Measurements of Particle Concentrations and Size Distributions in Three Parking Garages

M. Obaidullah, I. V. Dyakov, L. Peeters, S. Bram and J. De Ruyck

Abstract— Particulate matter (PM) emissions are a major concern nowadays because the presence of particles diameter less than 2.5 µm in the ambient air have higher risk for human health. This study undertaken aimed to evaluate the indoor PM concentration in three parking garages in Belgium with varying traffic flow and varying layouts. Two garages A and B are located at the ground floor and basement respectively of different multi-storey buildings in Brussels, while another garage C is at the ground floor of a multi-storey building in Leuven. An Electrical Low Pressure Impactor Plus (ELPI+) instrument was used to conduct under this study. Parking places of the garages vary from in the range of 50-190 no. of cars. In this study, three size fractions of particles PM_1, $PM_{2.5}$ and PM_{10} concentrations together with number concentrations were measured on three working days during February and March 2012. Both particle mass and number size distributions were characterized in this investigation. Overall mean results of particle mass concentrations all the three garages were obtained from 28±1 to 50±5 µg/Nm^3 for PM_1, 43±3 to 60±9 µg/Nm^3 for $PM_{2.5}$, 58±13 to 90±27 µg/Nm^3 for PM_{10} respectively. In average PM_1 concentrations accounted for about 47-66% of the PM_{10} for all the garages while $PM_{2.5}$ accounted for about 60-80% of the PM_{10} fractions. All the three garages, it has been observed that $PM_{2.5}$ concentrations exceeded the 24h reference guidelines values recommended by WHO (World Health Organization) and USEPA (United States Environmental Protection Agency) while and PM_{10} concentrations exceeded WHO and EU (European Union). The particle number concentrations were in the range of 28E+03 to 47E+03 particles/cm^3. There were two distinct particle sizes of coarse and fine modes observed in the particle mass size distributions in all examined garages, while the observed number size distributions showed dominant quantities of fine particles.

Keywords—Particulate matter, air quality, parking garages, vehicle emissions, mass concentration, number concentration, size distributions.

I Introduction

The content of Particulate Matter (PM) in the ambient air has increased during recent years. PM refers to the solid and liquid particles that dispersed into ambient air. These particles can be classified into primary and secondary particles based on their formation mechanism **[1]**.

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Primary particles are emitted directly as particles from natural and anthropogenic sources, whereas secondary particles are formed from precursor gases in the atmosphere through gas to particle conversion. Particles smaller than 1 µm (micro meter) in diameter are often called fine particles **[1-2]**. Particles larger than 1 µm in diameter are called coarse particles. The notations PM_1, $PM_{2.5}$ and PM_{10} refer basically to particles with an aerodynamic diameter smaller than 1, 2.5 and 10 µm respectively **[3-4]**.

Particulate matter is considered as a quite severe pollutant involved in a number of adverse health effects **[4-6]**. Several studies have shown that increased particulate matter concentrations in the ambient air correlate with a negative influence on the health condition of the exposed population. Particles less than 2.5 µm in diameter are considered more dangerous to human health because they can travel deeper into the lower respiratory tract **[3-10]**. Moreover, fine particles can be transported through the blood to other body organs such as liver and brain within 4 to 24 hr after exposure **[11]**.

Modern urban areas consist of numerous elements and some of them are subjected to intensive air pollution. Parking is an integrated part of modern city planning. Generally, it is considered as a very significant factor for the planning and management of modern traffic systems **[12]**. There are many varieties in the layout of parking garages: underground garages, parking establishments, parking houses in multi-floor concepts. Smaller garages are often naturally ventilated while larger garages have mechanical ventilation systems.

Air pollution is getting more emphasis in recent research and legislations due to its impact on human health and overall environmental quality. Vehicle's exhaust is a complex mixture originated from unburned fuel, lubricant oil and combustion products. Its main components are carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_x), sulphur oxides **(**SO_x), volatile organic compound (VOC) and particulate matter **[13-16]**. These emissions are released directly from the vehicles to the air in the garages. There could also be additional emissions from vehicles because of the evaporation from engines and fuel tanks **[12]**.

The air quality in the garages depends on many factors such as nature of the vehicle's engine, operating conditions, lubricating oil, emission control system, fuel consumption, garage volume, parking capacity, air exchange rate, etc. **[17]**. Furthermore, it has been shown that garages can become a source of particulate matter and cause infiltration into adjoining occupied office buildings and housing apartments **[17-18]**.

There are poorly available of experimental data on particulate matter concentration in parking garages in the literature. As mentioned above, parking garages have high levels of mobile source-related PM pollutants. So, even though the occupation level by people in parking garages might be low, there is a strong justification to study PM concentrations in parking garages. The objective of this study was to characterize indoor particulate matter concentration in real time. The measurements are divided into particle mass concentrations with three size fractions (PM_1, $PM_{2.5}$ and PM_{10}), number concentrations and their size distributions. An Electrical Low Pressure Impactor Plus (ELPI+) instrument was used to continuously sample and measure particle matter at three enclosed parking garages in Belgium under this study. The results obtained from the present study are discussed with previous studies focused on particle concentrations related to roadside measurements.

II MATERIAL AND METHOD

The following sub-sections present the brief literature review, the existing guidelines for ambient particulate matter, the selected sampling sites, the instrumentation and the experimental set-up conducted for particle measurements.

A. Literature review

This section briefly reviews the findings/results published in the research articles available in the literature related to traffic emissions.

Kim et al. **[18]** investigated carbon monoxide (CO) and particle bound polycyclic aromatic hydrocarbons (pPAH) in an urban parking garage during weekdays and weekends. CO and pPAH were measured by an L15 CO Exposure Monitor and a PAS2000 Monitor with a flow rate 2 lpm (litre per minute) respectively. Average CO-concentrations during the weekdays and weekends were 3.3 mg/Nm^3 and 1.5 mg/Nm^3 respectively, while average pPAH were 19 ng/Nm^3 and 2.6 ng/Nm^3.

Fondelli et al. **[19]** evaluated urban particle concentration inside commuting vehicles such as buses and taxis in Florence city of Italy. A portable particle sampler (pDR 1200) with a flow rate of 4 lpm was used for sampling inside four diesel powered busses and four taxis during eight working days. The average $PM_{2.5}$ mass concentrations obtained inside the buses and taxis were 56±15 µg/Nm^3 and 39±15 µg/Nm^3 respectively. The urban background $PM_{2.5}$ concentrations differed between the buses and taxis of 29±12 µg/Nm^3 and 19±12 µg/Nm^3 measurements. They found that $PM_{2.5}$ mass concentrations inside the vehicles correlated well with the urban ambient air of $PM_{2.5}$ concentrations measured at the monitoring stations.

Hess et al. **[20]** investigated particulate matter with a size fraction of 2.5 µm at passenger shelters of bus stops. Two model 8520 DustTrak Aerosol monitor instruments with a flow rate of 1.7 lpm were used to measure simultaneously particulate matter concentrations. They found that average $PM_{2.5}$ concentrations at the inside and outside of a bus shelter were 17.24 µg/Nm^3 and 14.72 µg/Nm^3 respectively. Inside PM concentrations were higher than the exposure of an outside bus shelter due to the presence of cigarette smoke.

Weingartner et al. **[21]** performed aerosol emissions measurement in a road tunnel of 3.25 km long, which is divided into separate tubes with only one direction of the traffic flow in each tube. Measurements were performed simultaneously at two test stations during workdays, Saturday as well as Sunday. The first station was located about 100 m after the tunnel entrance, while the second was located 100 m before the tunnel exit. Particle mass concentrations, PM_3 (diameter less than 3 µm) were measured with two tapered element oscillating microbalance (TEOM) devices having a flow rate of 3 lpm. The average PM_3 concentrations from the entrance and exit test stations were 25 µg/Nm^3 and 201.6 µg/Nm^3 for workdays, 12.8 µg/Nm^3 and 70.9 µg/Nm^3 for Saturday, 10.9 µg/Nm^3 and 52.7 µg/Nm^3 for Sunday. It is observed that all cases particle mass emissions at the exit test point give higher concentrations with 8 times than the entrance concentration for workdays, 6 times for Saturdays and 5 times for Sundays.

Fischer et al. **[22]** evaluated particulate matter ($PM_{2.5}$) concentrations of air pollutants outside and inside homes in streets with low and high traffic intensity in Amsterdam. Test measurements were performed for 24 h average with Harvard impactors operated at 10 lpm for both indoor and outdoor conditions during a total of 19 days in winter and spring. Outdoor $PM_{2.5}$ concentrations for high traffic and low traffic intensity were 25 µg/Nm^3 and 21 µg/Nm^3 respectively, while indoor $PM_{2.5}$ concentrations were 27 µg/Nm^3 and 12 µg/Nm^3. It is observed from this study that for high traffic conditions, indoor PM concentrations are about 10% higher than outdoor.

The above review briefly illustrates that a number of studies on particulate matter concentrations related to traffic emissions in tunnels, inside commuting vehicles, passenger shelters have been conducted previously. But, no publications were found in literature regarding particulate matter concentration in enclosed parking places.

B. Existing guidelines for ambient PM

The most commonly used existing reference guidelines/standards for ambient particulate matter concentrations are those of the World Health Organization (WHO), United States Environmental Protection Agency (USEPA) and the European Union (EU). They are based on results from research on adverse health effects of particulate matter performed in the last decades. All current air quality standards for PM refer to the weight of particles measured in units of µg/m^3. Table 1 shows the current reference guidelines/standards for ambient particulate matter concentrations **[23-25]**. The air quality guidelines have two limit values with annual average and daily average for ambient $PM_{2.5}$ and PM_{10} concentrations respectively.

Table 1 Reference guidelines for ambient PM **[23-25]**

Particle size fractions	WHO	USEPA	EU
$PM_{2.5}$			
annual mean (µg/m^3)	10	15	not set
24 hour mean (µg/m^3)	25	35	not set
PM_{10}			
annual mean (µg/m^3)	20	50	20
24 hour mean (µg/m^3)	50	150	50

C. Sampling site

Garage measurements have the advantages that the enclosed garage can act as a large dilution tunnel with well known boundary conditions as traffic intensity, air flow and garage volume, etc. Indoor PM measurements were performed at three different enclosed parking garages A, B and C in two cities of Belgium with varying vehicle intensity and different layouts. Figure 1 shows Belgium country map and the measurements sites conducted in two cities. Two garages A and B are located at the ground floor and basement respectively of different multi-storey buildings in Brussels, while another garage C is at the ground floor of a multi-storey building in Leuven. Garage A is equipped with natural ventilation, whereas B and C have a combined mechanical and natural ventilation. Mechanical ventilation systems are generally installed in larger enclosed garages to supply adequate fresh air and to remove the air contaminants within a reasonable amount of time in order to maintain an acceptable level of air quality.

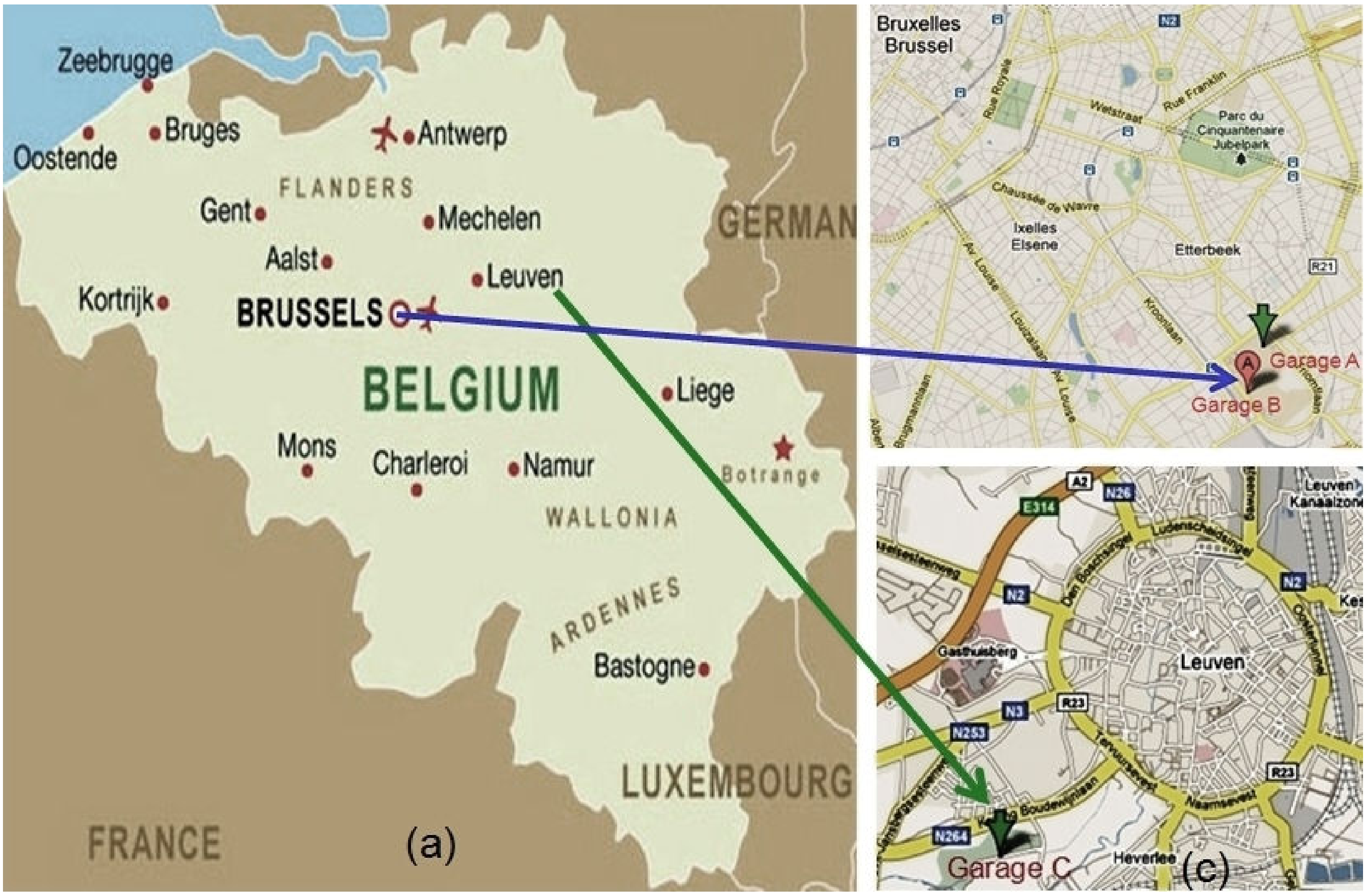

Fig. 1 (a) Belgium country map, (b) shows the exact sampling location for garages A and B in Brussels, (c) shows exact sampling location for garage C in Leuven (source: Google).

Parking capacity of the garages A, B and C is 50, 130 and 185 car spaces respectively. It is observed that all the garages are used for mostly employee's and visitor's cars. The sampling and measuring position in the garages was placed near the midpoint of each garage where observed traffic flow was significant. For all garages, there is only one gate that is used for cars entering and leaving the garage. The measurements presented in this paper were conducted on three different working days: 27 February 2012 for garage A, 13 March 2012 for garage B and 6 March 2012 for garage C.

Table 2 presents the general overview of the garages and meteorological data. Indoor temperature of the garages was recorded by the ELPI+ device, while other remaining parameters such as outside air temperature, humidity and wind velocity data were collected from the metrological website **[26]**. It has been observed that indoor temperature in the garages was about 5^{o}C higher than the outside air temperature. It can also be mentioned that variations of the metrological parameters in all the garages were relatively very small.

Table 2: Overview of the garages and meteorological parameter

Particulars	Garage A	Garage B	Garage C
Type	Ground Floor	Basement	Ground Floor
City	Brussels	Brussels	Leuven
Parking spaces	50	130	185
Area (sm)	1300	3400	5000
Ventilation system	Natural	Natural and Mechanical	Natural and Mechanical
User	Employees and visitors	Employees and visitors	Employees and visitors
No. of entrance and exit point	1	1	1
Indoor temp (^{o}C)	16	16	13
Outside temp (^{o}C)	11	12	8
Humidity (%)	76	76	74
Wind velocity (m/s)	5.5	5.1	5.8

D. Sampling instrument

An Electrical Low Pressure Impactor Plus (ELPI+) instrument manufactured by Dekati Ltd., Finland was used in this study to measure indoor particle mass concentrations, number concentrations and their particle size distribution in real time. It is a widely used instrument for particle sampling measurements with accurate size distributions.

Fig. 2 shows the working principle of the ELPI+ instrument. Sample particles entering the ELPI+ are first charged in the charger. After being charged, the particles are introduced in the cascade impactor in order to be separated on the basis of their inertia and their aerodynamic diameter. This cascade impactor separates the particle on the basis of their aerodynamic equivalent cut-off diameter (D) at 50 % efficiency.

The impactor has 14 stages in the range of 6 nm to 10 µm and all stages are electrically insulated. The charged particles collected in each impactor stage produce an electrical current which is recorded by the respective electrometer. This measured current is proportional to particle numbers via mathematical algorithms **[27]**.

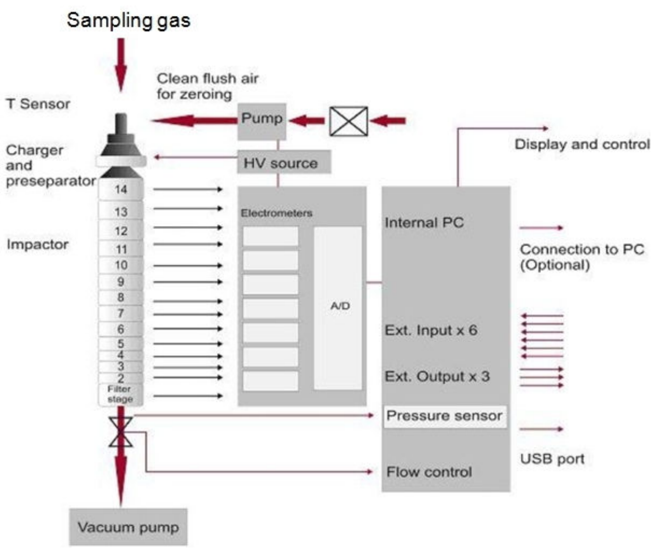

Fig. 2 working principle of the ELPI+ instrument

A vacuum pump with a flow rate of 10 lpm is connected to a power supply in order to suck the sampling air through the ELPI+. In addition, the ELPI+ contains a flush pump and a high voltage (HV) power supply. The flush pump is used to zero the electrometers by pumping High Efficiency Particulate Air (HEPA) filtered air through the instrument. Before staring each measurement, the ELPI+ device was started at least 45 min in advance and allowed to warm up the device and perform the electrometer zeroing with flush on. Three sizes of particles including PM_1, $PM_{2.5}$ and PM_{10} were characterized under this study. Aluminium foils with a diameter of 25 mm and thickness of 0.1 mm were placed on each impactor stages during particle sampling.

E. Experimental set-up

Fig. 3 presents the experimental setup conducted for particle sampling for all the garages. The ELPI+ device was placed on a table at a height of 0.85 m from the floor. All samples were collected inside the garages for several hours during workdays, starting from 8:00 am in the morning for each measurement.

An ELPI+VI software was used with the ELPI+ instrument to transfer the measured data into a data acquisition system for further processing. The ELPI+VI software analyzes indoor particles size distributions with respect to mass, number concentrations and stored them automatically on every second in files at the attached computer with ELPI+ instrument. The stored sampling data can be converted to various parameters to determine the aerodynamic property according to the size distribution. ELPI+VI software can display data in graphs and tables or view statistical information, and can also export data for use in other applications. Sampling data can be generated into many categories; either mass or number, or raw currents with graphs of these. Data exporting can be done either manually or automatically in a delimited text file.

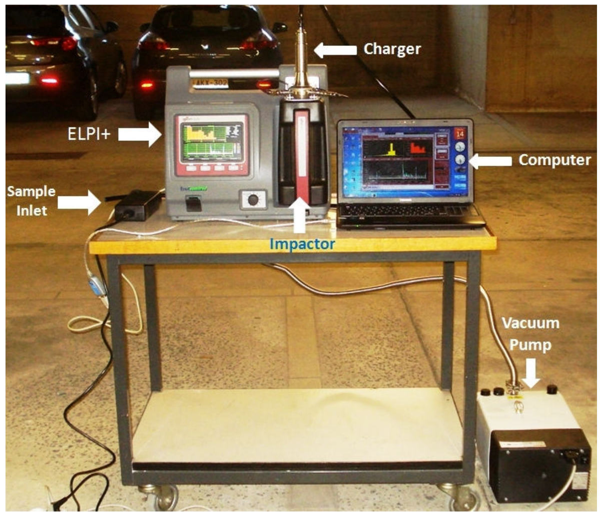

Fig. 3 experimental set-up for PM measurement conducted in the garages

III Results And Discussions

The particle emission characteristics are generally expressed in terms of mass concentrations, number concentrations and particle size distributions. The measurements of the particulate matter at the three garages in the range from 6 nm to 10 µm were combined in three size fractions as PM_1, $PM_{2.5}$ and PM_{10} using EPLI+VI software.

It can be mentioned that particle sampling time for all the measurements conducted for particle sampling varied from 3hr 20 min to 5hr 15 min. The average results along with their standard deviations on PM_1, $PM_{2.5}$, PM_{10} and particle number concentrations obtained from the indoor PM measurements at the three garages are summarized in Table 2. In general, it can be mentioned that traffic emissions from vehicle contribute the major source of fine particle pollution not only in enclosed parking garages but also in urban environments. It was observed during particle sampling that all garages were occupied for approximately 80% with passenger's cars.

The following sections are divided into several sections, including ratios of PM_1/PM_{10} and $PM_{2.5}/PM_{10}$, particle mass concentrations, particle mass size distributions, particle number concentrations and particle number size distribution.

Table 2: Average particle mass PM_1, $PM_{2.5}$, PM_{10} and number concentrations obtained from different garages

Pollutants	Garage A	Garage B	Garage C
Sampling time	3hr 20m	5hr 10m	5hr 15m
PM_1 (µg/Nm^3)	28±1	42±3	50±5
$PM_{2.5}$ (µg/Nm^3)	43±3	55±7	60±9
PM_{10} (µg/Nm^3)	58±13	90±27	76±41
Particle number (particles/cm^3)	28E3±6E3	47E3±14E3	39E3±12E3
PM_1/ PM_{10}	0.48±0.08	0.47±0.11	0.66±0.12
$PM_{2.5}$/ PM_{10}	0.74±0.23	0.61±0.26	0.79±0.22

A. *Ratios of PM_1/PM_{10} and $PM_{2.5}/PM_{10}$*

In average PM_1 concentrations accounted for about 47-66% of the PM_{10} for all the garages while $PM_{2.5}$ accounted for about 60-80% of the PM_{10} fractions. From this analysis, it can be mentioned that PM_1 concentrations accounted more than 50% of PM_{10}. Regarding the PM_1/PM_{10} and $PM_{2.5}/PM_{10}$ ratios, it can vary widely among the other measurements depending on the measurement locations, metrological conditions, measuring instruments, etc. Our results are between 0.6 to 0.8 in accordance with the other results conducted in regional background sites **[28],** northern Greece **[29]** and road side particulate air pollution in Bangkok **[30]**. The high ratio means that a major part of total mass concentration of particulate matter comes from the anthropogenic sources such as fuel combustion, industrial processes, non-industrial fugitive sources and transportation sources.

B. *Particle Mass Concentrations*

Mass concentration of particle is defined as the mass of particles per unit volume of air. Figs. 4 to 6 show comparisons of particle mass concentrations of PM_1, $PM_{2.5}$ and PM_{10} measured in the three garages under examinations and compared with the 24 hr reference values recommended by the WHO, USEPA and EU.

Fig. 4 shows PM_1 concentrations observed in all three garages ranging from 28 µg/Nm^3 to 50 µg/Nm^3. Garage C had higher PM_1 concentrations by 44% and 17% compared to garages A and B respectively. A plausible explanation might be an inadequate ventilation in garage C with respect to its number of vehicle parking places. Our particle mass concentration results for PM_1 can be compared with another study. For example, Lee et al. **[31]** investigated PM_1 mass concentration in heavily traffic area in Hong Kong using a Partisol Plus (Model 2025) instrument operated at 16.7 lpm. Average concentrations of PM_1 were 35.9±12.4 µg/Nm^3.

$PM_{2.5}$ concentrations observed in all three garages vary from 43 µg/Nm^3 to 60 µg/Nm^3. Garage A had lower $PM_{2.5}$ concentrations than garages B and C as shown in Fig. 5. $PM_{2.5}$ concentrations in the three garages A, B and C exceeded the WHO 24h reference values with 71%, 121% and 140% respectively, the USEPA 24h reference value were exceeded with 22%, 58% and 71% respectively.

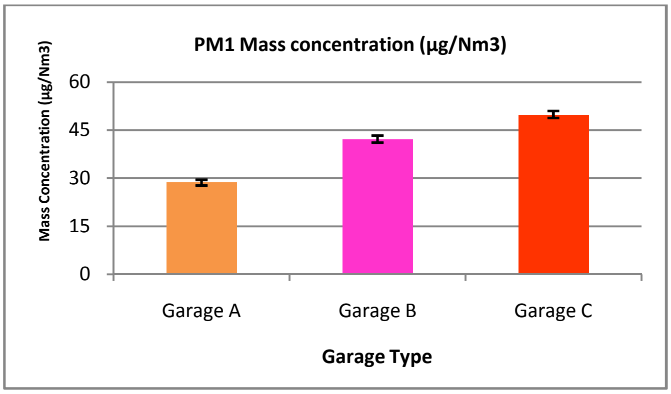

Fig. 4 PM_1 concentrations in different garages

The $PM_{2.5}$ concentrations level obtained in this study can be compared with other studies conducted at road side measurements. For example, $PM_{2.5}$ mass concentrations were measured near a street side with high traffic flow in Amsterdam using Harvard impactor **[22]**. Average outdoor $PM_{2.5}$ concentrations were 25 µg/Nm^3. In another study PM_3 (particle diameter less than 3 µm) concentrations were measured in a road tunnel of 3.25 km long at Zurich, Switzerland using tapered element oscillating microbalance (TEOM) device with a flow rate of 3 lpm. The average PM_3 concentrations from the entrance and exit test stations were 25 µg/Nm^3 and 201.6 µg/Nm^3 for workdays **[23]**. In another study, average $PM_{2.5}$ mass concentrations in heavily traffic area in Hong Kong using a Partisol Plus (Model 2025) instrument operated at 16.7 lpm were 52.3±18.3 µg/Nm^3 **[31]**.

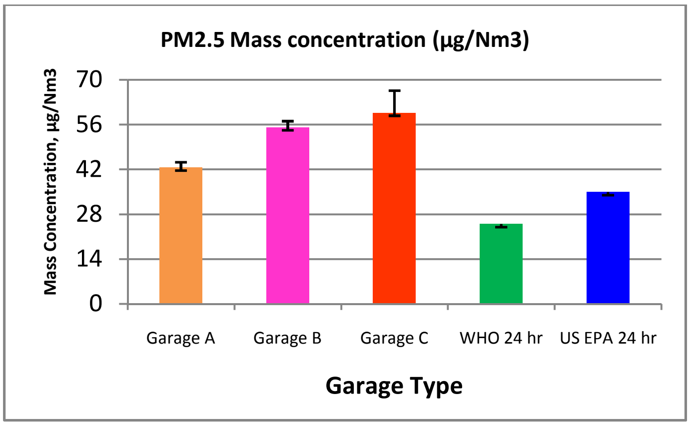

Fig. 5 $PM_{2.5}$ concentrations in different garages

PM_{10} concentrations observed in all three garages vary from 58 µg/Nm^3 to 90 µg/Nm^3. Garage B gave higher PM_{10} concentrations by 35% and 16% compared to garages A and C respectively as shown in Fig. 6. All these garages had higher PM_{10} concentrations than the limit/reference values recommended by the WHO and EU. Our PM_{10} mass concentrations results were higher to the results of other studies that took place on road side measurements **[22, 32]**.

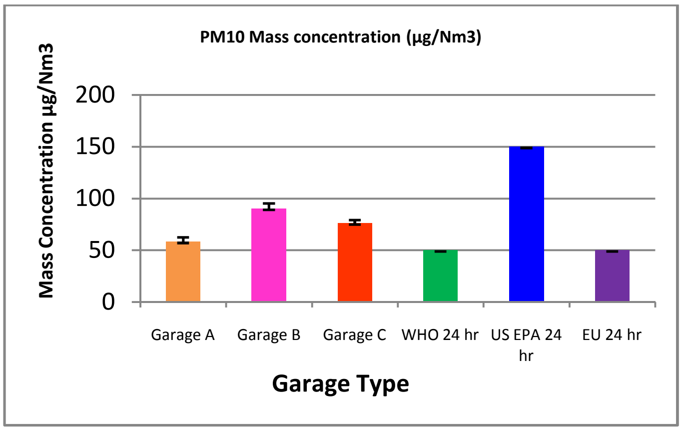

Fig. 6 PM_{10} concentrations in different garages

Adverse health effects of PM are mostly attributed to particulate matter of PM_1 and $PM_{2.5}$ fractions. A person inhales about 6 to 12 m^3 of ambient air per day, depending on age and physical activity **[33]**. This air contains a wide variety of different particle sizes from geological and biological sources as well as anthropogenic pollutants. The deposition of super-micron particles by inertial impaction and of submicron particles by diffusion depends on the gas velocity and residence time in various sections of the airway and lung. Most of the PM_{10} mass is deposited in the nose and throat, while 60% of inhaled fine particle is deposited in the lung **[33]**.

C. Particle Mass Size Distributions

The particle size distribution is a significant factor that needs to be discussed whenever the particulate matter pollutants are concerned. It refers to particle mass concentration distributed over particle size. Fig. 7 illustrates particle mass size distributions obtained from three garages A, B and C. The abscise represents the particle aerodynamic diameter in logarithmic scale plotted against the ordinate which shows the ratio of total mass concentration (dM) to the logarithm of the channel width (dlog(Dp)), where Dp is the aerodynamic diameter.

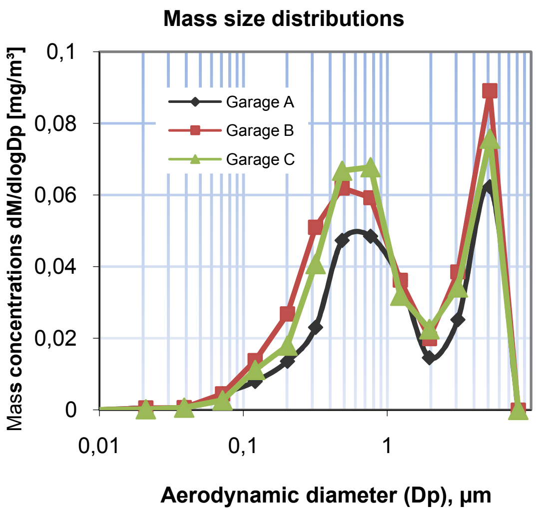

Fig. 7 mass size distributions measured by ELPI+, obtained from different garages

There are two distinct particle modes in the mass size distribution graphs shown in Fig. 7 obtained from all the measurements. One was having a maximum peak of the fine mode at around 500 nm of size and another was having a maximum peak of the coarse mode at around 5 µm size. The second mode is in the coarse mode particles which are typically formed mechanically by the abrasion of road materials, tyres and brake linings, soil dust raised by wind and traffic turbulence, etc. These larger particles may also cause health effects. The profiles of mass distribution represented in several modes have already been observed by other authors **[8, 16, 34-35]**. Since the formation mechanism of the particulate matter is quite complex and usually includes several concurrent paths, the particle distributions profile plotted in a logarithmic scale may reveal more than one peak.

D. Particle Number Concentrations

Number concentration of particles is number of particles per unit volume of air. The number concentrations measured in the garages were in the range of 28E+03 particles/cm^3 to 47E+03 particles/cm^3 as shown in Figure 8. The error bars correspond to the standard deviation of the mean values of the number concentrations. Garage B had higher particle number concentrations by 41% and 16% compared to garages A and C respectively. Particle number concentrations at the three garages were dominated by fine particles. As the garages are attached to the entrance of the buildings, these pollutants can migrate to the office spaces and thus degrade indoor air quality.

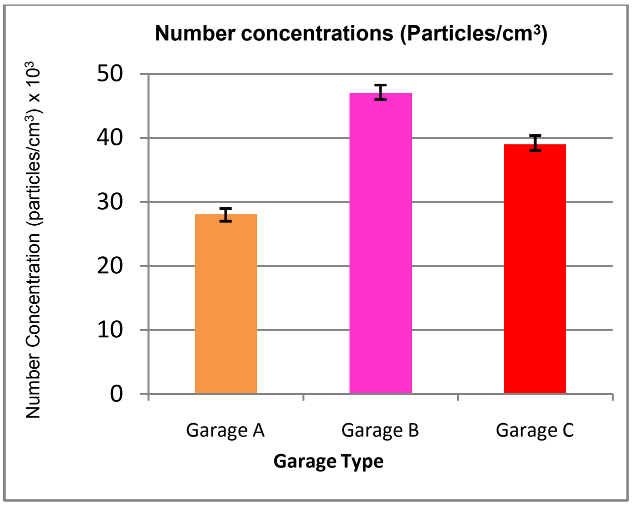

Fig. 8 particle number concentrations measured by ELPI+, obtained from different garages

The number concentrations obtained in our measurements can be compared with another study conducted particle concentration measurement near a motorway in the Brisbane area, Australia by SMPS 3934 **[36]**. The total average particle number concentrations were 15E+03 particle/cm3 which is lower than the our measurement.

E. Particle Number Size Distributions

Number size distribution is expressed as particle number concentration distributed over particle size. Fig. 9 shows typical number size distribution characteristics of particles measured at the three garages. Generally, the particle number size distributions observed at the three examined garages were dominated by submicron particles, and were consist of single modal. The particles were very small and the maxima of the number size distributions varied typically with aerodynamic diameter between 20 and 25 nm. Similar size distributions were observed in another study **[21]**.

It has been shown in the number size distribution graphs obtained from all the measurements that the smallest particles make the highest contribution to the total particle number concentrations, while only a small contribution to particle mass. It can be noted that vehicle emissions are highly dynamic and are formed from a reactive mixture of hot gases and particles. As the hot exhaust gases leave the tailpipe of a vehicle, they are cooling and condensing to form large numbers of particles in the air. These particles are generally in the size range less than 30 nm and compose the nucleation mode.

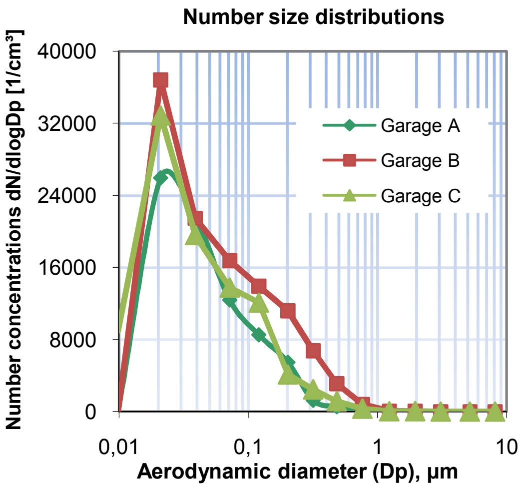

Fig. 9 number size distributions measured by ELPI+, obtained from different garages

IV CONCLUSIONS

Monitoring of particle mass and number concentrations is very important from the aspects of risk assessment to human health. Indoor PM concentrations at three enclosed parking garages in two cities of Belgium were measured continuously using an Electrical Low Pressure Impactor (ELPI+). The measurements of the particulate matter in the range from 6 nm to 10 µm were combined in three size groups as PM_1, $PM_{2.5}$ and PM_{10} and compared them with the reference limit values recommended by WHO, USEPA and EU. The following conclusions can be drawn from the present study.

- The results indicated that the average particles mass concentrations in the garages ranged from 28 µg/Nm^3 to 50 µg/Nm^3 for PM_1, 43 µg/Nm^3 to 60 µg/Nm^3 for $PM_{2.5}$ and 58 µg/Nm^3 to 90 µg/Nm^3 for PM_{10} respectively. The number concentrations were in the range of 28E+03 to 47E+03 particles/cm^3.
- In average PM_1 concentrations accounted for about 47-66% of the PM_{10} for all the garages while $PM_{2.5}$ accounted for about 60% to 80% of the PM_{10} fractions.
- $PM_{2.5}$ concentrations levels of the three garages A, B and C exceeded 71%, 121% and 140% respectively than the WHO 24h reference values, while 22%, 58% and 71% exceeded than the USEPA 24h reference value.
- There were two distinct particle sizes of coarse and fine modes observed in the particle mass size distributions in all examined garages, while the observed number size distributions showed dominant quantities of fine particles.
- The results of the present study can be used by the policymakers and concerned authorities to design and implement appropriate ventilation system with emission control measures. With proper garage volume, parking places, fuel composition, gearing, speed these factors needs to be considered strongly enough

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