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Investigation of Air Quality in the Underground and Aboveground Multi-Storey Car Parks in Terms of Exhaust Emissions

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Abstract

Exhaust emissions resulting from the motor vehicles have harmful and long lasting effects on both the human health and environment. Especially increasing concentrations of exhaust emissions in the closed environments and in the environments that cannot be sufficiently ventilated can cause damage on the human health and lead even to the death. The main harmful exhaust emissions based on the motor vehicles are gases such as CO (carbon dioxide), HC (hydrocarbons), and NOx (nitrogen oxides). In the circumstances of remaining under the influence of these gases, all the systems of the human body are generally get harmed. Therefore, the exhaust emission maps of the areas where there are the harmful exhaust emission concentrations in the high level, and the discharge methods of these gases in a very short space of time must be. In this study, the emission measurements have been carried out in four underground and five aboveground multi-storey car parks located in Istanbul. The effects on the human health of the measured fields were studied by the use of the results of the performed measurements, by comparing them with the maximum allowable concentration (MAC) and the threshold limit value - time weighed average (TLV – TWA) values. Taking into consideration all of the measurement results in the under-ground and above-ground multi-storey car parks, it is determined that the short-term use of the measured fields do not pose any risks in terms of human health. The suggestions regarding the improvement works of the car-parks were presented.

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Keywords: air quality, exhaust emissions, forced ventilation, human health, multi-storey car park

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1. Introduction and Literature Review

Air pollution can be defined as the presence of one or more contaminants, in such quantities and of such duration as they be or tend to be injurious to human life or property (Papakonstantinou et al., 2003). In other words air pollution is the deterioration of the natural components of air due to the reach to the abnormal density and quantity of the substances of the air components by the artificial ways in the result of the different consumption and industrial activities of people that are disturbing the ecological balance, and influencing the life in a negative way.

The air pollution caused by the motor vehicles has persistent and harmful effects on the human health and environment. Especially, the increase of the exhaust emission concentrations in the closed areas and in the places where the sufficient ventilation is not provided may cause the negative effects on the human health. The main harmful exhaust emissions caused by the motor vehicles are CO (carbon monoxide)[1], HC (hydrocarbons) and NOx (nitrogen oxides) gases. In the case of being exposed to the effects of these gases, generally, the whole system of human body is damaged.

The global transportation and car park problems are getting bigger every passing day due to the increase in the motor vehicles. The high level migration and urbanization in big cities influence this problem in a negative way (Çıkman, 2003). Nowadays the motor vehicles are inseparable from people's lives. Because of this reason, car parks are not considered in the separate locations from the living areas. An area is necessary for people to leave their vehicles after getting get out of their cars and going into another action. In this sense, many living areas, from the residential areas to the working areas, and from the recreational areas to the sports areas are not considered without car parks (Güngör, 2006).

The vehicle circulation problem that appeared proportionally with the increasing number of the vehicles in cities in the result of the inability of meeting the parking spaces for drivers, and the all negative effects caused by this confront us as the car park problem. When the problem is considered on the level of intercity transportation, the roads with the roadsides that are spared for the vehicle movements take the shape of the system that is incapable of performing the connection, access and movement functions by turning into the car parks. The unpreventable jams occur in the result of a transportation network where the necessary flow cannot be provided (Yardım and Ağrikli, 2009).

Gaston Bardet remarks that "About **2** hours of **24** hour life of the passenger cars (automobiles) in the cities pass "**in the driving state**", and the remaining **22** hours pass "**in the parking state**". But, **Litman** expresses this condition by the following statement: "About 1 hour of 24 hour life of the automobiles in the cities pass "**in the driving state**" and the rest 23 hours pass "**in the parking state**" (Litman, 2006). These approaches show the importance of the car parks that are domiciles for the automobiles that are depended on the area for a long time for a sustainable and livable city; that the car parks must be properly equipped with the tools/instruments that will provide a healthy environment for the management, environment, safety, technologic (Demir, 2011) and employees, or shortly show the importance of the limited + charged car parks.

In a research led by Uzun (2009), the influence of the ideal regularizations about the on-street parkings to the flow of traffic, and accordingly, to the formation of the exhaust emissions was investigated. In accordance with the data obtained in the result of the measurements and analyzes performed in Oguzhan Street of Fatih District, 4,94% increase in the vehicle passing density and 7,92% increase in the traffic flow speed were seen by the application of the charged parking strategy. After this strategy a 6,20% decrease in the exhaust emission pollutants was calculated according to exhaust emission results taken as a reference (Uzun, 2009).

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[1] The level of CO depends on air distribution, traffic density and ventilation rate (Koskela et al., 1991; Anonymous, 1991; Chan and Chow, 2004). The quantity of CO discharged from vehicles is a key factor in determining the ventilation rate (Chan and Chow, 2004).

In this study, in order to create the exhaust emission maps of the multi-storey car parks with the high harmful exhaust gas concentrations, the emission measurements were performed in nine car parks, four of them were underground car parks, situated in the different districts of Istanbul. The results obtained from the performed measurements were compared with MAC and TLV values, and the influence of the measurement areas on the human health was tried to be defined. In the direction of the obtained results, the executive and structural propositions were made in order to decrease the influence of the emissions of the harmful exhaust gases.

2. Materials and Method

The influences of the harmful emissions on the human health vary according to the receipt duration and receipt quantity. In this regard, three different concentrations are defined.

- MAC (Maximum Allowable Concentration); the quantity that won't harm in the result of the constant respiration.
- TLV - TWA (Threshold Limit Value - Time Weighed Avarage); average exposure on the basis of an 8 h/day, 40 h/week work schedule.
- STEL (Short Term Exposure Limit); the quantity that will cause a danger in a very short space of time. Spot exposure for a duration of 15 minutes, that cannot be repeated more than 4 times per day with at least 60 minutes between exposure periods.

The current limitations in respect of human health are given in the Table 1 as ppm (parts per pillion) or mg/m^3 appropriate to the definitions. The results obtained by measuring in this study are given as comparative with the values of the MAC and TLV. By this comparison, the influences of the measurement areas on the human health were tried to be emphasized.

Table 1. Risk limits of harmful emissions[2] (Borat ve Ark., 1992).

		MAC	TLV	STEL
CO	(ppm)	9	50	5000
HC	(ppm)	20	300	30000
HC HO	(ppm)	0.02	1	650
NO	(ppm)	0.15	-	-
NO_2	(ppm)	0.05	5	200
SO_2	(ppm)	0.1	5	400
Pb	(mg/m^3)	0.003	-	-
Pb $(C_2 H_5)_4$	(ppm)	-	0.01	-

2.1. Ventilation in Multi-Storey Car Parks

In order to protect human health, the discharge of the harmful exhaust gases from the multi-storey car parks is necessary. For this aim, basically two types of ventilation systems, ductwork system and jet jan ventilation systems are used (Fig.1 and 2). The ductwork ventilation system is known as a traditional ventilation system (Atmaca, 2010). Up to last decade the ventilation of underground car parks was based on a ductwork system to provide the exhaust of the contaminated air and the admission of fresh air or on natural ventilation systems. The performance[3] of such ventilation systems has been characterized by several studies (Chow, 1998; Noordijk and Lemaire, 2005; Zhang et al., 2007; Viegas, 2010).

[2] Petrol and diesel produce oxides of carbon and hydrogen as a consequence of incomplete combustion. Of the most concern are the primary pollutants: CO, CO_2, HC, NO, NO_2, SO_2, smoke and particulate material, lead and the range of organic compounds known generally as volatile organic compounds (Burnett and Chan, 1997).

[3] The ventilation efficiency reflects the performance of a system with regard to the average ability to remove pollutants. It is based on the average car park concentration, supply concentration and average exhaust concentration over a time period (Anonymous, 1991). Results from measurement were used to assess the ventilation system performance. The indication of performance is effectiveness of pollutant removal and fresh air supply. The evaluation also focuses on the spatial variation of pollutant and fresh air supply (Chan and Chow, 2004).

a  b 

Fig. 1. Underground multi-storey car parks with, (a) with ductwork type ventilation; (b) with jetfan type ventilation.

Recently a new solution appeared, based on the use of jet fans. They are able to generate the momentum necessary to drive smoke to exhaust openings. Therefore, air inlets and exhaust openings may be far from pollution or fire sources and may be concentrated at some points of the underground car park (Viegas, 2010).

The supply air and enclosure air are mixed by the actions of the supply momentum and buoyancy. Under this phenomenon, the supply air is used to dilute the concentration of CO, HC and NOx pollutants in the car park. The mixture of air and CO or other pollutants is then extracted away via the exhaust duct (Chan and Chow, 2004).

2.2. CO limit Value in Multi-Storey Car Parks

Day by day, parks and other green areas are wanted to be in the regions/cities where more people live. For this aim, every passing day, both more underground and aboveground multi-storey car parks are constructed. Especially in the closed car parks, the automated ventilation systems that are activated depending on the amount of the CO and/or LPG in surrounding air (Gurbetci et al., 2014). The design of the ventilation systems are successfully applied by considering CO values given in the Table 2. The ventilation ratio must be adjusted in accordance with CO values given in the Table 3.

Table 2. CO emissions (Anonymous, 2002).

Vehicle Type	**CO Emission *(m^3/h)***
Passenger car (for 5 people)	1.47 (0.41 l/s)
Passenger car (for 7 people)	2.52 (0.70 l/s)

Table 3. Max. CO level (Anonymous, 2002)

Location	**Traffic flow**	**Max. CO level (*ppm*)**
General parking area	Normal	50
	Maximum	100
Entrance and exit tunnels	Only for temporary stop/ occupancy	150

As far as short and long-term health problems are concerned CO compound, reducing CO emission levels in occupational spaces is an important issue. It was found that when ventilation was applicable the CO levels inside the garage fulfill the indoor air quality acceptance requirements (Papakonstantinou et al., 2003).

2.3. Emissions Measuring Areas

The main harmful exhaust emissions caused by the motor vehicles; CO, HC and NO_x gases. In the case of being subjected to the effects of these gases, generally the whole system of human body is damaged. Therefore, the creation of the emission maps of the areas with the higher harmful exhaust gas concentrations, and the determination of the discharge methods of these gases in a very short space of time are necessary.

In this study, the emission measurements (Table 4) of the nine car parks in Istanbul, four of them are underground car parks, were determined by the measurements performed at the hours when there were the highest density of the motor vehicles.

2.4. Measuring of Emission Values

The device used in the measurements of the exhaust emissions can perform CO, HC, NOx, CO_2, O_2, soot, lambda and air-fuel ratio (AFR) measurements. The measurement parameters, measurement limitations and sensibilities of the exhaust emission measuring device are given in the Table 5. However, 50 emission measurement value was used in the measurement of each harmful emission. In the determination of these sample measurements, while the selection of the different measurements were given the priority, the taken sample measurements were made sure to represent all the measurement results.

As the exhaust emission measurement was performed in open areas with continuously variable air movements, the stable measurement conditions could not be created. The conditions of the performed measurements were constantly shown variability. The exhaust emission measurement points were defined as the points where there were the highest formation possibilities of the exhaust emission concentrations and the points that would represent the whole parking area.

Because of the lower formation of the soots, they were not taken into the evaluation. The CO_2 and O_2 concentrations that were registered in every measurement were not taken into the consideration as they do not bear the harmful effects. For the evaluation of the harmful effects of the obtained results, the average values of the results were given in accordance with the MAC and TLV in a comparative way.

Table 4. Multi-storey car-parks' properties.

Car-park Code	**Type**	**Capacity**	**Ventilation Type**	**Number of Floors**	**Average Annual Turn-over Rate**	**Average Parking Time *(h)***	**Working Period *(Day/h)***
G1	AG	305	Natural	6	0,65	11	7/24
G2	AG	700	Natural	7	0,78	2,5	7/24
G3	AG	630	Natural	9	1,01	6,5	7/24
G4	AG	580	Natural	6	2,06	3,5	7/24
G5	AG	760	Natural	5	1,98	3	7/24
GA	UG	314	Ductwork	3	0,95	4,5	7/24
GB	UG	500	Ductwork	3	0,35	5,5	7/24
GC	UG	370	Ductwork	1	0,56	7	7/24
GD	UG	401	Jet fan	4	0,06	6,5	7/24

Table 5. Exhaust emission testing device's measurement parameters, limits and sensitivities.

Parameters	**Measurement Limits**	**Sensitivity**
CO	0 - %10	%0,0005
CO_2	0 - %20	%0,01
HC	0 – 1000	1 ppm
O_2	0 - %25	%0,01
NOx	0 – 500	1 ppm
Lambda	0,5 – 2,00	0.001
AFR	5 – 30	-
Opacity	%0 – 100	%0,10
Smoke density	0 – 9,99	1/0,01 m
Workplace temperature	-5 ˚C…+ 50 ˚C	%0,01
Detection time	< 3 s	-

3. Emission Testing

In this study, measurements were performed in 5 aboveground and 4 underground multi-storey car parks. The CO, HC and NOx concentration values in these measurements were investigated and evaluated in the terms of MAC and TLV.

3.1. Measurement Results of the Aboveground Multi-Storey Car Parks

In this study, the measurements were performed in the 5 aboveground multi-storey car parks (Cihangir, Gedikpaşa, Karaköy, Ümraniye and Üsküdar) (G1-5) indicated in the Table 4. As the side walls of the storeys were open, generally, no emission value that may cause a danger was determined. But on the underground multi-storeys the emission values do not reach to the harmful level as there is a low vehicle density. The highest emission values in the multi-storey car parks were determined in the entrances and exits of the car parks. As we can see in the Fig. 2, the average CO, HC and NO_x concentration values in the measurement areas of 5 aboveground multi-storey car parks are shown. While the CO concentration measurement values indicated in the Fig. 4, which are among the emission measurement data, are above the MAC values in the whole car parks, it stayed below the TLV except the G5 car park. As we can see in the Fig. 6, the HC concentration measurement values stayed below the MAC values. Therefore, in the areas where the measurement was performed, it can be stated that the HC emissions do not pose a significant hazard. But, in the Fig. 6, the NO_x concentration values are above the MAC and below the TLV. All of the measurements were performed at the time that happened heavy parking traffic.

In the CO measurements performed in the G1 multi-storey car parks, generally the 9 ppm MAC value was exceeded. However, the CO emission concentrations, 50 ppm TLV value was not exceeded and the measured maximum value was determined as 45 ppm. The average CO value of the 50 measurement was calculated as 13.2 ppm. These results indicate that CO emissions do not pose hazard for the car park users in G1 multi-strorey car park. However, it was suggested that the working hours of the car park employees must not exceed 8 hours. In the case of exceeding this duration, the possibility of the employees be harmed can be concluded. In the HC emission measurements 20 ppm TLV value was not exceeded and the measured maximum HC value was determined as 17 ppm. The average HC value of the 50 measurement was found as 4.32 ppm. These results indicate that the HC emissions did not reach to the harmful values in the G1 multi-storey car park. In the NO_x emission concentrations, all of the measurements were found bigger than the MAC. However, in the NO_x emission concentrations the 5 ppm TLV value was not exceeded and the measured maximum NO_x value was 4 ppm. The average NO_x value of the 50 measurement was found as 1.38 ppm. These results indicate that the NO_x emissions do not pose hazard to the car park users in the G1 multi-storey car park either. However, it is suggested that the working hours of the car park employees must not exceed 8 hours. In the case of exceeding this duration, the possibility of the employees be harmed is understood.

In the CO emission concentration in the **G2** multi-storey car park, generally the 9 ppm the MAC value was exceeded, and in some measurements the TLV was also exceeded, and the measured maximum CO value was measured as 70 ppm and the average CO value of the 50 measurement was found as **30.7 ppm**. These results indicate that the employees of the G2 multi-storey car parks must not exceed the 8 hour working period. In the case of exceeding this duration, it was concluded that they could be harmed from the CO emissions. The 20 ppm MAC value in the HC emission measurements was not exceeded the maximum measured HC value was determined as 17 ppm. The average HC value of 50 measurement was calculated as **4.22 ppm**. As the average value is lower than the MAC value, it can be said that the HC emissions did not reach to the harmful values in G2 multi-storey car parks. But, the NO_x concentrations were usually found bigger than the MAC values. Some NO_x concentrations exceeded 5 ppm TLV values, too. The maximum measured NO_x value was 6 ppm. But, the average NO_x value of 50 measurement is **2.2 ppm**. From these results it is understood that the car park employees must not exceed the 8 hour working period because of the NO_x emissions in the **G2** muli-storey car park, in the case of exceeding this working period the employees may got harmed.

In the CO measurement in the **G3** multi-storey car park, generally the MAC value was exceeded and in some measurement the TLV values was also exceeded, and the measured maximum CO value was determined as 75 ppm.

The average CO value in the all measurements was calculated as **29.4 ppm**. But, in the HC emission concentrations, the 20 ppm MAC value was exceeded and the measured maximum HC value was measured as 23 ppm. The average HC value in the all measurements was found as **7.34** ppm. As the average value was found below the MAC value, it can be said that HC emission in this multi-storey car park did not reach to the harmful values. But the NO_x emission concentrations were usually found bigger than the MAC values. Some NO_x emission concentrations exceeded 5 ppm TLV values, and the measured maximum NO_x value was measured as 7 ppm and the average NO_x value was found as **3** ppm. These results indicate that the employees must not exceed the 8 hour working period in the G3 multi-storey car park because of both CO and NO_x emissions, in the case of exceeding this working period the employees may got harmed.

In the G4 multi-storey car park, generally the MAC value was exceeded in the CO emission measurement and in some cases the TLV value was exceeded too, and the measured maximum value was determined as 70 ppm. The average CO value in the all measurements was found as 27.9 ppm. But, in the HC emission concentrations, the MAC value was exceeded and the measured maximum HC value was found as 22 ppm. The average HC value in the all measurements was calculated as 8.02 ppm. Generally, the NO_x emission concentrations were found bigger than the MAC values. Some NO_x emission concentrations exceeded the TLV value and the measured maximum NO_x value was found as 6 ppm. And the average value of 50 measurement was found as 2.6 ppm. From these results it is understood that the employees must not exceed the 8 hour working period in the G4 multi-storey car park because of both CO and NO_x emissions, in case they need to exceed or exceed this working period, the employees may got harmed. As for the HC emissions, as the average value was found below the MAC value, it can be sated that these emissions did not reach to the harmful values.

In the CO emissions measurements in the G5 multi-storey car park, generally, the MAC value was exceeded and in some cases the TLV value was exceeded too, and the measured maximum CO value was measured as 70 ppm. The average CO value was found as 30.9 ppm. But, in the HC emission concentrations, the MAC value was not exceeded and the measured maximum value stayed at 17 ppm. The average HC value was found 3.96 ppm. But, the NO_x concentrations generally were found bigger than the MAC value, which is bigger than expected. Some NO_x concentrations exceeded even some TLV values and the measured maximum NO_x value was determined as 8 ppm. The average NO_x value was found as 2.52 ppm. According to these results, the employees must not exceed the 8 hour working period in the G5 multi-storey car park because of the average value was found below the MAC values in respect of HC emissions.

3.2. Measurement Results of the Underground Multi-Storey Car Park

The measurements were performed in the underground multi-storey car parks **(GA-D)** shown in the Table 4. The automated ventilation system, such as ductwork or jet jan, was used in these car parks. The emission measurements were performed at the times when there was the highest density of the motor vehicles. As it can be seen in the Fig. 3, the average CO, HC and NO_x concentration values in the measurement areas of the 4 underground multi-storey car parks were shown.

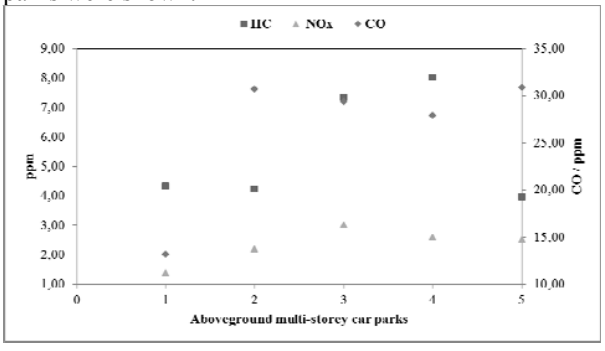

Fig. 2. The average CO, HC and NOx concentration values measured in five aboveground multi-storey car parks.

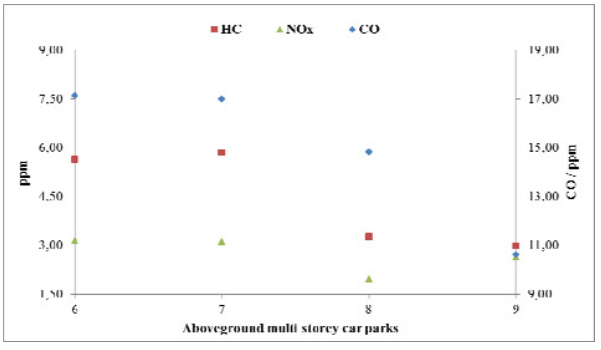

Fig. 3. The average CO, HC and NOx concentration values measured in four underground multi-storey car parks.

40 different emission measurements were performed in the GA underground car park at the peak busy entry and exit times of vehicles, and the emission changes of the obtained CO, HC and NO_x are respectively shown in Figure 2. In the CO emission measurements the MAC value was generally exceeded, but the TLV value was not exceeded and the measured maximum value was determined as 45 ppm. The average CO value was found as **17.12** ppm. In the HC emission concentrations, the MAC value was not exceeded and the measured maximum value stayed at 18 ppm. The average HC value was found as 5.65 ppm. But, the NO_x emission concentrations were generally found bigger than the MAC value. Some NO_x emission concentrations exceeded the TLV value and the measured maximum NO_x value was found as 8 ppm and the average NO_x value was found 3.15 ppm. According to these results it can be stated that the employees must not exceed the 8 hour working period in the GA underground car park because of the NO_x and CO emissions, in case they exceed this working period, they may got harmed. Moreover, it is determined that the HC emissions did not reach to the harmful values in the legal working periods.

The changes of measured CO, HC and NO_x emissions are respectively shown in the Fig. 3. In the CO emission measurements the MAC value was generally exceeded and in some measurements the TLV value was not exceeded, the measured maximum CO value was determined as 45 ppm and the average value was determined as 17 ppm. In the HC emission concentrations the MAC value was not exceeded and the measured maximum value was found as 18 ppm and the average value was found as 5.86 ppm. But, the NO_x emission concentrations were generally found bigger than the MAC value and some NO_x emission concentrations exceeded even the TLV value. The measured maximum NO_x value was found as 8 ppm and the average NO_x value was found as 3.1 ppm. According to these results it can be stated that the employees must not exceed the 8 hour working period in the GB underground car park because of both CO and NO_x emissions, in case they exceed this working period they may get harmed. And also, it can be stated that the harmful values were not reached to the harmful values in respect of the HC emissions in the same car park.

30 different emission measurements were performed in the GC underground car park at the peak busy hours, and the emission changes of the obtained CO, HC and NO_x are respectively shown in Fig. 4. In the CO emission measurements the MAC value generally was exceeded, and the TLV values was not exceeded. The measured maximum CO value was found as 35 ppm and the average value was found as 14.83 ppm. In the HC emission concentrations, the MAC value was not exceeded and the measured maximum HC value was determined as 8 ppm and the average HC value was determined 3.36 ppm. As the average value was below the MAC value, it can be stated that the HC emissions did not reach to the harmful values in the GC underground car parks. NO_x emission concentrations, generally was bigger than the MAC value and smaller than the TLV value. The measured maximum NO_x value was found as 5 ppm and the average value was found as 1.96 ppm. According to these results, it is understood that the employees must not exceed the 8 hour working period in the GC underground car park because of both CO and NO_x emissions, in case they exceed this working period, they may get harmed.

40 different emission measurements were performed in the **GD** underground car park at the peak hours. In the CO emission measurements, the MAC value generally was exceeded but in some measurements the TLV value was not exceeded. The measured maximum CO value was 25 ppm while the average CO value was found 10.62 ppm. But, in the HC emissions the MAC value was not exceeded, the measured maximum value was found as 8 ppm and the average value was found as 2.98 ppm. NO_x emission concentrations was generally found bigger than the MAC value. Some NO_x emissions exceeded even the TLV value, the measured maximum NO_x value was found as 7 ppm and the average value was found as 2.52 ppm. Due to the NO_x emissions, it was determined that the car park employees must not exceed the 8 hour working period, in case they exceed, they may get harmed. And also, it was determined that the harmful values were not reached in respect of the HC emissions.

4. Results and Discussion

As we can see in the Figure 3 and 5, the CO concentration measurements were measured above the MAC value in the all car parks. The reason why the CO amount in the G2, G3, G4, and G5 car parks was found higher than the G1 car park is because the turn-over rate of these car parks are higher. The stopping period at the entrance for

paying the cost also triggers the increases in the emissions. Especially, in order to decrease the emissions at the entrances and exits of the car parks, automatic payment machine and nonstop access systems may be applied.

In respect of NO_x amount, a value below the MAC value was measured only in the G1 car park. Moreover, in the aboveground multi-storey car parks, in respect of the HC emissions, the MAC and TLV values were not exceeded. However, the highest value in the G4 car park was measured as 8.02 ppm Figure 3.

When the Figure 4 is examined, the average CO and NO emissions in four underground multi-storey car parks were measured above the MAC value. One other important point is that the CO amount in these car parks was measured below the values of the aboveground multi-storey car parks. This case was caused due to the ventilation system that works dependent on the CO amount.

As we see in Fig. 6, the HC concentration measurement values stayed below the MAC value in the all car parks. For this reason, it can be stated that the HC emissions do not pose an important hazard in the measured areas.

The average NO_x concentration value indicated in Fig. 7 stayed above the MAC value and generally stayed below the TLV values in the all car parks. This case indicates that the NO_x emissions won't pose an important hazard in the measured areas provided that the stay is less than 8 hours.

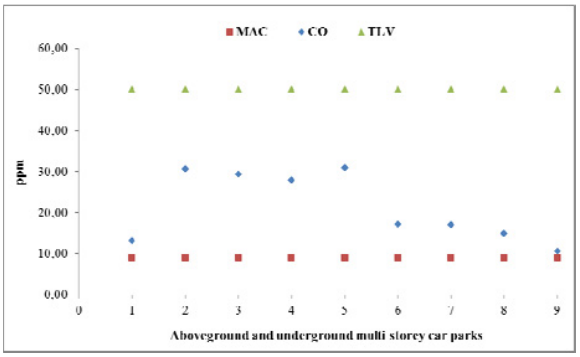

Fig. 4. The average CO concentration values measured in all underground and aboveground multi-storey car parks.

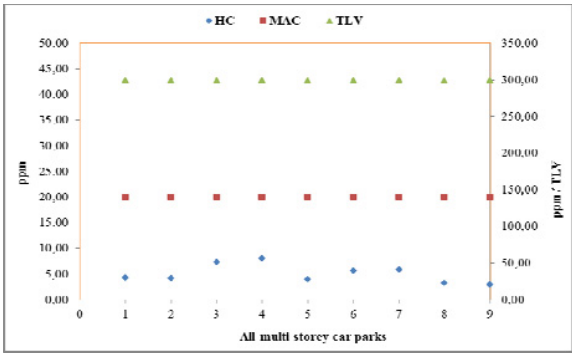

Fig. 5. The average HC concentration values measured in all underground and aboveground multi-storey car parks (ppm).

Among the factors that affect the exhaust emissions in the car parks; the design of the car park and geometrical dimensions, turn-over rate, the numbers of entrance and exit, geometrical designs at the entrances and exits, the payment method (automatic pay stations and/or payment at exit), ventilation facilities (natural or forced -ductwork or jet fan-), the types of cars using the car park and participation in road, etc.

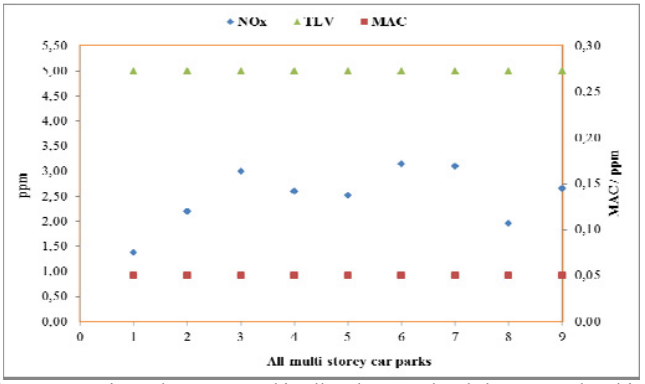

Fig. 6. The average NOx concentration values measured in all underground and aboveground multi-storey car parks (ppm).

5. Conclusion and Recommendations

Nowadays people and the motor vehicles are inseparable. Because of this reason, the car parks are considered one of the living areas. In the construction and management of car parks the human health and safety must be taken into the consideration. As there is a dense movements of the motor vehicles in car parks, the harmful exhaust emission concentrations caused by the motor vehicles may reach to the dangerous levels. In case the sufficient ventilation is not provided in the underground and aboveground multi-storey car parks, these emission concentrations may reach to more dangerous levels for the car park employees who spend the bigger part of their lives in there. Because of this reason, in respect of the car park users and especially car park employees, it is required that the hazardous emissions are measured and harms are decreased and/or kept under control. In this study, emission measurements were performed in nine multi-storey car parks, four of which were underground car parks. The influences on the human health of the measured areas were determined by comparing the results obtained from the performed measurements with the MAC and TLV values. In these analysis:

- The HC concentration value in the all measured areas stayed below the MAC value. For this reason, it can be stated that the HC emissions won't pose an important hazard in the measured areas.
- While the average CO concentration value in the measured areas exceeded the MAC value it stayed below the TLV value. For this reason, it can be stated that the CO emissions won't pose an important danger provided that the stay is less than 8 hours in the measured areas, however, the dangerous effects of the CO emissions would be observed in case the stay is longer than 8 hours in the measured areas.
- The average NO_x concentration values in the measured areas generally stayed below the TLV value. In this case, it can be stated that the NO_x emissions won't pose an important hazard provided that the stay is less than 8 hours.
- The amount of the CO in the underground multi-storey car parks was measured below the values in the aboveground multi-storey car parks. For this case, it can be stated that the use of the automatic ventilation system that starts automatically depending on the CO amount in the underground car parks is effective.

Moreover,

- Making payment at the entrance and the waiting duration in this period cause the increase of the emissions. For this aim, in order to decrease the emission ratios at the entrances and exits in the car parks; automatic payment, automatic pay stations and nonstop access systems can be applied (by the control of camera and the methods like RFID).
- The designs and geometrical dimensions of car parks are the most basic structural factors that influence the fuel consumptions of the vehicles depending on the movements within the car parks and consequently emissions.
- The ventilation systems in the car parks must start automatically depending on the emission concentrations in the surrounding area for the aim of energy efficiency. The ventilation systems must not run continuously and the efficiency must be able to be controlled by the automation systems.
- As we can see from the results of the research, the use for the short periods of the measured areas in the car parks subjected to the study does not pose any hazards for the human health. However, the long stays of the employees in the measured areas may cause some chronical problems in respect of the employees' health. In order to decrease the negative effects the employees are exposed to, the working areas of the employees must be pressurized and/or ventilated. Moreover, the working areas of the employees must be periodically changed considering the emission conditions.

Abbreviation

AFR	Air Fuel Ratio	NOx	Nitrogen Oxides
AG	Above-Ground	ppm	parts per pillion
CO	Carbon Dioxide	RFID	Radio-Frequency IDentification
CO_2	Carbon Dioxide	SO_2	Sulphur Dioxide
G	Car-Park / Garage	STEL	Short Term Exposure Limit
HC	Hydro-Carbons	TLV-TWA	Threshold Limit Value/Time Weighed Ave.
MAC	Maximum Allowable Concentration	UG	Under-Ground
NO	Nitrogen Oxide	VOCs	Volatile Organic Compounds
NO_2	Nitrogen Dioxide		

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References

Anonymous. (1991). A guide to contaminant removal effectiveness, *Air Infiltration and Ventilation Centre*, Technical Note AIVC28.2, UK.

Anonymous. (2002). Design recommendations for multi-storey and underground car parks, *The Institution of Structural Engineers*, Third Edition.

Atmaca, M. (2010). Investigation of usability of the ductwork and jet jan ventilation systems in multi-storey car parks, *Technical Report,* [in Turkish].

Borat, O., Balcı, M. & Sürmen, A. (1992). Air pollution and control technique, *Technical Education Foundation*, [in Turkish].

Burnett, J. & Chan, M. Y. (1997). Criteria for air quality in enclosed car parks, *Proc. Instn Civ. Engrs*, Transp., 123, May, 102 – 110, Paper 11337.

Chan, M.Y. & Chow, W.K. (2004). Car park ventilation system: performance evaluation, *Building and Environment*, 39, 635 – 643.

Chow, W.K. (1998). On safety systems for underground car parks, *Tunnelling and Underground Space Technology* 13 (3), 281–287.

Çıkman, G. (2003). A study on the investigation of the car-parking needs in cities and their design options, *Masters Degree Thesis*, Dokuz Eylül University Institute for Graduate Studies in Pure and Applied Sciences, Izmir, Turkey, [in Turkish].

Demir, A. & Gümüş, M. (2011). Investigation of the effects of the on-street parking strategy to the traffic density and exhaust emissions, *International Car-parking Policies and Applications Symposium*, Presentation Book, May 25, [in Turkish].

Güngör, E. K. (2006). Car-parking problems and solutions in downtown of Konya, *Masters Degree Thesis*, Selchuk University, Institute for Graduate Studies in Pure and Applied Sciences, Konya, Turkey, [in Turkish].

Gurbetci, K., Demir, A. & Karaahmet, A. (2014). Technology, environment and safety factors in the car-parking applications, *Ilke Publishing*, ISBN: 978-605-5961-38-1, [in Turkish].

Koskela H.K., Rolin I.E. & Norell L.O. (1991). Comparison between forced-displacement and mixing ventilation in a garage, *ASHRAE Transaction*, 97:1119–26.

Litman, T. (2006). Parking management best practices, *American Planning Association*, Victoria Transport Policy Institute.

Noordijk, L. & Lemaire, T. (2005). Modelling of fire spread in car parks, *HERON 50* (4), 209–218.

Papakonstantinou, K., Chaloulakou, A., Duci, A., Vlachakis, N. & Markatos, N. (2003). Air quality in an underground garage: computational and experimental investigation of ventilation effectiveness, *Energy and Buildings* 35, 933–940.

Uzun, Ö.L. (2009). Car-parking problems in Istanbul, *Masters Degree Thesis*, Marmara University, Institute for Graduate Studies in Pure and Applied Sciences, Istanbul, Turkey, [in Turkish].

Viegas, J.C. (2010). The use of impulse ventilation for smoke control in underground car parks, *Tunnelling and Underground Space Technology* 25, 42–53.

Yardım, M. S. & Ağrikli, M. (2009). Automatic car-parks and the application potential for the solution of the car-parking problems in Turkey", *http://www.e-kutuphane. imo.org.tr/pdf/3209.pdf*, [in Turkish].

Zhang, X.G., Guo, Y.C., Chan, C.K. & Lina, W.Y. (2007). Numerical simulations on fire spread and smoke movement in an underground car park, *Building and Environment* 42, 3466–3475.