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Investigation of Indoor Air Quality Characteristics in Automotive Compartments

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Abreast: Indoor air quality is an indicator level of human comfort confined with thermal conditions. This study mainly focuses on to predict the indoor air quality in inside car cabin at the time of traffic. Three different car has been used were SUV, sedan and hatchback types, mainly chosen is to differentiate the vehicle inside space diversely. To measure PM 2.5, PM 10, CO2, temperature and RH were recorded by using IAQ monitor with Data Acquisition (DAQ). At the time of measurement, four different cases are concern is window open (WO), window half open (WHO), window close (WC) and air conditioning with window close (ACWC). SUV achieved a better low temperature of 30ºC in ACWC and hatchback has a more temperature of 42.8ºC in WC due to vehicle space difference and severe concentrations of CO2 and particulate matter. RH are increased by the way of temperature get increased in indoor cabin. Hatchback indoor cabin rapidly generate CO2 emission, because indoor spaces is congested compared to other two cars. Windows and indoor spaces more in SUV, so outdoor pollutant easily get exposure to indoor pollutant while in the cases of window open (WO) and window half open (WHO).

***Index Terms*: automotive, car cabin, IAQ, pollutant.**

I. INTRODUCTION

Human comfort of indoor occupied humans in vehicle has become more important due to increasing necessary of comfortable living space. Indoor air quality is a parameter of physical factors to determine the human comfort. Typically commuters spend 5.5% of time spend inside a car cabin, it could expose to air quality. Comparatively to the building, it seems only few researchers are contribute in the field of IAQ, especially in an inside car cabin environment. This study proposes the important factor about IAQ by comparative study of three different type of car cabin.

Bin Xu et al., reviewed more than 90 studies across over 10 country and stated that air recirculation with high efficiency air filter is the most effective compare to lower air pollutant concentrations [1]. Joanna Faber et al., reviewed that synthetic material increase more VOCs in new vehicle indirectly proportional to their vehicle age [2]. Anna Barbara Janica et al., indicated that need of research continuation in material science toxicology aspect due to VOCs and benzene concentration exposure is not safety in high class of vehicle. Recent emerging of advanced materials in textiles, plastics, foam, solvents in glues, paints, lacquers and car cosmetics are internal sources of pollution could possible to affect the air quality [3].

Joanna Faber et al., calculated total VOCs concentration from nine new vehicles is ranged from 1.5 mg/m^3 to 2.1 mg/m^3 and 200 different organic compounds were detected in vehicles [4]. Anna Golda Kopek et al., concluded that total no of 330 VOCs were identified inside the four new tested vehicle by using thermal desorption and GCMS/FID [5]. L.D.Knibbs et al., estimate the pollutant exposure inside the vehicle cabin in six passenger car at three ranging speeds and four different ventilation settings. Proposed that air infiltration into the cabin was between 1 and 33.1 air changes per hour (ACH) at 60 km/hr speed and between 2.6 and 47.3 ACH at 110 km/hr [6]. M. Ozgun Korukcu et al., investigated that in the heating period CO_2 emissions for two sedentary persons have 1.24 times greater than that of one sedentary persons [7].

M.Kilic et al., recommended that an advanced climate control system may to reduce the energy usage for the cooling of a vehicle cabin [8]. Joanna Faber et al., examined five new vehicles and stated that concentrations of identical VOCs and three main group of compounds (aliphatic, aromatic and cycloalkanes), as well as 18 target compounds and 10 main hydrocarbons are presented [9]. Jan Pokorny et al., developed a new computational software Virtual Testing Stand for the transient prediction of environment and heat load in car cabin [10]. Daniel Muller et al., indoor car quality may be improved by windows opening, or accurate usage of fans or automated air conditioning systems [11].

L. Abi-Eser et al., conducted experiments on six car with different ages to measure $PM_{2.5}$ and carbon monoxide (CO) in both inside and outside of the vehicle with different ventilation mode, one window half opened, fresh air intake and air recirculation inside cabin on commercial residential area and highway. Concluded that temperature and humidity difference also affected CO IO ratios [12]. Yulong Yan et al., studied VOCs, carbon mono-oxide (CO) and PM10 in six different car park and estimated that 3.73×10^{-4} and 5.60×10^{-6}, respectively cancer risks for car park staff and casual parking users, indicating definite and possible risks [13]. M.J.Mendell et al., proposed that reducing school attendance

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Table I Outdoor Measured Parameter of Tested Cars

S. No	Car Type	$PM_{2.5}$ ($\mu g/m^3$)		PM_{10} ($\mu g/m^3$)		CO_2 (ppm)		Temperature (°C)		RH (%)	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
1	SUV	90.2	113.3	218.5	269.1	379	523	30.7	45.1	18.4	55.9
2	Sedan	91.3	116.8	202.4	241.5	380	456	31.1	44.1	20.8	56.4
3	Hatchback	94.6	117.7	188.7	246.1	382	659	30	45.8	17.9	51.8

Due to present higher indoor concentrations of NO2 and low ventilation rates decreased the performance of students in indoor environments of school [14]. You Ke wei et al., predicted VOCs for one new vehicle and two old vehicle is 4940 $\mu g/m^3$, 1240 $\mu g/m^3$ and 132 $\mu g/m^3$ by using the Thermodesorber-Gas Chromatograph/Mass Spectrometer (TD-GC/MS) [15]. P.Thirumal et al., Gray Relational Analysis (GRA) and Response Surface Methodology (RSM) optimization techniques are used in indoor air quality characteristics with varying human load, fresh air supply and air velocity [16]. Andy T. Chan et al., in fresh air ventilation mode the indoor–outdoor air quality (IO) ratios is approximately 0.5 to 3 and NO concentration varying from 0.5 to 5 for naturally ventilated were obtained at travel from highway to rural area in light good vehicle [17].

II. EXPERIMENTAL PROCEDURE

A. Experiment Environment

All the three tested cars are measured in identical place, which is located nearby moderate traffic state road, karaikudi (latitude 10.09052 ° N, longitude 78.78145 ° E), state of Tamilnadu, India, aerial view of experiment location in Fig. 1.

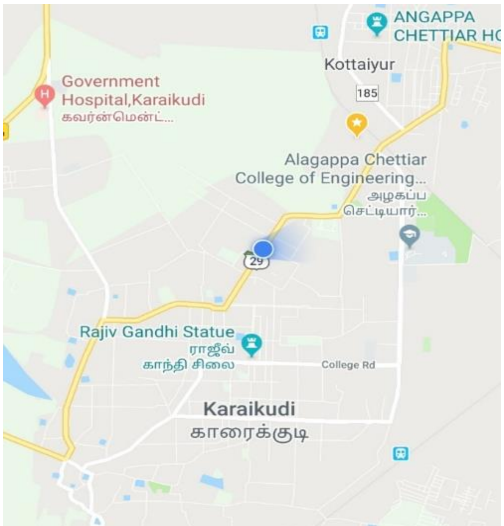

Fig. 1 Aerial View of Experiment Location

The vehicles are simultaneously moving on the road nearby tested car approximately 2100/hr. The experiment was taken for three days successively with each tested car per day. CO_2 meter with humidity and thermometer of Extech instruments is used for measuring outdoor parameters equivalent to indoor time represented in Table I.

B. Experimental Equipment's

In this research there are three type of car is carried out SUV, sedan and hatchback, which is shown in Fig. 2. Mainly chosen these cars to differentiate vehicle indoor space drastically. The specifications of three cars were mentioned in Table II. To measure indoor parameters are PM2.5, PM10, CO2, temperature and relative humidity by using IAQ monitor of Rave innovations. Technical details of IAQ monitor is specified in Table III. IAQ monitor with Data Acquisition system (DAQ) in Fig. 3.

(a) SUV

(b) Sedan

(c) Hatchback

Fig. 2 Experimental Tested Cars

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Table II Specifications of Tested Cars

S. No	Specifications	SUV	Sedan	Hatchback
1	Length (mm)	4430	4830	3690
2	Width (mm)	1817	1820	1665
3	Height (mm)	1975	1465	1485
4	Seating Capacity	7	5	5
5	Displacement (cc)	2523	2354	1405
6	Fuel Type	Diesel	Petrol	Diesel

C. Methodology

The period of testing the car's front side is placed to the direction of the sun azimuth angle is 56.6º and elevation angle is 189.56º. Before done the experiment, cars are soaked to 15 minutes with all the door opening for dilute indoor pollutant to outdoor pollutant. Each and every trail the foresaid method was followed. The measurement was taken in the middle of vehicle space in all the conditions and tested time is 20 min per trail. Two sedentary persons are consistent respectively in all experiments as a driver and back left side passenger. Engine is running in all cases, it will helpful to track down the air quality in indoor vehicle at traffic time. For the air conditioning situation the fresh air supply is established and full fan speed is introduced instead of recirculation mode.

The following cases are followed for each tested car:

1) Case 1: Window Open (WO)
2) Case 2: Window Half Open (WHO)
3) Case 3: Window Close (WC)
4) Case 4: Air Conditioning with Window Close (ACWC)

Table III Technical Details of IAQ Monitor

S. No	IAQ3007R	Specifications		
1	Principle	Light Scattering for PM_{10} and $PM_{2.5}$ NDIR for CO_2		
2	Range	PM_{10}	$PM_{2.5}$	CO_2
		0 – 1000 $\mu g/m^3$	0 – 700 $\mu g/m^3$	400 – 2500 ppm
3	Resolution	PM_{10}	$PM_{2.5}$	CO_2
		1 $\mu g/m^3$	1 $\mu g/m^3$	10 ppm
4	Temperature	0 – 50 ° C		
5	Relative humidity	0 – 95 %		

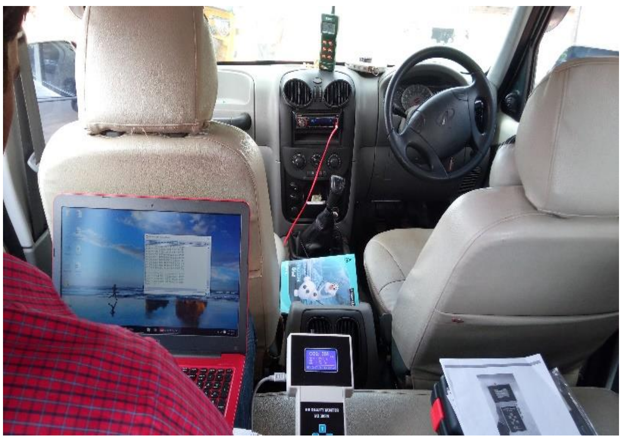

Fig. 3 IAQ Monitor with DAQ

III. RESULTS AND DISCUSSION

A. Effect of Temperature

As per guidelines of ASHRAE Standard 55-2013, human comfort temperature lies between 20ºC to 28ºC. From Fig. 4 represents the mean value of temperatures for all the cases. In Table IV, Contrary to the tested cars, SUV achieved a better low temperature of 30ºC in ACWC and hatchback has a more temperature of 42.8ºC in WC due to vehicle space difference and severe concentrations of CO2 and particulate matter. The maximum obtained high temperature difference was approximately 5ºC between SUV and hatchback in WO case.

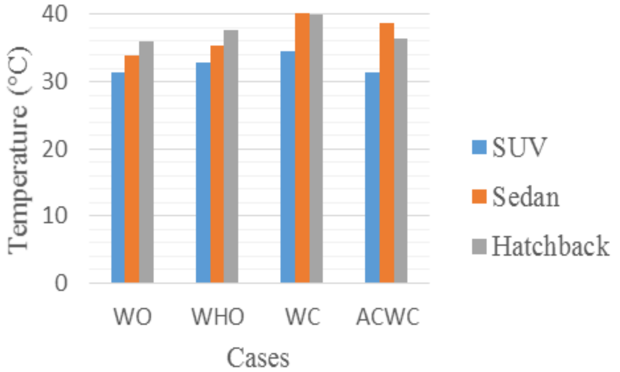

Fig. 4 Average Temperatures for all the Cases

B. Effect of RH

ASHRAE Standards recommends that less than 65 % of relative humidity in occupied spaces in summer. Average results of RH for the three car type represents in Fig. 5. WC of SUV took a maximum RH of 70%, compare to other two cars it feel too hot. Very low humidity of 35% is obtained in ACWC for hatchback. RH are increased by the way of temperature get increased in indoor cabin.

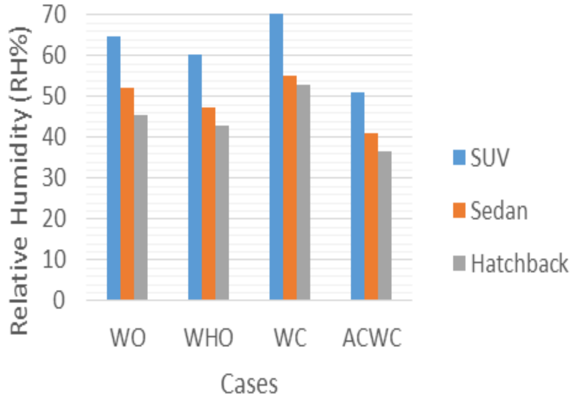

Fig. 5 Average RH for all the cases

C. Effect of CO_2

ASHRAE standard commended of CO_2 for indoor spaces is 1000 ppm. In all the cases of CO_2 emission is gradually increased with indirectly to vehicle spaces. Mainly in WC case are traversed above 1000 ppm in a particular time as SUV in 7 min of 1145 ppm, sedan in 6 min of 1054 ppm and hatchback in 4 min of 1134 ppm.

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Therefore hatchback compartment rapidly generate CO_2 emission, Because indoor spaces is congested compared to other two cars. Fig. 6 represents the average CO_2 emission of tested cars. Air conditioned closed cabin achieved best thermal comfort with dilution of carbon dioxide.

D. Effect of $PM_{2.5}$

Compare to the SUV and sedan, hatchback $PM_{2.5}$ has low concentration is in the range of 83.6 $\mu g/m^3$ to 113.3 $\mu g/m^3$. Fig.7 represents the average $PM_{2.5}$ of all tested cars. The maximum obtained $PM_{2.5}$ concentration in WHO is 138.6 $\mu g/m^3$ in SUV.

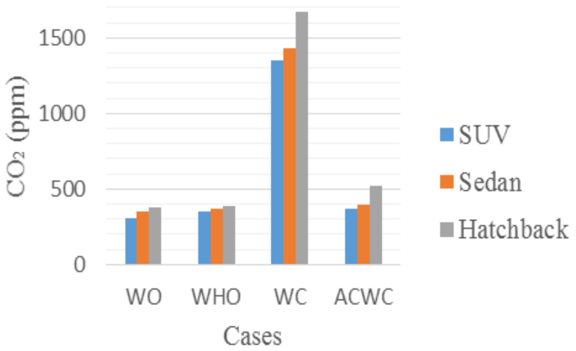

Fig. 6 Average CO2 Emission for all the Cases

Table IV Maximum and Minimum of Measured IAQ Parameters

IAQ parameters	Cases		SUV	Sedan	Hatch -back
Temperature (ºC)	WO	Min	30.8	33.4	35.4
		Max	31.8	34.3	36.5
	WHO	Min	32.3	34	36.6
		Max	33.6	36.6	39.1
	WC	Min	33	37.2	36.7
		Max	35.4	42.7	42.8
	AC WC	Min	30	38	34.3
		Max	32.8	40.4	38.9
Relative Humidity (%)	WO	Min	64	49	45
		Max	67	55	46
	WHO	Min	59	43	41
		Max	62	53	44
	WC	Min	65	48	43
		Max	73	57	57
	AC WC	Min	46	37	35
		Max	55	43	39
CO_2 (ppm)	WO	Min	234	308	331
		Max	361	391	452
	WHO	Min	264	316	349
		Max	437	438	410
	WC	Min	213	279	354
		Max	2080	2080	2080
	AC WC	Min	337	287	428
		Max	427	463	647
$PM_{2.5}$ (µg/m³)	WO	Min	100	100.1	83.6
		Max	118.8	130.9	113.3
	WHO	Min	106.7	86.9	89.1
		Max	138.6	116.6	101.2
	WC	Min	96.8	85.8	88
		Max	112.2	111.1	106.7
	AC WC	Min	95.7	69.3	85.8
		Max	113.3	86.9	110
PM_{10} (µg/m³)	WO	Min	209.3	209.3	174.8
		Max	280.6	253	236.9
	WHO	Min	227.7	181.7	184
		Max	296.7	243.8	211.6
	WC	Min	209.3	179.4	184
		Max	236.9	232.3	223.1
	AC WC	Min	200.1	144.9	179.4
		Max	236.9	181.7	230

Fig. 7 Average $PM_{2.5}$ for all the cases

E. Effect of PM_{10}

The particulate matter of PM_{10} is high in all cases except WO. The maximum 247 $\mu g/m^3$ of high concentration is obtained in WO. Fig. 8 represents the average PM_{10} for all the cases. Windows and indoor spaces more in SUV, so outdoor pollutant easily get exposure to indoor pollutant while in the cases of WO and WHO.

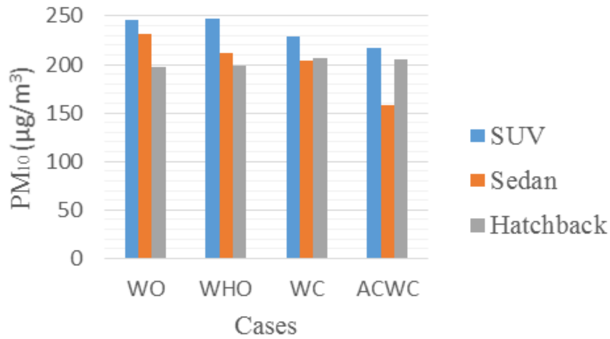

Fig. 8 Average PM10 for all the cases

IV. CONCLUSION

Indoor environmental quality is a good indicator of the performance of car cabin, being linked to the comfort and health conditions. This study mainly focuses on to predict the indoor air quality in inside car cabin at the time of traffic. To measure PM 2.5, PM 10, CO2, temperature and RH were recorded by using IAQ monitor with Data Acquisition (DAQ). At the time of measurement, four different cases are concern is window open, window half open, window fully close and air conditioning with window fully close for all cars. SUV achieved a better low temperature of 30ºC in ACWC. And hatchback has a more temperature of 42.8ºC in WC due to vehicle space difference and severe concentrations of CO2 and particulate matter.

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RH are increased by the way of temperature get increased in indoor cabin. Hatchback indoor cabin rapidly generate CO2 emission, because the indoor spaces is congested compared to other two cars. Windows and indoor spaces more in SUV, so outdoor pollutant easily get exposure to indoor pollutant while in the cases of WO and WHO.

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