COMMUTER EXPOSURE TO FINE PARTICULATE MATTER IN PRIVATE ROAD TRANSPORT MODES IN SALEM, INDIA

by

Ramesh Kumar AYYAKKANNU[a*], Jayabal SUBBAIAN[b], Manikandaprabu PANDIAN[a], and Daniel Lawrence IRUTHAYARAJ[c]

[a] Department of Mechanical Engineering, Sona College of Technology, Salem, Tamil Nadu, India
[b] Department of Mechanical Engineering, Government College of Engineering, Thanjavur, Tamil Nadu, India
[c] Department of Mechanical Engineering, Loyola Institute of Technology, Chennai, Tamil Nadu, India

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Private vehicles are high dominant mode of transport in Salem, India, since there is no any commuter personal exposure information on air pollution. This is the first pollutant exposure study in different private vehicles across Salem city. In this study, critical air pollutant of fine particulate matter, $PM_{2.5}$, was measured. In addition, accumulation of CO_2, concentration also assessed in closed vehicles. The measured vehicles were motorcycle, auto rickshaw, hatchback car, sedan car, sports utility vehicle car, and multi utility vehicle van. The four-wheeler (car and van) in-vehicle concentrations were assessed under four different ventilation conditions. Student's t-test statistical analysis was carried out to determine the significance exposure level between the vehicles. It is observed that there is no statistically significant difference ($p > 0.05$) between the vehicles of motorcycle and sedan, motorcycle and multi utility vehicle van, and auto rickshaw and sports utility vehicle for $PM_{2.5}$ pollutant. A regression analysis shows a strong negative correlation between $PM_{2.5}$ and CO_2 concentration in an air-conditioning cars.

Key words: *in-vehicle concentration, commuter, PM, private transports, CO_2*

Introduction

In this modern world, people spend more time in transports, especially in urban areas. At the time of travel, commuters' easily exposed to tiny and suspended particles of $PM_{2.5}$. The $PM_{2.5}$ is a definite concern that contains various amounts of numerous toxic metals and acids. The aerodynamic size of $PM_{2.5}$ is less than 2.5 μm ($< 2.5 \times 10^{-6}$). Therefore, $PM_{2.5}$ pollutant has the potential to pass through the respiratory tract and settle down into the lungs.

The previous studies were revealed that exposure to airborne particles causes allergies, hypersensitivity reactions, cardiovascular diseases, and respiratory problems [1-3]. Also, the accumulation of CO_2 inside the vehicle cabins can lead to drowsiness and slowing of reactions, which causes the risk of accidents [4]. Previous studies were quantitatively assessed the PM [5-7] and CO_2 [8-10] in different transport modes of the bicycle, cars, buses, and trains

* Corresponding author, e-mail: rameshkumara@sonatech.ac.in

[11, 12] under different ventilation conditions include AC ON/OFF, windows closed/open and fresh air supply mode/recirculation mode [13, 14].

Approximately 10-50% commuters' exposed to in-vehicle ultra-fine particles daily an hour from the road traffic at Los Angeles, California [15]. Zagury *et al.* [16] found that the Paris taxi drivers exposed to fine suspended particles four times higher than the threshold limit of the World Health Organisation (WHO). Chan *et al.* [17] quantified the $PM_{2.5}$ and PM_{10} in eight different public transportation modes, and the results showed that PM were 3 to 4 times higher in the tram roadway (non-air conditioning) than the train transport mode. Hudda *et al.* [18] determined that particle number reduction take place under recirculation ventilation condition and negatively correlated with increasing vehicle air exchange rate. Fine particles were acted within the same manner, but coarse particles behave opposite and dissimilar for the different weather and traffic conditions [19].

The $PM_{2.5}$, ultrafine PM (particle number), and CO, concentrations were measured in Jakarta, Indonesia, world most substantial pollutant traffic exposure, detected that mean levels are higher in public transports than the car vehicles [20]. For the first time in Vienna, Strasser *et al.* [21] studied the PM_1, $PM_{2.5}$, and PM_{10} concentrations among the transport modes of the subway, tram, bus, car, and bicycle. They reported that $PM_{2.5}$ and PM_1 pollutants were higher levels in subway transport than the bus. Han *et al.* [22] studied the sixty-eight worker's traffic-related occupational exposure $PM_{2.5}$ concentrations in Trujilio, Peru. They noticed that gas station attendants and office workers had experienced the lowest exposure around 64 ±26.5 (mean ± SD) μg/m^3 and 65 ±8.5 μg/m^3, respectively and the bus drivers are exposed the highest concentrations around 161 ±8.9 μg/m^3. Lawrence *et al.* [23] find out that constant active ventilation systems gave better indoor comfort in-hospital patient rooms by experimented with two human loads.

The PM is one of the rising key pollutants in India, which is frequently exceeding the local standard limits in many cities [24]. In India, earlier studies are mostly about particle concentrations in school classrooms, indoor buildings and outdoor environments, and only few studies are available related to in-vehicle air pollution. This study measured the $PM_{2.5}$ and CO_2 levels in different private transport modes under various ventilation conditions in Salem, India. Our study is the first attempt about the investigation of in-vehicle concentrations in Salem, India. This study results will be helpful to the development of in-vehicle air quality strategies in private vehicles.

Experiments

Site descriptions

The study was carried out in the busy routes of Salem city, which is located in the state of Tamil Nadu, India is shown in fig. 1. The geographic location of Salem city lies at latitude 11° 39′ North and longitude 78° 8′ East. The city occupies the sixth largest population among 32 urban agglomerations in the state of Tamil Nadu [25] and covered the surface area about 116 km^2. Nearly thirty-one large scale industries are situated in and around the Salem city. Salem city, also referred to as *Steel City* because of the Salem steel plant, a unit of Steel Authority of India (SAIL), produces a hot-rolled stainless-carbon steel alloy and cold-rolled stainless steel.

The heavy traffic routes during evening peak hours was selected to study the in-vehicle air quality concentrations. The measured routes covered the following traffic signals were Sona College of Technology bus stop, Five Roads, Hasthampatty Roundabout, Thiruvalluvar Sillai, Four Roads, New Bus Stand, Three Roads and Railway Junction, fig. 1. It is covered ~14 km length for a single trip. The reason behind selecting this study routes other than congestion, bridge construction works were undergone in selected routes from the past two years. All vehicle test runs were start and end at the Sona College of Technology bus stop. The study was conducted during a winter month of November 2019 in evening rush periods from 5 p. m. to 6.30 p. m. The traffic flow volume was calculated at Sona College of Technology bus stop using surveillance camera. The summary of vehicles flow per hour on first day of measurement is shown in fig. 2. Experiments were avoided during rainy days and relative humidity > 80%. Approximately 80 to 100 minutes were taken to complete one single trip for all the test runs.

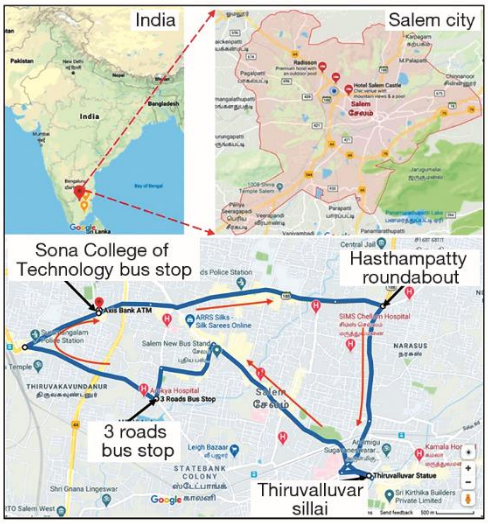

Figure 1. Location of Salem city in India with study routes

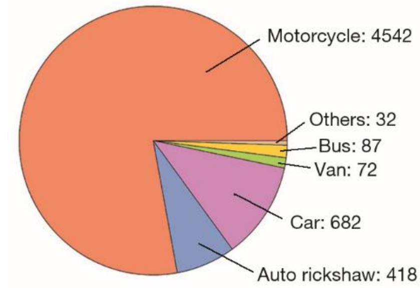

Figure 2. Summary of traffic flow per hour during evening rush hour at Sona College of Technology bus stop

Measurements

Two real-time portable monitoring instruments were used to measure $PM_{2.5}$ and CO_2 concentrations. The IAQ device (model 3007R; Rave Innovations, New Delhi, India) was used to monitor $PM_{2.5}$, and it is functioning on the principle of light scattering method. This IAQ device can measure maximum range up to 500 μg/m^3 with a resolution of 1 μg/m^3. To measure the CO_2 concentration, the Extech instrument (model CO250; FLIR Commercial Systems Inc., USA) was used. It is working on the principle of non-dispersive infrared (NDIR) method, and the instrument can measure maximum capacity of 5000 ppm with a resolution of 1 ppm. Multipoint calibration and field measurements were performed to both instruments before the commencement of experiments. The measurement devices were fixed at breathing level in middle of the cabin. The devices were set to record the data as one-minute time interval and end of each test the values were transferred to the data acquisition system (laptop).

In this study, six different private road transport modes were chosen, such as motorcycle, auto rickshaw, hatchback car, sedan car, sports utility vehicle (SUV) car, and multi utility vehicle (MUV) van. In India, selected study vehicles has been frequently used by private commuters. Typical details of measured private transport modes are given in tab. 1. Car and van transports were right-side driving vehicles. Maximum two passenger loads were concerned in all the test runs including the driver. The second commuter sat back seat on left side of the driver in car and van transports. Out of six private mode of transports, five vehicles

Table 1. Typical details of measured private vehicles

Transport	Air conditioning	Fuel type	Speedometer [km]
Motorcycle	No	Petrol	3796
Auto rickshaw	No	Diesel	11096
Hatchback car	Yes	Petrol	12805
Sedan car	Yes	Petrol	8272
SUV car	Yes	Diesel	22273
MUV van	No	LPG	29320

were chosen from the same local company except auto rickshaw. That renowned local company does not manufacturing the three-wheeled auto rickshaw transport. The rear passenger engaged the both handheld instrument at breathing level in motorcycle transport. Figure 3 shows the schematic diagram of methodology used in this study.

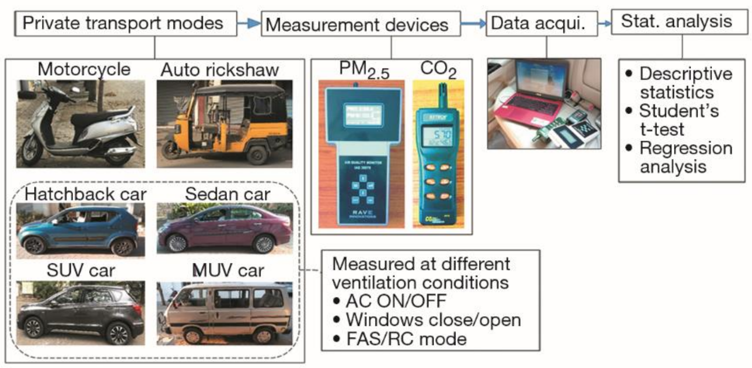

Figure 3. Schematic diagram of experimental set-up; FAS – fresh air supply, RC – recirculation, and AC – air conditioning

Methods

In car and van transports, the doors were opened for ten minutes before commencing the experiments for stabilize the indoor concentrations from outdoor concentrations. Smoke-free drivers were used for all the test runs to avoid the interruption during sampling period. Hence, drivers were fully aware about the target experiments. The cabin air filters were replaced to a new one before commencement of first experiment and the working of HVAC system was also ensured by company manufacturer in car and van transports.

The $PM_{2.5}$ and CO_2 concentrations were measured under four different ventilation conditions in car and van transports:

- AC OFF – Windows open and fresh air supply mode (WO-FAS)
- AC OFF – Windows open and recirculation mode (WO-RC)
- AC ON – Windows closed and fresh air supply mode (WC-FAS)
- AC ON – Windows closed and recirculation mode (WC-RC).

In recent studies also measured the air pollution in car and taxi cabin under above ventilation conditions (two or more) [26-28]. However, for non-air conditioning (NAC) MUV van, concentrations were measured under above ventilation conditions without AC mode:
– AC OFF – Windows open and fresh air supply mode (WO-FAS)
– AC OFF – Windows open and recirculation mode (WO-RC)
– AC OFF – Windows closed and fresh air supply mode (WC-FAS)
– AC OFF – Windows closed and recirculation mode (WC-RC).

The fan speed was set to moderate in all ventilation conditions. The ventilation conditions are inappropriate for the motorcycle and auto rickshaw transports. A total of 18 trips were carried out and three trips on each transport mode on different days. The ventilation conditions were changed in above sequence for every 20 minutes to track the sudden variation of in-vehicle concentrations in car and van transits.

Results and discussion

Influence of particulate matter

The descriptive statistical data of $PM_{2.5}$ for the six transport modes with ventilation conditions is given in tab. 2. The results showed that the lowest mean $PM_{2.5}$ concentration [13.08 ±5.11 μg/m^3 (mean ± SD)] was obtained in hatchback car transport under WC-RC ventilation condition. The WHO and National Ambient Air Quality Standards (NAAQS) set the benchmark for $PM_{2.5}$ concentration is 25 μg/m^3 and 60 μg/m^3, respectively [29, 30].

The obtained $PM_{2.5}$ concentration mean value for an auto rickshaw, sedan, and SUV were 126.21 ±26.42 μg/m^3, 90.68 ±28.82 μg/m^3, and 124.81 ±27.56 μg/m^3, respectively. According to the WHO and NAAQS criteria, auto rickshaw, sedan, and SUV transports mean $PM_{2.5}$ were exceeds the standard limits. The reason behind that this closed vehicles have large opening for air circulation could easily exposed to outdoor concentrations. Accordingly, mean $PM_{2.5}$ concentration in auto rickshaw transport is higher compared to the car cabins. The auto-rickshaw mean PM concentration was 2.21 times higher than the motorcycle transport [31]. The obtained mean PM concentration for the motorcycle was 56.96 ± 29.08 μg/m^3, which exceeds the WHO criterion.

Figure 4 shows the PM concentration for different ventilation conditions in AC car transports. It is observed that sedan and SUV cars were exceeded both standard limits (WHO and NAAQS) in all ventilation condition except WC-RC mode. However, the low volume space of hatchback car PM concentration was below the NAAQS level in all ventilation conditions. Even in WC-RC ventilation mode, the hatchback PM concentration occurred below the WHO (25 μg/m^3) standard limit. PM exposure concentration was lower in windows closed than windows open in AC cars [32]. At AC mode in all car cabins, PM concentrations are consecutively lower, specifically in WC-RC ventilation condition [33]. During recirculation mode, fresh air inlet vents are closed due to that cease the outdoor concentrations intermingle to the indoor car cabins.

Also observed that, when altered ventilation condition from AC ON WC-FAS mode to WC-RC mode, PM concentration was lowered to 2.53, 1.84, and 1.38 times in hatchback, sedan, and SUV transports, respectively. In NAC van, mean PM levels were obtained below NAAQS standards and consistent in all ventilation conditions. Henceforth, AC system plays a significant role in transports for commuter PM exposure level.

The statistical Student's t-test for PM concentration between the private transports is given in tab. 3. For analysis purposes, AC ON windows closed samples were taken for car

Table 2. The $PM_{2.5}$ and CO_2 descriptive statistical data for the six private transport modes

Transport	Ventilation condition	$PM_{2.5}$					CO_2				
		Min. [μgm^{-3}]	Max. [μgm^{-3}]	Mean [μgm^{-3}]	SD [μgm^{-3}]	CV [%]	Min. [ppm]	Max. [ppm]	Mean [ppm]	SD [ppm]	CV [%]
Motorcycle	–	25.3	148.5	56.96	29.08	51.05	379	442	410.95	16.52	4.02
Auto rickshaw	–	82.5	205.7	126.21	26.42	20.93	465	667	541.53	44.22	8.17
Hatchback	WO-FAS	20.9	74.8	47.3	16.51	34.9	397	465	434.45	22.7	5.22
	WO-RC	24.2	71.5	48.84	16.09	32.95	409	466	436.5	16.01	3.67
	WC-FAS	18.7	77	33.18	15.93	47.99	428	667	589.75	77.42	13.13
	WC-RC	7.7	22	13.08	5.11	39.1	628	1728	1183.78	391.68	33.09
Sedan	WO-FAS	88	133.1	112.2	16.86	15.02	538	620	570.73	25.9	4.54
	WO-RC	80.3	140.8	102.18	20.84	20.39	506	561	532.56	15.57	2.92
	WC-FAS	75.9	124.3	95.3	14.46	15.18	566	687	644.36	32.81	5.09
	WC-RC	28.6	84.7	51.59	18.32	35.51	703	1807	1189.2	389.17	32.73
SUV	WO-FAS	89.1	178.2	128.9	25.44	19.74	489	561	532.73	22.85	4.29
	WO-RC	111.1	178.2	142.45	24.8	17.41	496	597	538.1	32.26	6
	WC-FAS	103.4	168.3	127.88	17.34	13.56	509	827	694.75	101.08	14.55
	WC-RC	69.3	129.8	92.54	23.56	23.56	808	1339	1044.13	199.23	19.08
MUV (NAC)	WO-FAS	36.3	67.1	46.44	10.36	22.31	416	500	442.89	26.6	6.01
	WO-RC	46.2	88	56.87	12.93	22.74	390	451	418.3	16.77	4.01
	WC-FAS	47.3	67.1	54.27	6.65	12.25	445	834	651.9	147.91	22.69
	WC-RC	44	73.7	55	9.9	18	894	1802	1297.78	318.24	24.52

Note: Min. – minimum; Max. – maximum; SD – Standard deviation; CV – coefficient of variation; NAC – non air-conditioning; WO-FAS – windows open and fresh air supply mode; WO-RC – windows open and recirculation mode; WC-FAS – windows closed and fresh air supply mode; WC-RC – windows closed and recirculation mode

transports, and AC OFF windows open samples were taken for MUV van. The mentioned ventilation methods are usually preferred by commuters in corresponding vehicles for our ambient condition. It is observed that no statistically significant difference between the vehicles of motorcycle – sedan, motorcycle – MUV, and auto rickshaw – SUV ($p > 0.05$) at a 95% confidence level. It is indicated that motorcycle and sedan commuter were exposing the same level of PM concentration during driving period, similarly for motorcycle – MUV, and auto rickshaw – SUV transports.

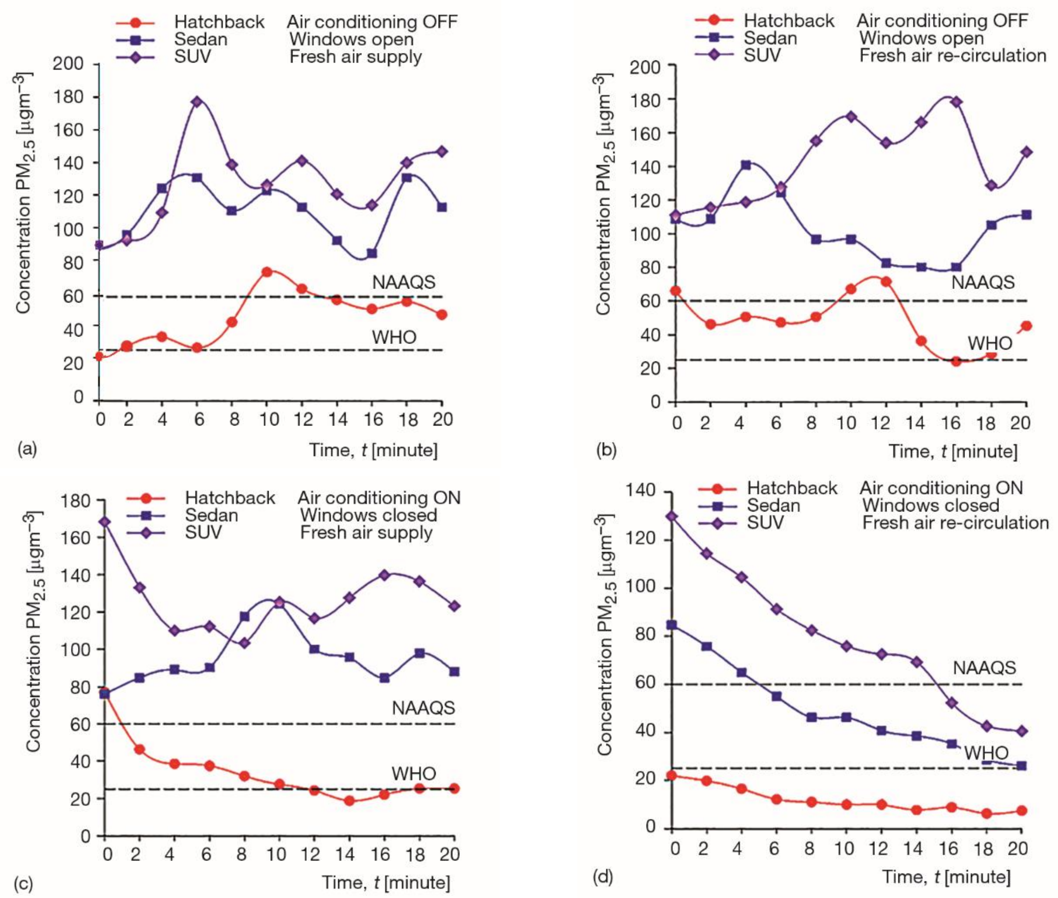

Figure 4. Car transports $PM_{2.5}$ concentration under different ventilation condition

Accumulation of CO_2

Prolong accumulation of CO_2 concentrations inside the vehicle cabin may cause symptoms of headache, fatigue, and dizziness for occupants. Also, CO_2 quantity is the best indicator for either a good or bad air quality in indoor buildings. Similarly, to find the air quality inside the vehicle cabin, CO_2 concentration was measured in six transport modes [8, 9]. However, CO_2 concentration was measured in motorcycle transport to find the quantity of CO_2 commuter exposure level between open and closed vehicles.

Table 2 summarizes the descriptive statistical CO_2 data for the six transport modes with ventilation conditions. The American society of heating, refrigerating, and air-conditioning engineers (ASHRAE) standards advices for healthy indoor building environments, CO_2 level should maintain below 1000 ppm [34]. Henceforth, the same criterion would take into consideration for measured private transports. Accordingly, it was found that all transports mean CO_2 concentrations occurred below the ASHRAE criterion, except AC ON WC-RC ventilation condition. As before mentioned in the ventilation mode of recirculation, the outdoor air inlet vents are closed due to that cease the outdoor concentration intermingle to the indoor of car and van transports. Also, humans are the only primary source to build up indoor

CO_2 concentration. Therefore, CO_2 accumulation was high during the recirculation mode ventilation condition [35]. It indicates the poor in-vehicle air quality during recirculation mode ventilation condition in AC cars, and it raises health symptoms, reduced attention, and impaired performance [36].

Table 3. Student's t-test of $PM_{2.5}$ and CO_2 mean concentrations between the private transport modes

t-test	Transport	$PM_{2.5}$					CO_2				
		Mean [μgm^{-3}]	SD [μgm^{-3}]	MD [μgm^{-3}]	t	p-value	Mean [ppm]	SD [ppm]	MD [ppm]	t	p-value
1	Motorcycle Auto rickshaw	58.2 126.2	29.8 26.4	–68	–10.53	< 0.001	410.1 541.5	16.3 44.2	–131.4	–17.19	< 0.001
2	Motorcycle Hatchback	59.1 24.6	31.4 15.9	34.5	4.5	< 0.001	408.9 844	15.8 394	–435.1	–5.06	< 0.001
3	Motorcycle Sedan	59.1 74.5	31.4 27.5	–15.4	–1.68	0.1*	408.9 904	15.8 383	–495.1	–5.92	< 0.001
4	Motorcycle SUV	60.8 113.7	31.2 25.8	–52.9	–5.84	< 0.001	409.9 835	15.6 227	–425.1	–8.36	< 0.001
5	Motorcycle MUV	64.3 52.3	31 12.9	12	1.53	0.14*	409.4 429.9	15.8 24.8	–20.5	–3.05	0.005
6	Auto rickshaw Hatchback	124.7 24.6	21.6 15.9	100.1	17.09	< 0.001	517.2 844	32.9 394	–326.8	–3.79	0.001
7	Auto rickshaw Sedan	124.7 74.5	21.6 27.5	50.2	6.58	< 0.001	517.2 904	32.9 383	–386.8	–4.61	< 0.001
8	Auto rickshaw SUV	124.9 113.7	22.1 25.8	11.2	1.47	0.15*	515.3 835	32.5 227	–319.7	–6.23	< 0.001
9	Auto rickshaw MUV	125.8 52.3	22.8 12.9	73.5	11.93	< 0.001	514.6 429.9	33.2 24.8	84.7	8.91	< 0.001
10	Hatchback Sedan	24.6 74.5	15.9 27.5	–49.9	–7.2	< 0.001	844 904	394 383	–60	–0.5	0.623*
11	Hatchback SUV	21.9 113.7	10.7 25.8	–91.8	–14.7	< 0.001	865 835	392 227	30	0.3	0.764*
12	Hatchback MUV	19.7 52.3	8.53 12.9	–32.6	–8.92	< 0.001	886 429.9	392 24.8	456.1	5.06	< 0.001
13	Sedan SUV	74.4 113.7	28.2 25.8	–39.3	–4.6	< 0.001	921 835	384 227	86	0.86	0.395*
14	Sedan MUV	73 52.3	29.5 12.9	20.7	2.74	0.012	937 429.9	388 24.8	507.1	5.69	< 0.001
15	SUV MUV	109.6 52.3	23 12.9	57.3	9.23	< 0.001	852 429.9	219 24.8	422.1	8.33	< 0.001

Note: *no significant difference ($p > 0.05$); MD – Mean difference term

Figure 5 shows the CO_2 concentration for different ventilation conditions in AC car transports. It can be seen that the CO_2 level was raised AC ON period. However, during the AC OFF period, the CO_2 concentration was consistent between approximately 400 ppm to 600 ppm in all car transports. Also, noticed that significant drastic changes in CO_2 accumulation during windows closed recirculation mode. It is found that the mean CO_2 concentration increased as 594.03 ±314.26 ppm, 544.84 ±356.36 ppm, and 349.38 ±98.15 ppm from WC-FAS to WC-RC ventilation mode in hatchback, sedan, and SUV, respectively. Increased CO_2 levels in micro-environment vehicles cause reduced heart rate and blood pressure [37].

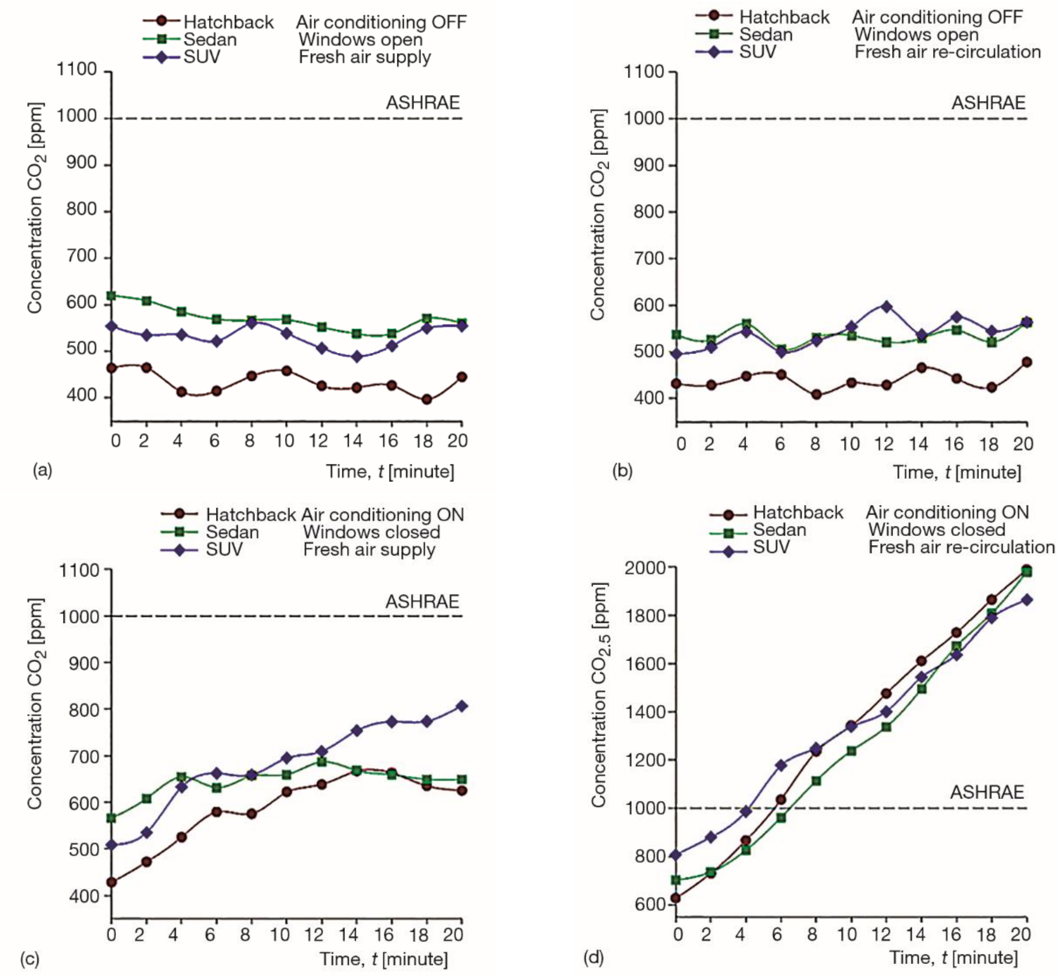

Figure 5. Car transports CO_2 concentration under different ventilation condition

Compared to other closed vehicles, motorcycle commuter do not have any block against the air pollution produced in outdoor and pollution are easily diluted to the atmosphere. Hence, the least mean CO_2 concentration recorded in motorcycle transport was 410.95 ±16.52 ppm. When compared motorcycle transport CO_2 to other vehicles, CO_2 concentrations was 2.88, 2.89, 2.54, and 3.15 times higher in fully closed vehicles of hatchback, sedan, SUV, and MUV transports, respectively under WC-RC ventilation condition. The highest mean CO_2 concentration (1297.78 ±318.24 ppm) was obtained in MUV transport mode under WC-RC ventilation mode, as a result of non-air conditioning condition with windows closed. Partially closed vehicle of auto rickshaw mean CO_2 concentration was 1.32 times higher than the motorcycle.

The Student's t-test for CO_2 concentration between the private transports is given in tab. 3. It was observed that meaningful statistically significant differences among the motorcycle, auto rickshaw, AC cars, and MUV van transports at a 95% confidence interval ($p < 0.05$). Also, there is no significant difference between the hatchback, sedan, and SUV transports (AC cars).

Correlation between $PM_{2.5}$ and CO_2

The relationship between $PM_{2.5}$ and CO_2 concentration was investigated using linear regression analysis for all the transport modes. The results showed that poor correlation between $PM_{2.5}$ and CO_2 concentration for motorcycle (R^2 = 0.0059), auto rickshaw (R^2 = 0.020), and NAC MUV (R^2 = 0.1215) transports is shown in fig. 6. As expected, weak correlation was obtained for open vehicle motorcycle transport, as a result of no barrier like in closed vehicles (car or van) and pollutants easily diluted to the atmosphere. Partially closed auto rickshaw transport also have poor correlation because of large opening in vehicle cabin. For MUV van, windows open samples were taken for regression analysis. Poor correlation was obtained for van transport, because pollutants are easily diluted inside the van cabin due to air flow passes from outdoor to indoor through open windows.

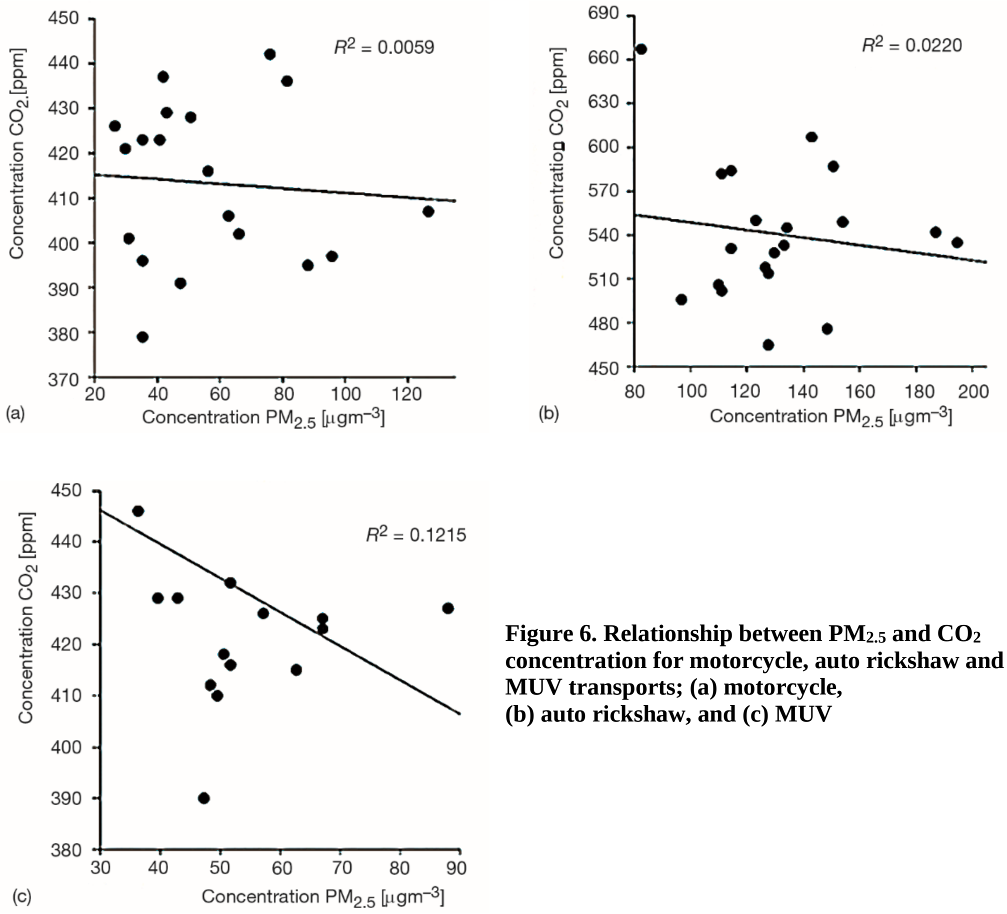

Figure 6. Relationship between $PM_{2.5}$ and CO_2 concentration for motorcycle, auto rickshaw and MUV transports; (a) motorcycle, (b) auto rickshaw, and (c) MUV

However, there is a strong negative correlation between $PM_{2.5}$ and CO_2 concentration in car transports under AC ON ventilation condition is shown in fig. 7. The obtained R^2

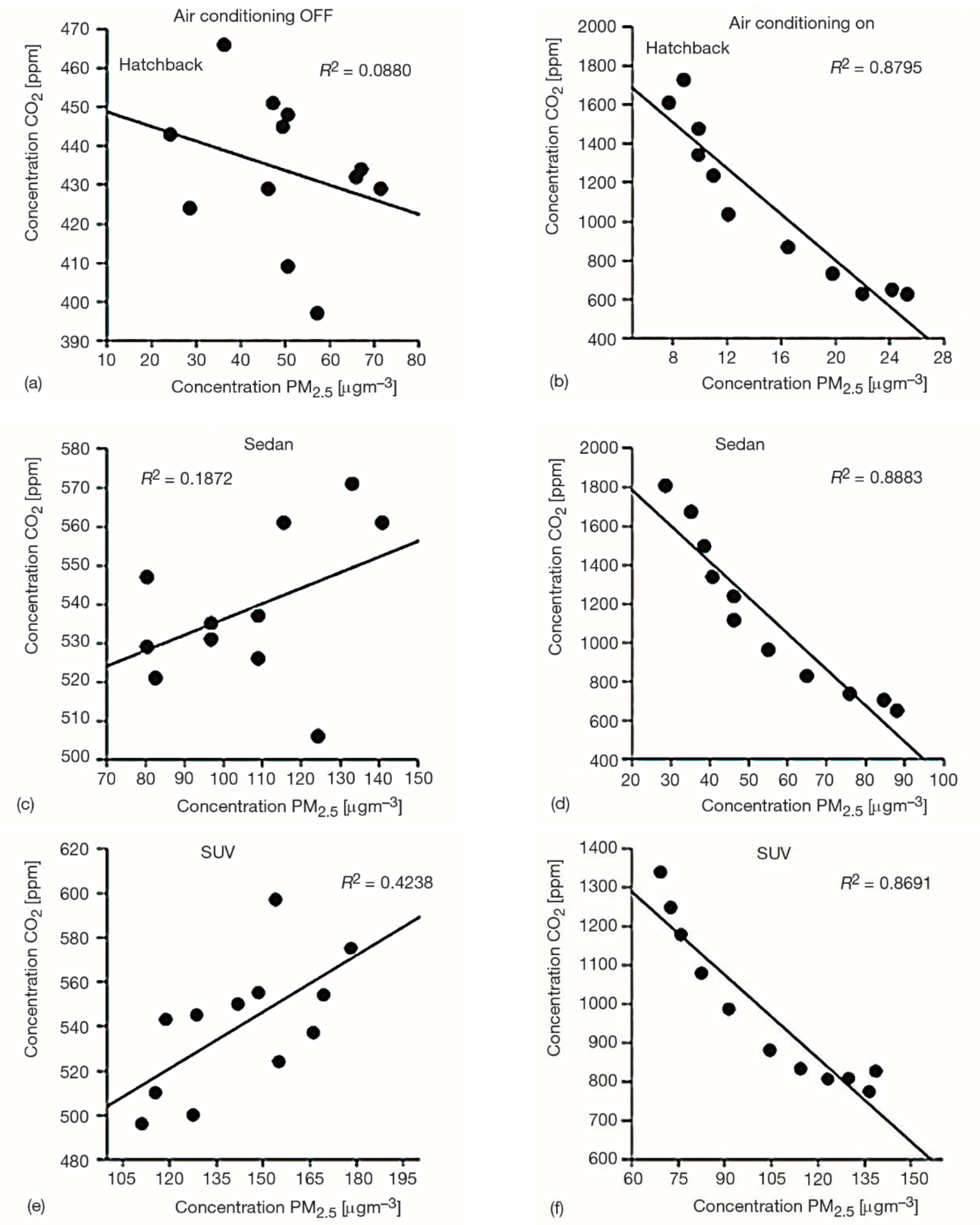

Figure 7. Relationship between $PM_{2.5}$ and CO_2 concentration during air-conditioning OFF and ON position in car transports

value for hatchback, sedan, and SUV car transports was 0.8795, 0.8883, and 0.8691, respectively under AC ON ventilation mode. Also, results showed a poor correlation between $PM_{2.5}$ and CO_2 concentration under AC OFF condition in car transports. Therefore, it shows that the air conditioning part plays a significant role for both $PM_{2.5}$ and CO_2 concentrations in AC transports. In AC cars, $PM_{2.5}$ levels was decreased in AC ON position under WC-RC ventilation mode, but CO_2 levels are raised drastically [38]. To expose under acceptable limit of both PM (60 μg/m^3) and CO_2 (1000 ppm) concentrations in AC cars, commuters' are recommend to travel under WC-FAS ventilation condition.

Conclusion

In this study, measured the in-vehicle air quality concentrations of $PM_{2.5}$ and CO_2 in six private transport modes. Also, assessed the $PM_{2.5}$ and CO_2 concentrations under four different ventilation conditions in car and van vehicles. The results showed that the least $PM_{2.5}$ concentration occurred in hatchback car under AC ON WC-RC ventilation condition. Mean $PM_{2.5}$ pollutant in auto rickshaw, sedan, and SUV transports were exceeds both NAAQS and WHO standard limits. The PM concentrations was lessened to 2.53, 1.84, and 1.38 times in hatchback, sedan, and SUV transports, respectively, when changed ventilation condition from windows open to windows closed (AC ON). In contrast, for car transports, CO_2 concentration were higher in AC ON recirculation mode ventilation condition. Mean CO_2 concentrations in hatchback, sedan, and SUV were elevated as 594.03 ±314.26 ppm, 544.84 ±356.36 ppm, and 349.38 ±98.15 ppm, respectively, when ventilation condition altered from WC-FAS to WC-RC. The student's t-test showed the meaningful statistical significant difference ($p < 0.05$) among the motorcycle, auto rickshaw, AC cars, and MUV van for CO_2 concentration. In this study, found that the car commuter exposed to $PM_{2.5}$ and CO_2 concentrations below the standard limit of NAAQS (< 60 μg/m^3) and ASHRAE (<1000 ppm), respectively in AC ON position under windows closed fresh air supply (FAS) mode. Therefore, recommend the AC car commuters operate the AC ventilation system in FAS mode during driving to expose concentrations under acceptable limits.

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