NLE) according to Equation (3) and by NHO 01 norm. NLE is the level of noise exposure measured at a specific time and converted to a standard workday.

$$NLE = LE + 10\log\left(\frac{T_E}{480}\right) \quad (3)$$

NLE = Normalized Level of Exposure (dB(A));
LE = Level of Exposure to noise (dB(A));
T_E = Exposure time – sampling time (minutes).

4. Results and Discussion

4.1. CO and CO_2

The maximum average daily CO concentration was 1.1 ppm. The CO levels inside the bus were in accordance with CONAMA 03/90 standard, which has established an average limit concentration of 9 ppm for 8 hours.

Figure 2 shows the results for carbon monoxide and the CONAMA 03/90 standard in the box-and-whisker plot. The CO concentrations in the bus ranged between 0 and 10.2 ppm. Only 0.06% data were above the limit.

In the monitoring days, the maximum mean for CO_2 was 920 ppm. The daily means were below ANVISA standard, which indicates a 1000 ppm concentration as a factor of external air change, recommended for comfort and well-being.

Results for carbon dioxide and ANVISA 09/03 limit are shown in the box-and-whisker plot in **Figure 3**. The values of carbon dioxide concentration ranged between 491 and 1959 ppm. In general, CO_2 concentrations were under 1000 ppm, however 1.97% of the measurements were above the limit.

The amounts of CO and CO_2 did not damage the workers' health because they were below the limits established. Furthermore, significant human health symptoms start to appear when the CO level is above 70 ppm and CO_2 is above 5000 ppm [23] [24].

On each round trip (which took one hour), the passed the downtown area twice. The higher values for both components were reached when the bus passed downtown, area with the most circulation of pedestrian and cars in the city. As CO_2 is an indicator of air renewal rate and the bus is ventilated naturally and the highest concentrations are in the central region, we can conclude that pollutants are coming from the external environment.

Because CO is a product of the combustion of fossil fuels, the high values found can be associated with mechanical failures in the vehicles. Without proper maintenance vehicles tend to emit gases with higher concentrations of pollutants. For example, if an engine is unregulated, the burning of fuel increases. Moreover, defective catalysts, part of the exhaust system of the vehicle, can change the transformation reactions of gases produced by emitting larger quantities of carbon monoxide. Such problems are common in urban areas and can be observed by the release of black smoke with characteristic odor from diesel automobiles, like buses.

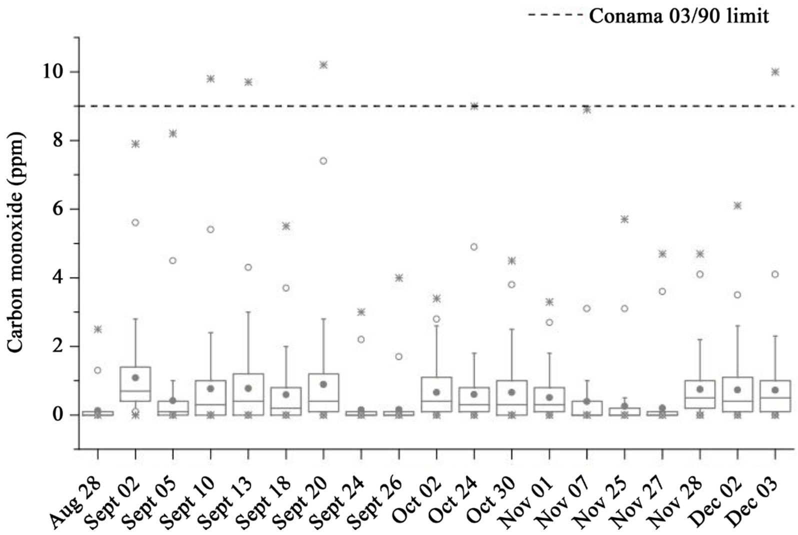

Figure 2. Carbon monoxide concentrations.

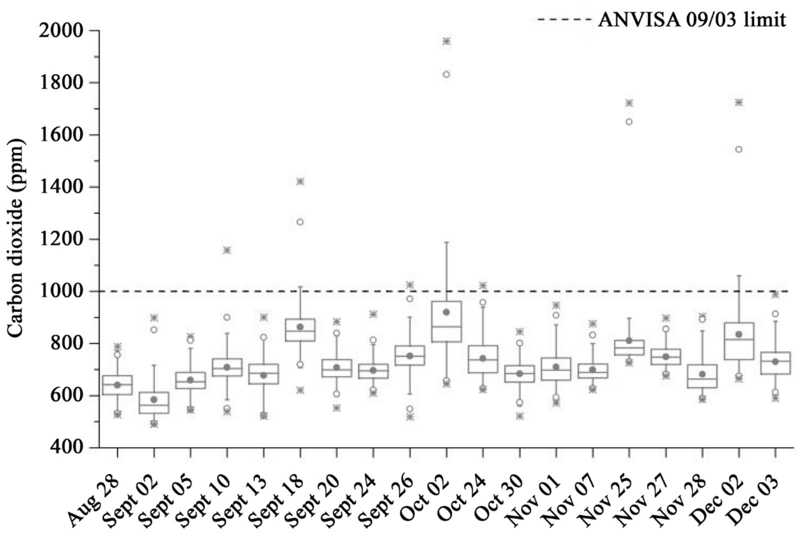

Figure 3. Carbon dioxide concentrations.

4.2. Temperature and Relative Humidity

In the case of bus drivers, NR-15 indicates "driving" and activities like "sitting and resting" as light work, for which the maximum tolerance of heat exposure is 30˚C. In 74% of the days and 41% of measurements, the temperature values exceeded the limit (**Figure 4**). The maximum and minimum temperatures found were 38˚C and 17˚C, respectively.

The maximum and minimum relative humidities were 87% and 19%, respectively. In 63% of the days and 57% of measurements, RH values were below the minimum recommended by NR-17, *i.e.*, above 40% (**Figure 5**).

Regarding the Heat Index, all monitored days showed values above 80˚F, which is the limit indicated for comfort (**Figure 6**). The minimum and maximum values found in the data set were 69˚F and 104˚F, respectively. 50% of the data are found in the interval between 80˚F and 90˚F, which indicates a state of alert according to the US National Weather Service. Accordingly, the individual would likely suffer fatigue in cases of prolonged exposure. In 63% of the days, the Heat Index exceeded 90˚F (27% of total measurements). This level is related to the possibility of cramps, exhaustion and heatstroke in the workers.

Thermal comfort depends not only on temperature and relative humidity but other variables, such as air speed (the ability of objects to absorb and emit heat), clothing and activity level of individuals [25] [26]. However, the

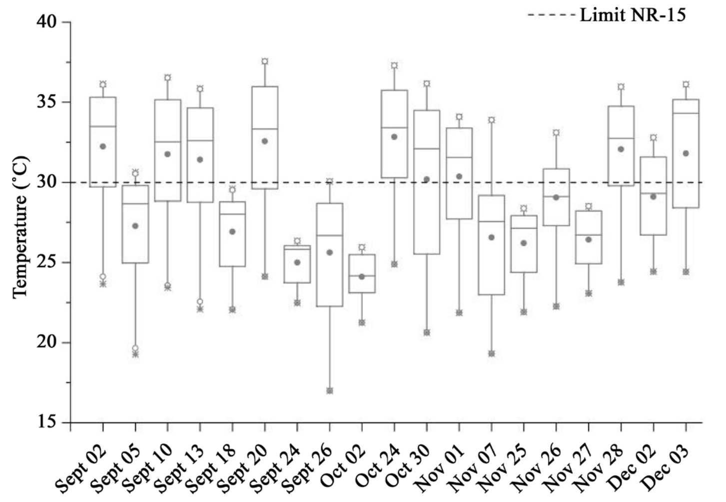

Figure 4. Results of temperature.

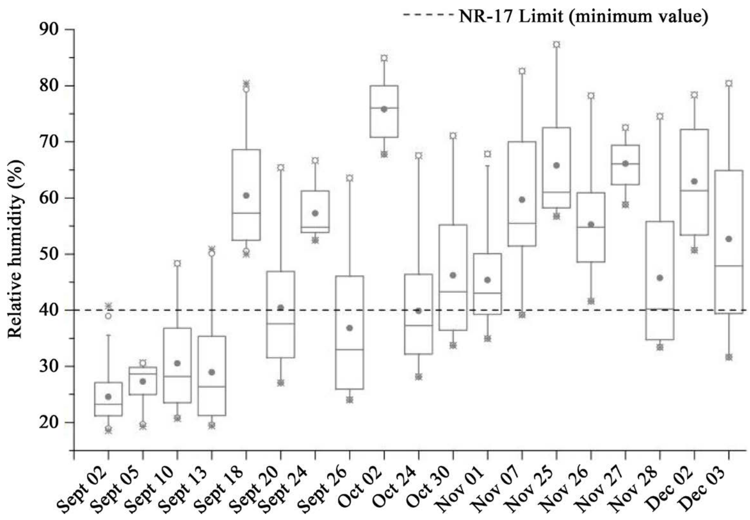

Figure 5. Results of relative humidity.

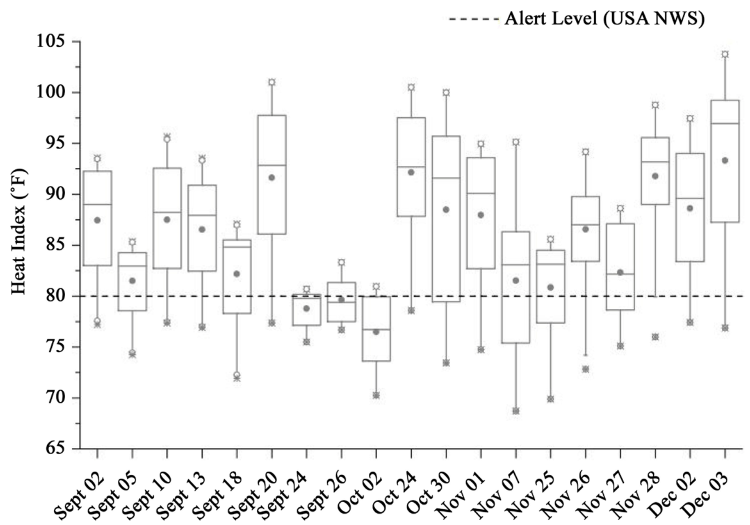

Figure 6. Results of heat index.

analysis of temperature and relative humidity in this study revealed the indoor bus environment is unhealthy for workers.

Inadequate levels of temperature and relative humidity may cause health problems. In extreme hot environments, the heart rate can speed up and the blood pressure fluctuates [27]. Heat stress can lead to a reduction in enthusiasm and productivity of workers and increase the heat illness and death rates [28].

4.3. Noise

The highest and lowest values found for noise were 92 dB(A) and 68 dB(A), respectively (**Figure 7**). The average daily limit of 85 dB(A), imposed by the NR-15 norm, was not exceeded and complied with labor laws. However, if we consider recent studies on noise, this resolution (created in 1978) should be outdated.

The auditory system can be damaged temporarily or permanently by sudden or intense exposure to noise. When such an exposure is intense and continuous (85 dB(A)) on average for eight hours a day), some ear cells can be destroyed, which leads to a noise-induced hearing loss (NIHL). Another type of hearing impairment caused by exposure to loud noise is transient threshold shift (TTS), which starts from an exposure to 75 dB(A). The TTS constitutes a loss of hearing since the continual hearing fatigue tends to be very harmful to health [29] [30].

Inadequate noise may also affect the workers' psychological system and lead to stress and more serious complications, as increased blood pressure and heart disease. Individuals exposed to a level above 60 dB (A) may be more susceptible to myocardial infarction [31]-[33]. NR-17 norm indicates the comfort level should be up to 65 dB(A).

This study has shown the bus drivers and workers were exposed to levels above 75 dB(A) and 60 dB(A) daily. Although sometimes the noise seems imperceptible to the ear, it tends to cause problems, as stress and auditory fatigue.

4.4. Particulate Matter

The adequate amount of respirable particulate matter inside the bus was checked by the WHO limits of 25 μg/m³ for $PM_{2.5}$ and 50 μg/m³ for PM_{10}. **Figure 8** shows in 90% of the days, PM_{10} levels exceeded the limit of 50 μg/m³ recommended by the WHO. The maximum value for PM_{10} obtained was 109 μg/m³, *i.e.*, twice higher than the limit established.

In 95% of the monitored days, $PM_{2.5}$ concentrations were above 25 μg/m³. A peak of 48 μg/m³ was reached,

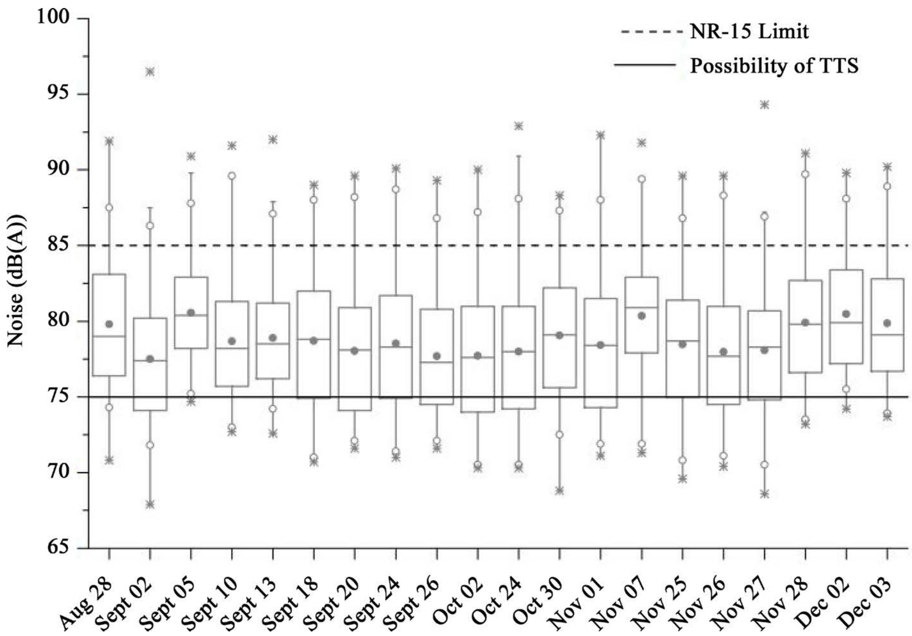

Figure 7. Levels of noise.

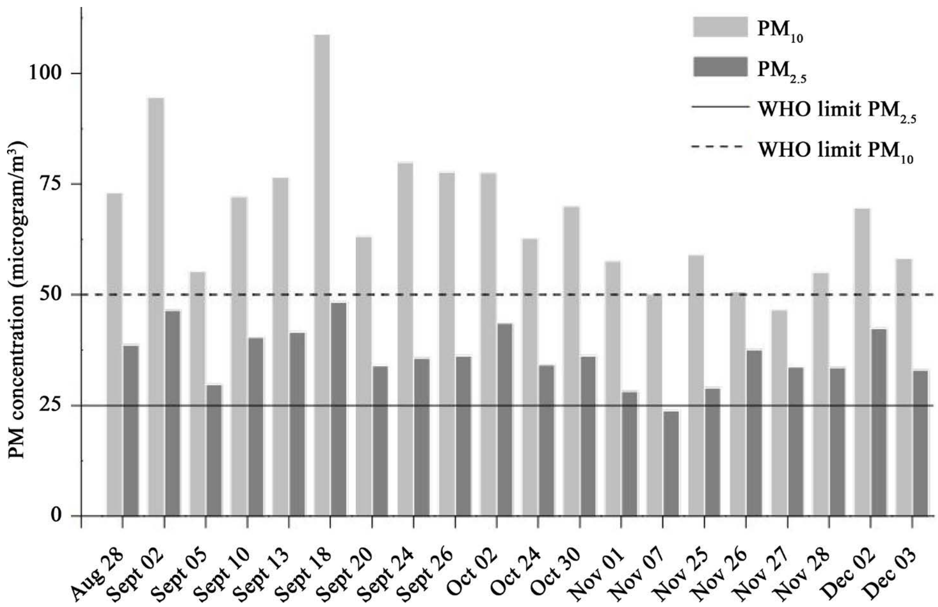

Figure 8. Results particulate matter.

which is approximately twice the value recommended by the WHO.

The amounts of PM in our sample were significantly larger than those established by the WHO. Therefore, the respiratory tract of the passengers may be damaged and diseases, as asthma and bronchitis may develop. Allergies and colds can also be aggravated by the inhalation of particulate matter at inappropriate levels [34]. Analyzing different PM metrics in distinct seasons, Pascal *et al.* [35] stated for all size particles, the largest impacts were observed during summer, especially for the non-accidental cardiovascular, cardiac and ischemic mortality. The health impacts by particulate matter on urban population can affect predominantly the respiratory and cardiovascular systems [19]. The quality of the air inside the bus was considered inappropriate in terms of particulate matter concentration.

5. Conclusions

This study has shown that the indoor environment of buses is unhealthy for drivers and collectors who work for many hours. Most of the measured pollutants were above the appropriate values for an adequate environmental quality.

Temperature and relative humidity are inadequate, according to Brazilian standards (NR-15 and NR-17). Moreover, the Heat Index, which associates both variables, was above 80˚F indicated for comfort (by NWS USA) in 77% of the measurements.

Noise was in accordance with NR-15 standard (85 dB(A)); however, some researchers have shown that levels above 60 dB(A) may cause health problems to the people exposed to it. Noise is a problem for bus workers because all levels were above 68 dB(A).

For particulate matter, average concentrations were above WHO standards (25 μg/m³ for $PM_{2.5}$ and 50 μg/m³ for PM_{10}) in 90% of the days.

The CO and CO_2 levels were adequate, according to Brazilian standards.

The study emphasizes the importance of evaluation of the indoor environment in the public transport and implementation of measures that improve its quality. Procedures, as proper vehicle maintenance could prevent the emission of pollutants and mitigate contamination levels stemmed from fuel combustion. Furthermore, programs of health assessment for bus drivers and collectors must be periodically established.

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