Particle exposure and inhaled dose while commuting in Lisbon

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ABSTRACT

While commuting individuals are exposed to high concentrations of urban air pollutants that can lead to adverse health effects.

This study aims to assess commuters' exposure to particulate matter (PM) in cars, bicycles and metro in Lisbon. Mass concentrations of particles with aerodynamic diameter (DA) smaller than 2.5 µm ($PM_{2.5}$) and 10 µm (PM_{10}), black carbon (BC) and number concentrations of particles with DA from 0.01 to 1 µm ($PN_{0.01-1}$) were measured in a route that is representative of the daily commutes in Lisbon. Measurements were performed over 18 days in a total of five times a day (8h, 10h30, 13h, 18h and 20h). The inhaled dose associated to each mode of transport was also accessed.

The highest $PM_{2.5}$ and PM_{10} average concentrations were observed in the metro. On the other hand, the highest BC and $PN_{0.01-1}$ average concentrations were found in car and bicycle journeys, respectively. The outdoor concentrations and the type of ventilation appeared to affect the concentrations inside cars. In fact, the use of ventilation led to a decrease of $PM_{2.5}$ and PM_{10} concentrations and to an increase of BC concentrations inside cars. The highest inhaled dose was observed in bicycle journeys, due to longer travel periods combined with enhanced physical activity and, consequently, higher breathing rates.

This study is part of the Project LIFE Index-Air whose objective is to create a tool to support the decision makers by identifying measures that improve air quality, well-being and human health.

Keywords: commuting; Lisbon; particulate matter; black carbon; exposure assessment; inhaled dose.

1. INTRODUCTION

Air pollution is a major concern around the world since exposure to air pollutants leads to an increase in mortality and morbidity owing to respiratory and cardiovascular diseases, cancer, and can also increase the risk of reproductive problems (Kampa & Castanas 2008; Steinle et al. 2015; Pinault et al. 2017). In particular, while commuting, individuals are inevitably exposed to high concentrations of urban air pollutants that usually exceed the limits set by air quality guidelines (EEA 2017) which, together with the considerable amount of time that people spend on their daily commutes, leads to adverse health effects.

Given the importance of assessing personal exposure to air pollutants, there are already many studies published with this purpose, however, in the city of Lisbon, this type of studies are scarce. Nevertheless, previous publications have already assessed exposure to air pollutants in different modes of transport (Adams et al. 2001; Asmi et al. 2009; Berghmans et al. 2009; Kaur & Nieuwenhuijsen 2009; de Nazelle et al. 2012; Huang et al. 2012; Goel et al. 2015; Alameddine et al. 2016). Among the several pollutants that affect air quality, special attention will be given to particulate matter (PM), namely PM mass concentrations ($PM_{2.5}$ and PM_{10}), black carbon (BC) and also number concentrations ($PN_{0.01-1}$) as they are some of the major contributors to the lack of air quality in the transports microenvironment (Alameddine et al. 2016). In fact, it is estimated that, in Southern Europe where Portugal is included, traffic accounts for 35% and 23% of $PM_{2.5}$ and PM_{10} air concentrations, respectively (Karagulian et al. 2015).

The assessment of exposure to these air pollutants is not trivial since there are several factors that may influence it, such as, mode of transport (Adams et al. 2001; de Nazelle et al. 2012; Goel et al. 2015; Ham et al. 2017), route (Adams et al. 2001; Huang et al. 2012), time of the day (Asmi et al. 2009; Berghmans et al. 2009; Betancourt et al. 2017), traffic intensity (Adams et al. 2001; Kaur & Nieuwenhuijsen 2009; Hatzopoulou et al. 2013; Li et al. 2017), meteorological conditions (Adams et al. 2001; Kaur & Nieuwenhuijsen 2009; de Nazelle et al. 2012; Alameddine et al. 2016), street configuration (Kaur et al. 2005; Hatzopoulou et al.

2013; Betancourt et al. 2017) and type of ventilation, among others. For this reason, exposure of each individual, which results from a variety of interactions between environment and human systems, has a wide spatial and temporal variability (Steinle et al. 2015).

By knowing the concentrations of pollutants to which individuals are exposed, it is possible to implement measures of risk management as well as urban mobility strategies (Tan et al. 2017) that allow the minimization of personal exposure (Moreno et al. 2015).

Finally, the aim of this study is to assess commuters' exposure to PM (in particular $PN_{0.01-1}$, $PM_{2.5}$ and PM_{10}), and BC in different modes of transport (car, bicycle and metro) in Lisbon.

2. METHOD

2.1. Field Study

The study was performed in the Lisbon Municipality that, in 2017, had 505 526 inhabitants (Pordata 2017). It was conducted in three of the most common modes of transport in Lisbon (car, bicycle and metro) in a route that is representative of the commutes performed by the Lisbon citizens. This route, represented in Figure 1, starts in Telheiras and ends in Praça dos Restauradores, in a total of 6.7 km. The metro route starts in station Telheiras (Green Line) and ends in Restauradores (Blue Line), passing also through the Yellow Line.

Measurements were perfomed 5 times a day (8h, 10h30, 13h, 18h and 20h) during 18 weekdays. Besides that, in cars, $PM_{2.5}$, PM_{10} and BC outdoor concentrations were also measured, in order to study the ratio between the indoor and outdoor concentrations and the influence of ventilation. The measurements were made in cars powered by different types of fuels: three Diesel cars (DC1, DC2 and DC3), two gasoline cars (GC1 and GC2) and one electric car (EC1). Moreover, three types of ventilation were tested: middle ventilation (MV), without ventilation (WV) and with air conditioning (AC).

Inhaled dose was determined as represented in equation (1).

$$P_{\text{inhaled dose}} = [P] \times IR \times T \qquad (1)$$

where [P] is the pollutant concentration ($PM_{2.5}$, PM_{10} and BC in µg/m^3 and $PN_{0.01-1}$ in #/cm^3), IR the inhalation rate (m^3/h) and T the time spent travelling (h). The inhalation rates are equal to 0.6 m^3/h for car and metro trips and 1.7 m^3/h for bicycle trips (Buonanno et al. 2011).

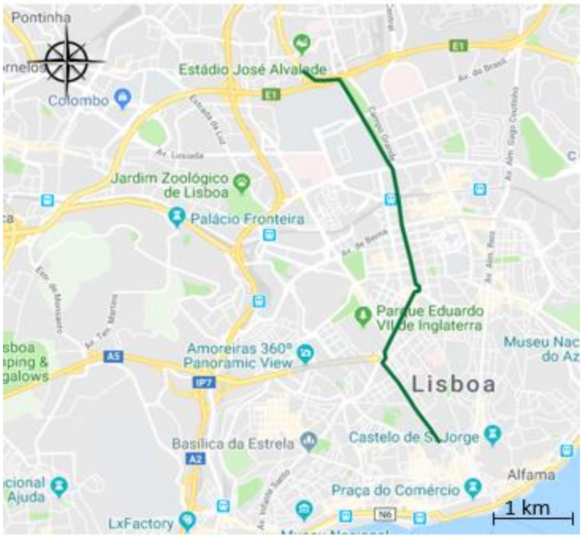

Figure 1. Route selected for this study (green line).

2.2. Measurements and sampling equipment

Measurements were performed with the equipment described in Table 1. $PM_{2.5}$ and PM_{10} mass collection was carried out using a Personal Environmental Monitor (PEM) that consists of compact personal sampling device that has a single stage impactor followed by filtration (Válio 2015). The PEM is connected to an air suction pump (SKC Leland Legacy) whose flow rate (10 L/min) was verified with a flow meter (Defender TM 510). Two microAeth AE51 measured BC mass concentrations through light absorption. $PN_{0.01-1}$ number concentrations were measured with a Condensation Particle Counter (CPC 3007) that uses isopropyl alcohol as the condensing liquid. Finally, a GPS was used to record position as a function of time.

Table 1. Measurement devices.

Equipment	Measures	Cars	Bicycle	Metro
PEM	$PM_{2.5}$ and PM_{10} mass concentrations	X (IN and OUT)	X	X
microAeth AE51	BC mass concentrations	X (IN and OUT)	X	X
CPC 3007	$PN_{0.01-1}$ number concentrations	X (IN)	X	X
GPS Garmin eTreck 20	Location and time	X	X	X

The equipment was placed as near as possible from the respiration area. The PEMs and the microAeth AE51 that measured outdoor concentrations in cars were fixed to a sponge that secured the equipment and also prevented air intakes to the interior of the cars.

The data obtained with the microAeth AE51 was corrected in the Optimized Noise-Reduction Algorithm (ONA) software (Hagler et al. 2011).

2.3. Statistical analysis

Statistical tests were carried out in STATISTICA software. Thus, Mann-Whitney U test was used for samples that are non-parametric and independent (as, for example, concentrations of a pollutant in two different modes of transport). This test compares medians to suggest if two samples are from the same population or not. The tests are significant if $p<0.05$.

2.4. Quality control

The accuracy and precision of the results depend on the method adopted, laboratory conditions, among others (Almeida 2004). The method adopted was tested through a quality control perfomed for the PEMs ($PM_{2.5}$ and PM_{10}) and the two microAeth AE51 (BC) used. CPC was not tested due to the lack of equipment to do so.

Thus, in order to test the reproducibility of the PEMs, this equipment measured concentrations in parallel with a Leckel MVS6, that operates in accordance to the European norms EN 12341 and EN 14907. The results are represented in Figure 2.

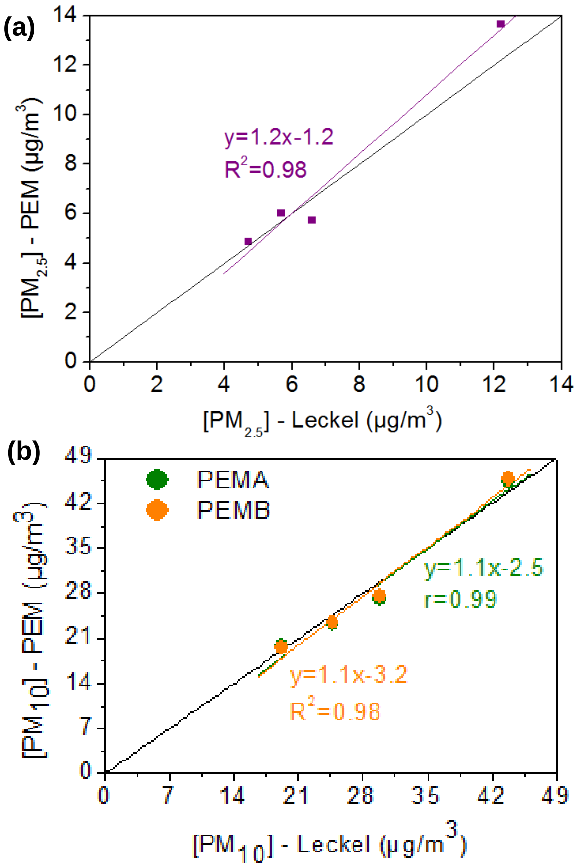

Figure 2. Quality control of the PEMs for $PM_{2.5}$ (a) and PM_{10} (b).

For both $PM_{2.5}$ and PM_{10} the correlation between the PEM and the Leckel was high, which allows the conclusion that the equipment can be used since they measure with precision PM concentrations.

A good correlation was also observed between the two microAeth AE51, as represented in Figure 3.

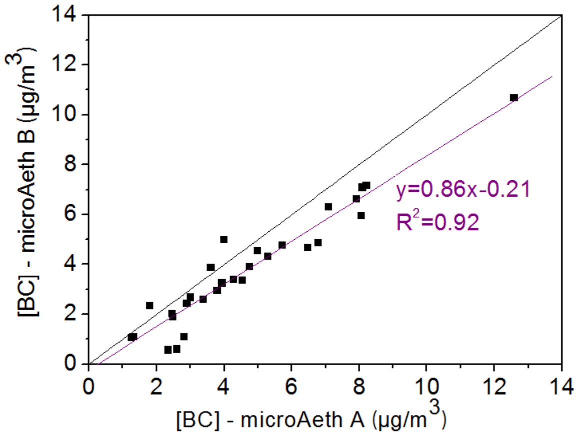

Figure 3. Quality control of the microAeth AE51.

3. RESULTS AND DISCUSSION

3.1. $PM_{2.5}$ and PM_{10}

3.1.1. PM Mean Concentrations

PM concentrations obtained through the gravimetric method are presented in Figure 4.

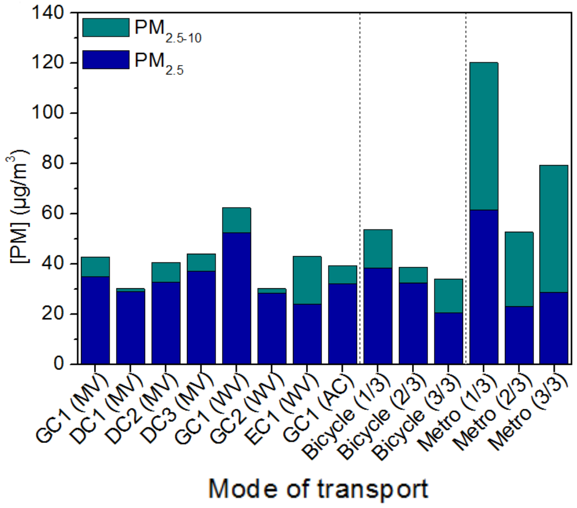

Figure 4. $PM_{2.5}$ and $PM_{2.5-10}$ mass concentrations.

$PM_{2.5}$ average mass concentrations were equal to 33.7±8.6 µg/m^3, 30.5±9.0 µg/m^3 and 37.8±20.8 µg/m^3, for car, bicycle and metro journeys. Furthermore, average PM_{10} mass concentrations were equal to 41.5±10.1 µg/m^3, 42.2±10.3 µg/m^3 and 84.1±34.0 µg/m^3 for car, bicycle and metro journeys. Exposure seemed to be enhanced in metro journeys. According to Martins et al. (2015), emission sources like abrasion of rails, wheels and brakes and the resuspension of particles due to turbulence can increase PM concentrations in the metro system. The car pathway was closer to mobile emission sources than the bicycle pathway and, for this reason, exposure was higher inside cars.

Furthermore, in the metro the coarser fraction of PM was more abundant (55.1 % in the metro compared to 18.8 % in cars and 27.5 % in bicycles), which is in accordance to what Moreno et al. (2015) found, and that is explained by the common sources of PM in the metro.

$PM_{2.5}$ mass concentrations inside cars were in accordance to what was determined in other cities in Europe. For example, in London, Adams et al. (2001) found that average $PM_{2.5}$ concentrations were 37.7 µg/m^3 and Kaur & Nieuwenhuijsen (2009) determined that average $PM_{2.5}$ concentrations were 33.4±13.1 µg/m^3. Moreover, Gulliver & Briggs (2007) found that, in Northampton (UK), mean PM_{10} concentrations inside cars were 43.2 µg/m^3 which is also similar to what was found in Lisbon. The variation in PM concentrations inside cars is explained by some factors that affect those concentrations as, for example, outdoor concentrations, type of car, ventilation settings, among others.

$PM_{2.5}$ concentrations inside cars were, on average, similar to the ones found in bicycle journeys. Bigazzi & Figliozzi (2014) concluded, through the study of 52 papers, that cyclists were exposed to $PM_{2.5}$ mean concentrations equal to 29.9±22.8 µg/m^3 and to 50.2±12.0 µg/m^3 for PM_{10}. This concentrations are also in agreement with the ones found in Lisbon.

Metro is a popular mode of transport across the world that is frequently associated to high PM exposure concentrations. In fact, Moreno et al. (2015) determined PM concentrations in the Barcelona metro system, and stated that average $PM_{2.5}$ concentrations were equal to 43.0 µg/m^3 which is in accordance to what was determined in Lisbon.

3.1.2. *Indoor to Outdoor ratio*

Differences in PM concentrations in the indoor and outdoor of the cars were influenced by the ventilation settings. Considering this, the six cars under study were separated according to the ventilation setting used during the measurements in each car, as represented in Figure 5.

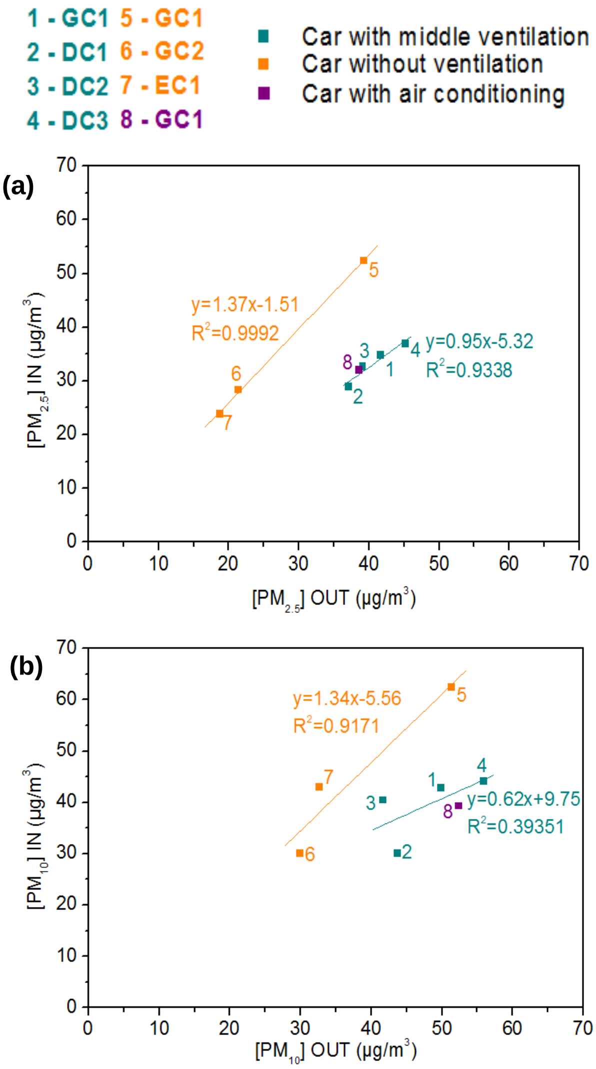

Figure 5. Indoor to Outdoor concentrations for $PM_{2.5}$ (a) and PM_{10} (b).

For both PM fractions the correlation between the indoor and outdoor concentrations was high for the considered types of ventilation. The type of ventilation clearly affected exposure to PM in a way that, according to the type of ventilation, the indoor concentrations were higher or smaller that the ones verified on the outside. Exposure to PM was maximized when the ventilation was switched off. Therefore, for both $PM_{2.5}$ and PM_{10}, if the ventilation was on (for middle ventilation or air conditioning) the indoor concentrations were lower than the outside ones. Moreover, with no ventilation the concentrations were higher in the indoor. Thus, the use of ventilation made the ratio IN/OUT smaller than 1.0 (for $PM_{2.5}$ it was moreless equal to 0.8 and, for PM_{10}, it varied between 0.7 and 1.0). When the ventilation was off the ratio IN/OUT was higher than 1.0 (it was approximately 1.3 for $PM_{2.5}$ and varied between 1.0 and 1.3 for PM_{10}). The use of no ventilation led to particle acummulation inside cars and, consequently, to higher PM concentrations. It was also found that the use of AC, in car GC1, did not decrease greatly the exposure to PM.

However, due to the small data collected, it was not possible to conclude with accuracy how AC influenced concentrations inside cars.

Finally, although the ventilation mode cleary conditioned PM concentrations, the same can not be concluded about the type of fuel used.

3.1.3. *Inhaled dose*

Despite of the PM concentrations, the inhaled dose was always higher in bicycles compared to the other modes of transport, as it is represented in Figure 6. PM inhaled dose was higher during bicycle journeys (66.7 µg of $PM_{2.5}$ and 92.5 µg of PM_{10}), followed by the metro (22.5 µg of $PM_{2.5}$ and 49.5 µg of PM_{10}) and, finally, car journeys (14.0 µg of $PM_{2.5}$ and 17.3 µg of PM_{10}). This is explained by the fact that, in bicycle journeys, the IR and travel times were higher.

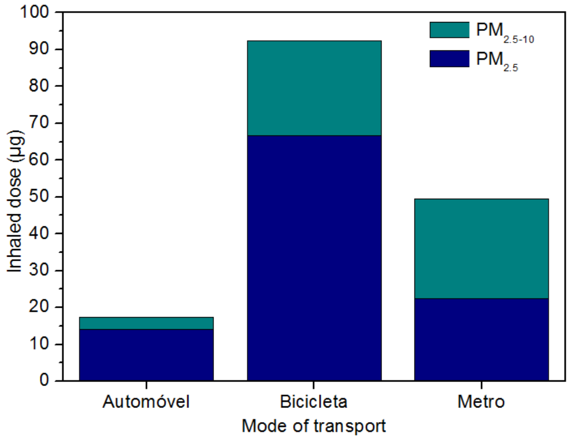

Figure 6. PM inhaled dose (µg).

3.2. Black Carbon (BC)

3.2.1. *BC mean concentrations*

BC average mass concentrations for each mode of transport are presented in Figure 7.

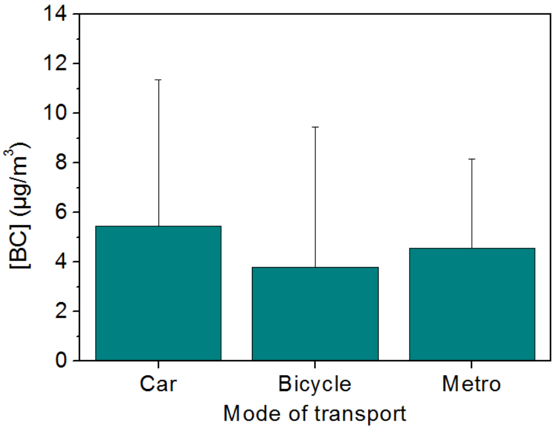

Figure 7. BC mass concentrations.

The exposure levels were higher in car journeys (5.5±5.9 µg/m^3), followed by metro (4.6±3.6 µg/m^3) and, finally, bicycle journeys (3.8±6.0 µg/m^3). The concentrations found in Lisbon are in accordance to what was determined in Flanders (Belgium), where Dons et al. (2012) found that BC average concentrations were equal to 5.6 µg/m^3 inside cars, 3.2 µg/m^3 in bicycle journeys and 5.1 µg/m^3 in the metro. However, in California, Ham et al. (2017) found BC concentrations substantially lower than the ones determined in Lisbon and equal to 0.5±0.4 µg/m^3 and 0.7±0.3 µg/m^3 for cars and bicycles, respectively.

The bicycle pathway is more distant from the mobile sources of BC that are mainly the exhaust of cars and, because of that, BC concentrations were significantly higher ($p<0.0001$) inside cars than in bicycle trips. Another reason for this difference, is that the indoor of the cars seemed to be a place where accumulation of BC occured. In the metro, BC concentrations were smaller than in cars but, at the same time, they were significantly higher ($p<0.0001$) than the ones verified in bicycle journeys. In this microenvironment there are no sources of incomplete combustion and, because of that, there are no direct sources of BC. Despite all this, BC from the outside can be transported into the metro through the ventilation system (often the air inlet is located near the road). In fact, particles associated to BC have small diameters and, therefore, are not efficiently removed by the filters in the ventilation system. Nevertheless, it must be considered that the results taken from the equipment microAeth AE51 may not be the real concentrations of BC, since the metro environment contains high concentrations of Fe that can lead to overestimations in BC concentrations since Fe absorbs light at wavelengths similar to BC (Chow et al. 2004; Karanasiou et al. 2015).

3.2.2. *Influence of ventilation on the indoor exposure in cars*

To test the influence of ventilation in BC concentrations inside cars, it was carried out a trip in car DC2 where, in the first part of the trip, the ventilation was switched off and, in the second part, ventilation was on and set at middle intensity. The results obtained are presented in Figure 8.

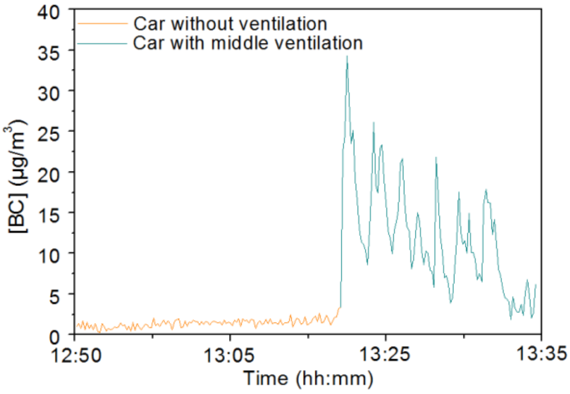

Figure 8. Influence of ventilation on BC exposure concentrations inside a car.

When ventilation was switched off, BC concentrations were significantly smaller ($p<0.0001$) than when ventilation was on. This attests the huge influence of ventilation on the exposure levels of BC inside cars. The low efficiency of filters in BC removal from the air that enters in the car cabins, lead to an accumulation of BC inside cars. However, when ventilation was switched off the low entrance of air in the cabin led to low BC concentrations.

3.2.3. *Indoor to outdoor ratio*

Besides the outdoor concentrations, BC concentrations inside cars depend also on the rate of air exchange, which is influenced by a number of factors as, for example, the type of ventilation, age of the car, among others (Ham et al. 2017). In the present study, due to the impossibility of controlling other factors, the influence of BC outdoor concentrations, ventilation configuration and the car used (considering the type of fuel) was taken into account. It has been found that the car DC3 behaves differently in that the concentration of BC inside the car was significantly ($p<0.0001$) lower than the recorded outdoors, unlike what happens in the other cars that used ventilation. In fact, DC3 air filter is a high efficiency activated carbon filter, whereas the filters in cars GC1, DC1 and DC2 are common pollen filters. Thus, since DC3 filter has a different behavior compared to the others and, in order to obtain the linear regression line for the cars operating with medium ventilation, it was decided to remove the concentration data of the car DC3 as it is represented in Figure 9.

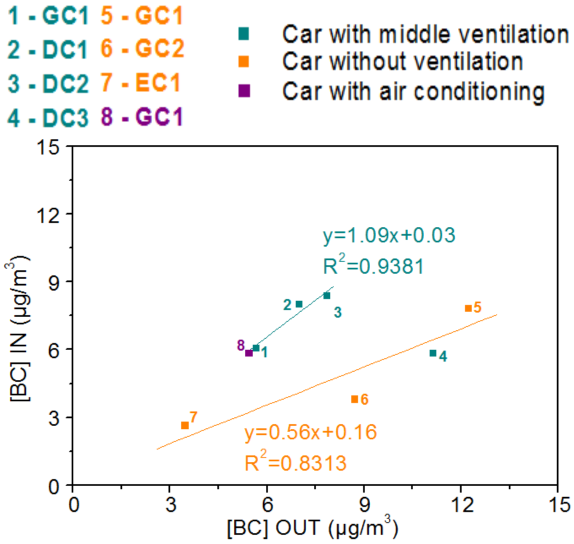

Figure 9. Indoor to Outdoor concentrations for BC.

The IN/OUT ratio varied between 0.5 and 1.1 when the car was operated using middle ventilation, and between 0.4 and 0.8 when the ventilation was switched off.

Exposure to BC inside cars was potenciated by the use of ventilation. BC is often associated to small particles Ning et al. (2013) that are hardly removed by common air filters from cars. When cars' ventilation was set on middle intensity, except for DC3, the filters were not sufficiently efficient to remove particles associated to BC and they entered in the car cabin leading to higher BC concentrations. On the other side, when the car had no ventilation, the effect of the outside concentrations was not so relevant (the correlation was high but smaller than the one associated to the use of ventilation) and, besides that, indoor concentrations were smaller than the ones verified in the outdoor, because the entrance of air was minimized. The use of AC led to smaller but similar concentrations to the ones verified with the use of middle ventilation and, thus, the use of AC did not decrease exposure significantly.

While the type of ventilation clearly conditioned the exposure levels inside cars, the same was not evident for the type of fuel used. In fact, concentrations of BC inside Diesel cars were not significantly higher than in gasoline cars ($p=0.061$).

3.2.4. *Influence of time period in BC concentrations*

BC mean concentrations in the different sampling periods of the day is represented in Table 2.

Table 2. BC average concentrations in each measurement hour.

		$\bar{x} \pm \sigma$				
		8h	**10h30**	**13h**	**18h**	**20h**
BC (µg/m³)	Car	5.9±5.5	5.9±6.3	5.7±6.7	4.9±5.8	5.1±5.0
	Bicycle	5.2±5.8	5.2±9.2	3.3±4.8	3.7±5.0	2.2±2.7
	Metro	6.2±4.8	4.5±3.2	4.3±2.9	4.5±3.0	3.1±2.9

For car and bicycle journeys there was not a clear pattern concerning the several days of measurements and, because of that, it was not possible to make explanations about the variation in BC concentrations.

In the metro, the frequency of carriages and the influx of individuals was maximum at 8h, followed by 18h, 10h30, 13h, and finally at 20h (Metropolitano de Lisboa 2018). A higher frequency of carriages and the influx of individuals led to a increase of BC concentrations, due to turbulence. For this reason, the concentrations of BC obtained at around 8h, when the influx of people and carriages was higher, were significantly ($p<0.0001$) higher than in the other hours of the day, not only due to turbulence but also to the influence of the outdoor (traffic intensity was the highest of the day in this period). On the other hand, BC concentrations at which the population was exposed at 8 h, were significantly lower ($p <0.0001$) than in the other hours of the day. At 18h, although the second highest average concentration BC was recorded, it was not significantly higher than the ones recorded at 10h30 or 13h, which may be related to the fact that at these times of the day the operating conditions of the metro were not really different.

A greater number of passengers in the subway led to a greater variability in concentrations. For this reason, as shown in Table 2, the standard deviation was lower at 20h, when there was a lower passenger influx. On the contrary, at 8h, when the inflow of people in the metro was higher, the standard deviation was also higher.

3.2.5. Spatial distribution of BC concentrations

Street morphology, traffic intensity and other factors resulted in differences in BC concentrations in the different areas of the route. In the residential area, concentrations were the lowest because traffic intensity was also the smallest. Nevertheless, in Avenida da Liberdade the concentrations were significantly higher because this street has a high traffic intensity and the street morphology, with high trees and buildings, did not allow a good dispersion of BC. The spatial variation of BC concentrations was not totally different for cars and bicycles except for Avenida do Campo Grande where the bicycle route is separated from the cars by trees and bushes making BC exposure concentrations significantly smaller ($p<0.001$) for bicycle journeys. In the metro, concentrations were significantly lower ($p<0.0001$) in the outdoor platforms where a good dispersion of BC occurs. Besides that, inside the train, concentrations were significantly higher ($p<0.0001$) because of the high concentrations of Fe and also because this space is closed and happened BC accumulation.

3.2.6. Inhaled dose

BC inhaled doses in each mode of transport are presented in Figure 10.

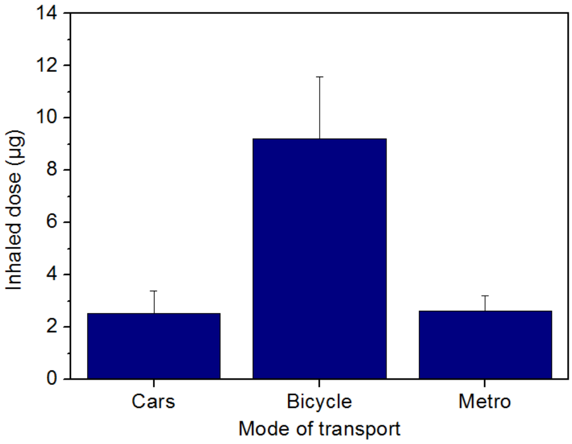

Figure 10. BC inhaled doses.

Once again, the inhaled dose was significantly higher ($p<0.0001$) in bicycle journeys (9.2 µg) than in metro (2.6 µg) or inside the cars (2.5 µg) trips. Although BC concentrations were lower in bicycles, the high IR and travel times led to higher inhaled doses of BC compared to the other two modes of transport.

3.3. PN$_{0.01-1}$

3.3.1. PN$_{0.01-1}$ mean concentrations

The average concentrations of PN$_{0.01-1}$ for the three modes of transport are presented in Figure 11.

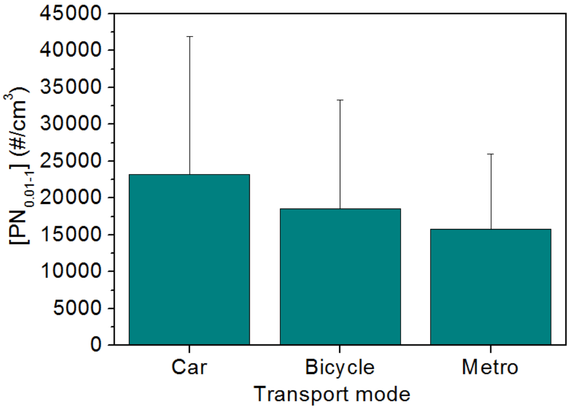

Figure 11. PN$_{0.01-1}$ average concentrations for the three modes of transport.

The concentrations were higher in cars (23213±18715 #/cm^3) compared to bicycles (18512±14740 #/cm^3) and to the metro (15775±10209 #/cm^3). One of the main sources of PN$_{0.01-1}$ in the transports microenvironment is the combustion that occurs in the motor of cars (Rivas et al. 2017) and, because of that, PN concentrations are influenced by traffic (Berghmans et al. 2009). Besides that, PN can be formed through photoquemical reactions. In this way, PN concentrations depend on different variables, such as, traffic intensity and meteorological variables such as temperature, relative humidity and the intensity of solar radiaton. In fact, the photochemical process occurs most likely when the intensity of solar radiation is higher than 100 W/m^2, what happened in all the days of measurements (Ma and Birmili 2015; MARETEC 2018).However, as Ma & Birmili (2015) reported, there has been an incidence of days in which the intensity of solar radiation was high and the photochemical phenomena did not occur. In conclusion, it is not possible to draw conclusions about the variation of PN concentrations in the three modes of transport.

In the metro, Mendes et al. (2018) found that the concentrations of ultrafine particles depend not only on the friction resulting from the movement of the metro but especially from the influence of the outside air. In the metro there are not sources of PN$_{0.01-1}$ and, because of that, concentrations were lower in this mode of transport. Although a precise comparison of the concentrations in the different modes of transport was not possible for the reasons given above, it was clear why $PN_{0.01-1}$ concentrations in the metro were smaller.

3.3.2. *Influence of ventilation in $PN_{0.01-1}$ concentrations*

Even though it was not possible to draw a precise comparison of the indoor and outdoor concentrations in the different cars, a review of the influence of the different ventilation modes measurements was conducted to see if ventilation influenced $PN_{0.01-1}$ concentrations. The results are presented in Figure 12.

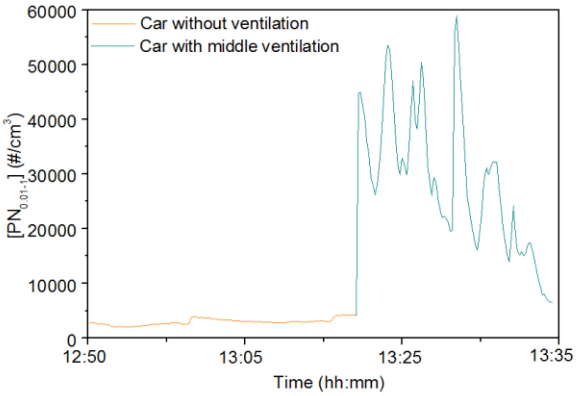

Figure 12. Influence of ventilation on $PN_{0.01-1}$ exposure concentrations inside a car.

It was clear that ventilation had a huge influence in $PN_{0.01-1}$ concentrations that were significantly smaller ($p<0.0001$) when the ventilation was switched off. Car filters were not efficient enough in the removal of smaller particles and the use of ventilation allowed its accumulation inside the cars. The disuse of ventilation led to a negligible air intake and thus, also to a smaller entrance of particles.

3.3.3. *Spatial distribution of $PN_{0.01-1}$ concentrations*

Given the influence of traffic in $PN_{0.01-1}$ concentrations, the spatial distribution of BC and $PN_{0.01-1}$ in the route was similar. That is, $PN_{0.01-1}$ concentrations were higher when traffic intensity was higher and the conditions of dispersion were weak. However, the concentrations were smaller in the residential area because the traffic intensity was the smallest in this area.

3.3.4. *Inhaled dose*

The inhaled dose was, once again, higher for bicycle journeys due to the higher IR and times of travel. The results are presented in Figure 13.

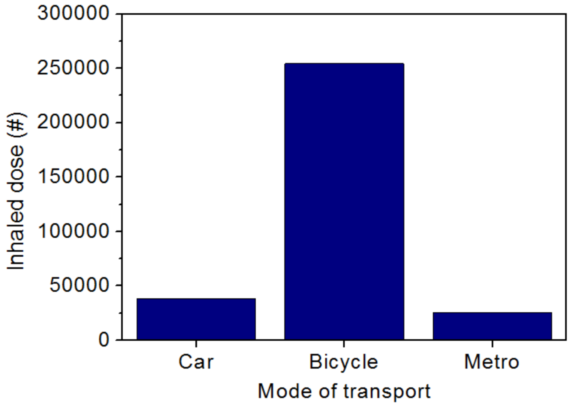

Figure 13. $PN_{0.01-1}$ inhaled doses.

4. CONCLUSIONS

Exposure to $PN_{0.01-1}$, $PM_{2.5}$, PM_{10} and BC was evaluated on a representative route of the daily commutes in the city of Lisbon in three modes of transport in the city (car, bicycle and metro) during 18 weekdays in five trips per day (8h, 10h30, 13h, 18h and 20h). For the study, 6 different cars were used, being these 3 diesel cars, 2 gasoline cars and 1 electric car.

Exposure to $PM_{2.5}$ and PM_{10} was potentiated by trips in the metro, followed by cars and bicycle journeys. In particular, the difference between concentrations inside cars and in the bicycles can be explained by the distance to PM sources as the combustion that happens in the motors of cars. The ratio between the indoor and the outdoor concentrations in cars depended heavily on the ventilation system. The common air filters were efficient in the removal of bigger particles and, because of that, the ratio indoor/outdoor (IN/OUT) was smaller than 1.0. Moreover, the disuse of ventilation led to higher concentrations in the indoor than in the outdoor.

BC concentrations were higher inside the cars, followed by bicycle journeys and the metro. BC is associated to smaller particles that were not so efficiently removed by common air filters in cars. For this reason, concentrations in the indoor of cars tended to be higher than in the outside and the ratio IN/OUT was bigger than 1.0. On the contrary, the disuse of ventilation led to ratios IN/OUT smaller than 1.0. The high efficiency filter with activated carbon was efficient in BC removal from the air that enters in the cabin. In any case, both for PM and BC the use of AC did not translate into much greater efficiency in the removal of pollutants compared to the use of medium ventilation.

For $PN_{0.01-1}$ concentrations, a clear evaluation of the concentrations was not possible because, besides the traffic influence, $PN_{0.01-1}$ can also be formed through photochemical processes.

For all the pollutants evaluated, concentrations were higher in the streets and avenues where the traffic intensity was higher and where the morphology of the streets did not allow the dispersion of pollutants. Besides that, concentrations tended to be higher when traffic intensity was higher, that usually happens in the morning period and at 18h.

Inhaled doses of each one of the pollutants under study were higher in bicycle journeys compared to the other modes of transport because in this case, the IR and travel times were also the highest.

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