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Full Length Research Paper

Transient effects of heater on CO_2 emissions in an automobile

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This study investigates the transient effects of heater on CO_2 emissions in an automobile. In the evaluation of comfort in automobiles, in general temperature, humidity and air velocity measurements are taken. It is also important to assess the CO_2 emission of the air inside a car. The aim of this study was to measure the CO_2 emissions with different occupant numbers, different air velocities with different heating options. All experiments were carried out in a Fiat Albea 2005, during winter months. CO_2 emissions and the air temperature values were measured from the breathing zone of the driver. It was observed that CO_2 emissions increased rapidly in the first 10 min and stayed stable after 15 min for air-recirculation mode and CO_2 emissions were significantly higher than that of air intake from the outside environment, which is 4.65 times of the air intake mode by mean values. Occupant numbers have effect on CO_2 emissions, and two sedentary persons have 1.24 times greater CO_2 emissions than that of one sedentary person without air-condition mode. Full heating period also affects the CO_2 emissions in a car, and 20 min of heating period have 1.12 times greater CO_2 emissions than that of 10 min of full heating period. It can be suggested that CO_2 emissions must be accounted for the driving safety parameters in the cars.

Key words: Air-condition, CO_2 emission, passenger comfort.

INTRODUCTION

The causes of accidents are mostly driver grounded. The importance to maintain the driving safety inside air of a car must be comfortable. It is also difficult to maintain a comfortable air-quality for individuals because of the complexity of parameters such as temperature, humidity and gases like CO and CO_2. One of the major causes of accidents is inattention of the driver. With high CO_2 emissions and temperature values driver's awareness decreases or the driver may begin to fall asleep. According to Maycock (1997), company car drivers were found to have a particularly high probability of falling asleep and have a relatively high accident frequency.

This paper presents the results of CO_2 emissions inside a car with different air-condition modes.

Carbon dioxide is a colourless, odourless gas that humans continuously exhale CO_2 formed in the body during metabolic processes and, where fuel is not being burnt, these emissions comprise the greatest contribution to indoor concentrations (Wanner, 1993). ASHRAE 62.1 explains the standards and procedures for indoor air-quality assessment, and widely used to evaluate the air quality for indoor environments. For a sedentary person, the CO_2 generation rate is 0.31 L/min, and about 7.5 L/s per person of outdoor air will dilute odors from human bioeffluents to levels that will satisfy a substantial majority (around 80%) of visitors entering to a space. According to ASHRAE 62.1, maintaining a steady-state of CO_2 concentration in a space not greater than about 700 ppm (6.89e-4 liters of CO_2 per liter of air) above outdoor air levels will indicate that a substantial majority of visitors entering a space will be satisfied with respect to human bioeffluents. CO_2 concentrations in acceptable outdoor air typically fluctuate between 300 and 500 ppm. Typical indoor CO_2 concentrations range between 700 and 2000 ppm but can exceed 3000 ppm during the use of

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Table 1. Accuracy of the equipments.

Parameter	Interval	Tolerance
CO_2 (ppm)	0–9999	± 5
Air velocity (m/s)	0–10	± 0.04
Relative humidity (%)	0–100	± 0.1
Temperature (°C)	- 20–70	± 0.4

Table 2. Mass flow rates.

Mass flow rate	Values (kg/s)
$\dot{m}_0$	0
$\dot{m}_1$	0.0097
$\dot{m}_2$	0.0172
$\dot{m}_3$	0.0204
$\dot{m}_4$	0.033
$\dot{m}_5$	0.055

unvented appliances (Arashidani et al., 1996). At moderate concentrations that are between 1000 and 1200 ppm, CO_2 can cause feelings of stuffiness and discomfort (Pettenfoker, 1858). Griffiths and Eftekhari (2008) studied the control of CO_2 in a naturally ventilated classroom and found that teachers and pupils control the ventilation into the classrooms by thermal comfort rather than indoor air quality. Papakonstantinou et al. (2001) obtained a numerical simulation of CO_2 dispersion in an auditorium both with air induction and abduction systems and also with different occupant numbers.

There are too many studies and standards about indoor air quality but there is no standard for automobile cabins therefore indoor air quality standards can also be applied with a little fluctuation to the vehicle air quality perceptions. Cheng et al. (2006) investigated the air quality in a commercial truck cabin during a two month monitoring period. They measured the CO, CO_2 and NO_2 emissions and found that the results were lower than their respective recommended levels. Chan and Chung (2003) investigated the indoor-outdoor air quality relationships in vehicle and studied effect of driving environment and ventilation modes. In their study, they used a light-good vehicle. The indoor and outdoor NO, NO_2 and CO concentrations and indoor-outdoor ratio vary not only for the ventilation mode but also depends on the driving environment. Galatsis et al. (2000) investigated the effect of the air inside a vehicle on fatigue and accident prevention was carried out. The idea is to have some of the alarm system based on continuous monitoring of oxygen and carbon monoxide that can alert the driver or trigger some automatic procedure such as opening the windows and stopping the engine to avoid health risks to car occupants.

METHODOLOGY

The experiments were carried out in a parked FIAT Albea 2005 outside. To prevent the possible accidents, damages on experimental equipments and unmeasured effects on the traffic the test car was not moved. The vents were located on the plane and side, which have 3 levels of air velocity. The data were collected during the winter months of December, January and February and there are three healthy male subjects chosen. The mean (SD) characteristics of the participants were as follows: age = 25 (2.64) yr, height = 176 (10) cm, weight = 79.67 (15.5) kg and body mass index = 25.61 (2.42) kg/m². Before the experiments, the subjects were briefed about the aim of the study, and procedure of the experiments.

The indoor CO_2 emissions and the air velocity measurements were made by a Testo 350 M/XL 454 probe in every 10 seconds. Accuracy and the measuring range of the equipments were presented in Table 1.

The mean outside CO_2 emission was measured 483 ppm (14.58), and all the other obtained measurements are subtracted from this outside CO_2 emission. The participants wore winter casual clothes, which is approximately 1 clo and level of metabolic activity was taken 1 met for a sedentary person (ISO 9920, 1993). All of the subjects stayed 30 min in the car because after 30 min of heating period, temperature values reached the steady state conditions. There are six different mass flow rates ($\dot{m}$), which values are represented in Table 2.

Effect of occupant number

To investigate the effect of occupant number, in the first case only one person set in the car without heater mode ($\dot{m}_0$) and in the second case, 2 persons set in the car without heater mode ($\dot{m}_0$) for a 30 min period of time. An independent sample T-test was performed to investigate the differences between these cases.

Effect of air circulation mode

There are two possible cases for air circulation in the car, the first is to re-circulate the air inside the car and the second is air intake from the outdoor environment. Both cases have different flow rates. In air recirculation mode, mass flow rates are $\dot{m}_1$, $\dot{m}_3$ and $\dot{m}_4$ respectively. On the other hand, in air intake mode there are five different mass flow rates; $\dot{m}_1$, $\dot{m}_2$, $\dot{m}_3$, $\dot{m}_4$ and $\dot{m}_5$ respectively. One person set in the car for 30 min for both cases. A two-way analysis of variance (ANOVA) applied to investigate the

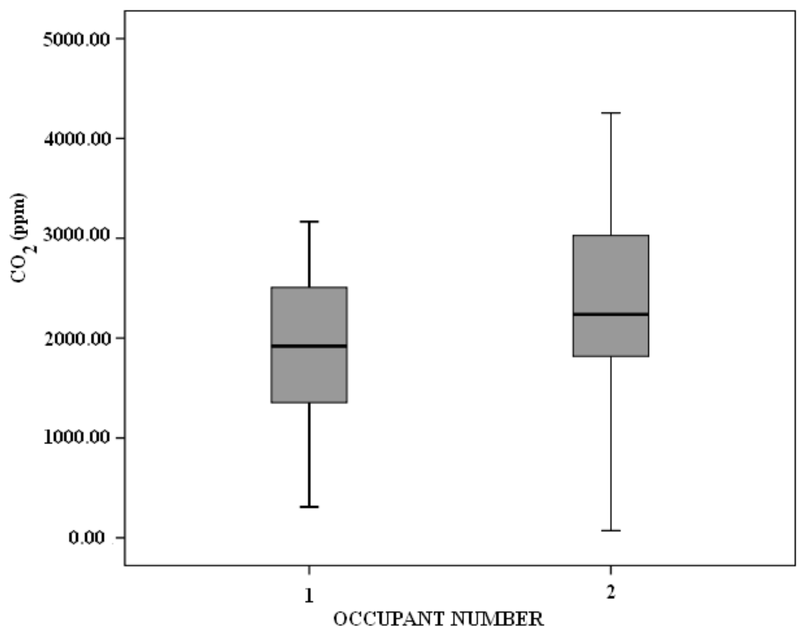

Figure 1. Mean CO_2 emissions for occupant numbers.

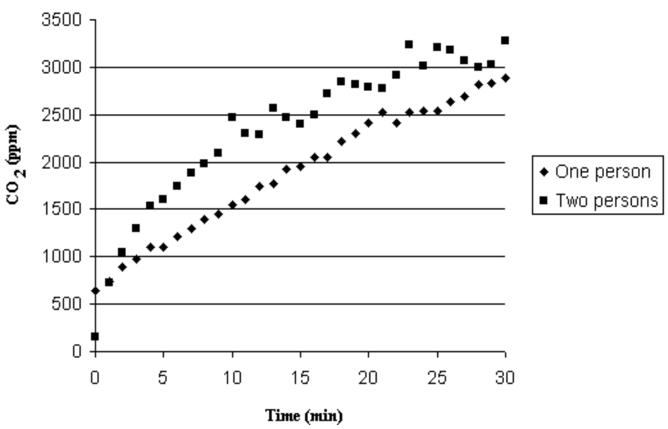

Figure 2. Change of CO_2 emissions with occupant numbers and time.

differences between mass flow rates, which have time and mass flow rate factors for each case.

Effect of heating period

In general, the driver adjusts the heater for his own preference; therefore, mass flow rates change within the heating period. Two cases were investigated to determine the significance between heating periods. In the first case, heater was adjusted to the full mode for the first 20 min and then adjusted to the half mode for the next 10 min, and in the second case, the heater adjusted vice versa. There are five different mass flow rates $\dot{m}_1$, $\dot{m}_2$, $\dot{m}_3$, $\dot{m}_4$ and $\dot{m}_5$ respectively. An independent sample T-test was performed to investigate the differences between these cases and, two-way analysis of variance (ANOVA) applied to investigate the differences between mass flow rates, which have time and mass flow rate factors for each case.

Comparison of all cases

All the possible cases during the experiments; occupant number, air circulation mode and heating period time were investigated with a 3-way analysis of variance (ANOVA), which has 3 factor levels case, mass flow rates and time respectively.

RESULTS

Effect of occupant number

Mean (and standard error) plots of CO_2 emissions for occupant numbers are given in Figure 1. As expected, in 2 occupant number condition CO_2 emissions are higher than that of one occupant. Results of the independent sample t-Test between two cases show that the means between cases are significantly different (F = 6.42, p < 0.05). Figure 2 represents the change of CO_2 emissions with time and occupant numbers. CO_2 emissions always increase with time for both cases.

Effect of air circulation mode

Mean (and standard error) plots of CO_2 emissions for air circulation modes are given in Figure 3. In air-recirculation mode, CO_2 emissions are higher than that of air-intake mode. Results of the independent sample T-test between two cases show that the means between

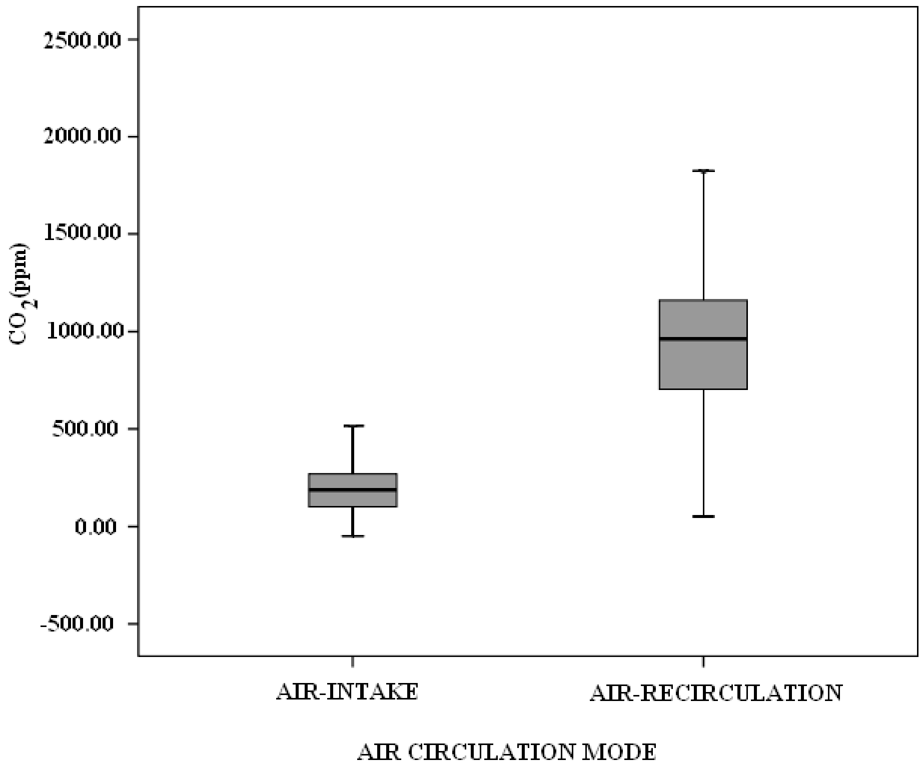

Figure 3. Mean CO_2 emissions for air circulation modes.

Table 3. Student-Newman Keul's Test of mass flow rates for air-recirculation mode.

Mass flow rate	N	Subset		
		1	2	3
$\dot{m}_4$	261	820.329		
$\dot{m}_3$	217		947.631	
$\dot{m}_1$	217			1132.95

cases are significantly different (F = 237.12, p < 0.05). Time was not significant (F_{TIME} [30, 29.272] =0.98, p > 0.05) in variance analysis (ANOVA) between air circulation modes.

There are two analysis of variance (ANOVA) made both for the air-recirculation mode and also for the air-intake mode. For air-recirculation mode, mass flow rates and time factors were significant (F_{MFR} [2, 57.514] =131.201, p < 0.05) and (F_{TIME} [30, 59.534] =29.998, p < 0.05) but on the other hand, mass flow rate and time interaction was not significant ($F_{MFRxTIME}$ [58, 604] =0.658, p > 0.05).

Table 3 shows the results of Student Newman Keul's Test. As seen on Table 3, there are 3 subgroups for air-recirculation mode. Figure 4 represents the change of CO_2 emissions with time and air circulation modes. In air-recirculation mode after 15 min, CO_2 emissions stays stable, on the other hand in air-intake mode, CO_2 emissions do not change as much as in the air-recirculation mode.

Figure 5 represents the change of temperature inside the cabin with time and air-circulation modes. In both air-circulation modes temperature values increase with time. Figure 6 represents the change of CO_2 emissions with time and mass low rates for the air-recirculation mode. CO_2 emission increases rapidly in the first 10 min and then stays stable after 15 min. For air-intake mode, mass flow rates and time factors were significant (F_{MFR} [4, 133.131] =62.283, p < 0.05) and (F_{TIME} [30, 52.697] =2.991, p < 0.05) but on the other hand, mass flow rate and time interaction was not significant ($F_{MFRxTIME}$ [78, 476] =0.355, p > 0.05). Table 4 shows the results of Student Newman Keul's Test. As seen on Table 4, there are 3 subgroups for air-recirculation mode.

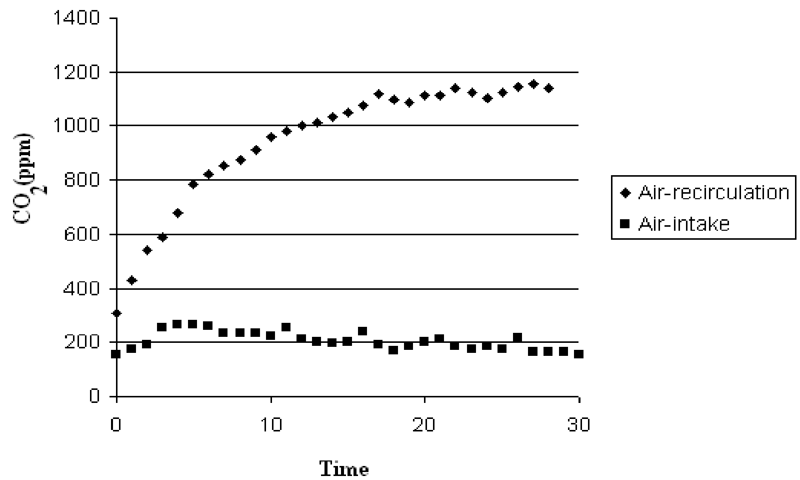

Figure 4. Change of CO_2 emissions with time and air circulation modes.

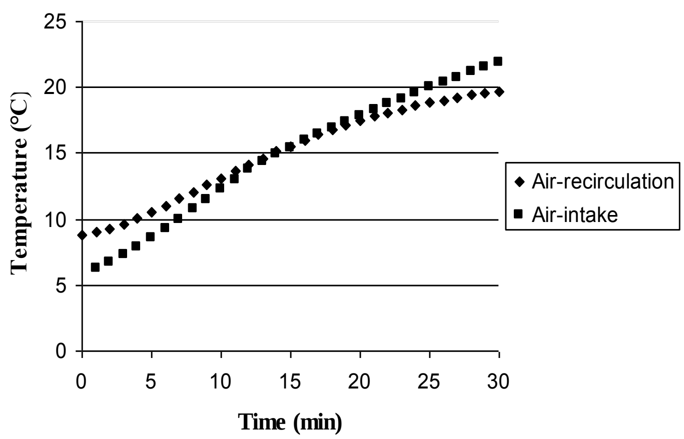

Figure 5. Change of cabin temperature with time and air-circulation modes.

Effect of heating period

Mean (and standard error) plots of CO_2 emissions for heating period times are given in Figure 7. In 20 min heating period of time CO_2 emissions are higher than that of 10 min heating period. Results of the independent sample T-test between two cases show that the means between cases are significantly different (F = 29.195, p < 0.05).

Figure 8 represents the change of temperature inside the cabin with time and heating periods. As seen from Figure 8 temperature values for 20 min of heating period is increasing with time but on the other hand temperature values for 10 min of heating period increasing much more slower after the first 10 min.

There are two analysis of variance (ANOVA) made both for the 20 min period of heating and also for the 10 min period of heating. For the 20 min of heating period, mass flow rates and time factors were significant ($F_{MFR}[4, 58] = 12.892$, $p < 0.05$) and (F_{TIME} [30, 60.865] = 3.651, p < 0.05) but on the other hand, mass flow rate and time interaction was not significant ($F_{MFRxTIME}[58, 217] = 0.455$, p > 0.05). Table 5 shows the results of Student Newman Keul's Test. As seen on Table 5, there are 3 subgroups for 20 min of heating period. For the 10 min of heating period, only flow rates factor was significant (F_{MFR} [4, 58] =139.87, p < 0.05), but on the other hand time factor was not significant (F_{TIME} [30, 58] = 1.364, p > 0.05). Mass flow rates and time interaction was also not significant ($F_{MFRxTIME}$ [58, 186] = 0.122, p > 0.05). Table 6 shows the results of Student Newman Keul's Test. As seen in Table 6, there are 2 subgroups for 10 min of heating period.

Comparison of all cases

All possible cases including number of occupants, air circulation mode and heating period of time were

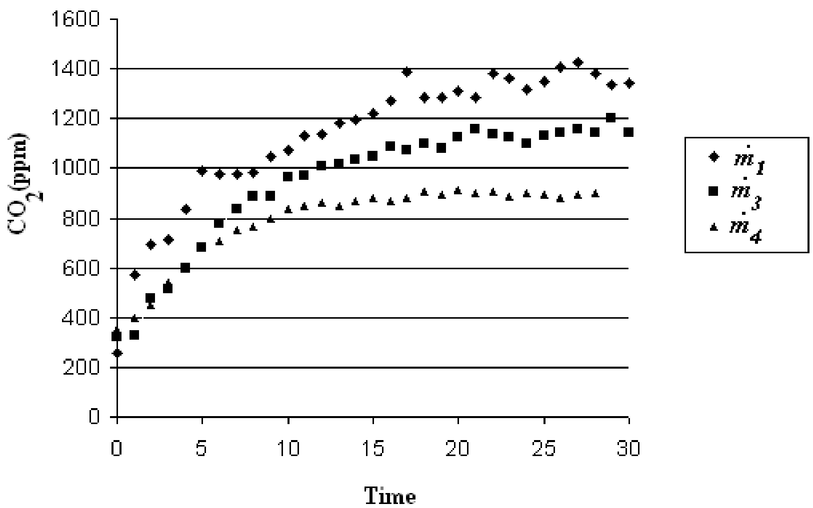

Figure 6. Change of CO_2 emissions with time and mass flow rates for air-recirculation mode.

Table 4. Student-Newman Keul's Test of mass flow rates for air-intake mode.

Mass flow rate	N	Subset		
		1	2	3
$\dot{m}_5$	90	117.68		
$\dot{m}_4$	186		165.00	
$\dot{m}_3$	96		199.37	
$\dot{m}_1$	117			269.05
$\dot{m}_2$	100			298.83

investigated and a 3-way analysis of variance (ANOVA) performed. The main factors were case, mass flow rate and time respectively.

Mean (and standard error) plots of CO_2 emissions for all cases are given in Figure 9. In 2 person without air-condition mode has the highest CO_2 emissions, and then one person without air-condition, air-recirculation mode and air-intake mode respectively. From the analysis of variance (ANOVA), mass flow rate (F_{MFR}[4, 202] = 72.286, $p < 0.05$) , time (F_{TIME}[30, 61.513] = 10.923, $p < 0.05$, case (F_{CASE}[2, 59.338] = 219.850, $p < 0.05$), interaction of mass flow rate and case ($F_{MFRxCASE}$[2, 48.373] = 37.493, $p < 0.05$), interaction of mass flow rate and time ($F_{MFRxTIME}$[96, 63.490] = 1.721, $p < 0.05$) and interaction of case and time ($F_{CASExTIME}$[58, 273.589] = 10.263, $p < 0.059$ were significant but interaction of all cases was not significant ($F_{MFRxCASExTIME}$[40, 1204] = 0.186, $p > 0.05$).

Table 7 shows the results of Student Newman Keul's Test of CO_2 emissions for all cases. As seen on Table 7, there are 4 subgroups for the possible cases. Table 8 shows the results of Student Newman Keul's Test of CO_2 emissions for mass flow rates of all cases. As seen on Table 8, there are 6 subgroups for the possible cases. In Figure 10, the change of CO_2 emissions with time and all of the cases is represented.

Conclusions

In this study, an evaluation with different heating modes for CO_2 emissions in a car was carried out. CO_2 emissions were investigated for different occupant numbers, air circulation in the car and heating period. Statistical analyses of results provide a confidence to the experiments. The following conclusions were drawn from the study:

1. The occupant number has an effect on CO_2 emissions inside a car. In the case of two persons, there were higher CO_2 emissions than that of one person condition. The mean CO_2 emission of one occupant is 1895.24 ppm and the mean CO_2 emission of two occupants is 2350.87

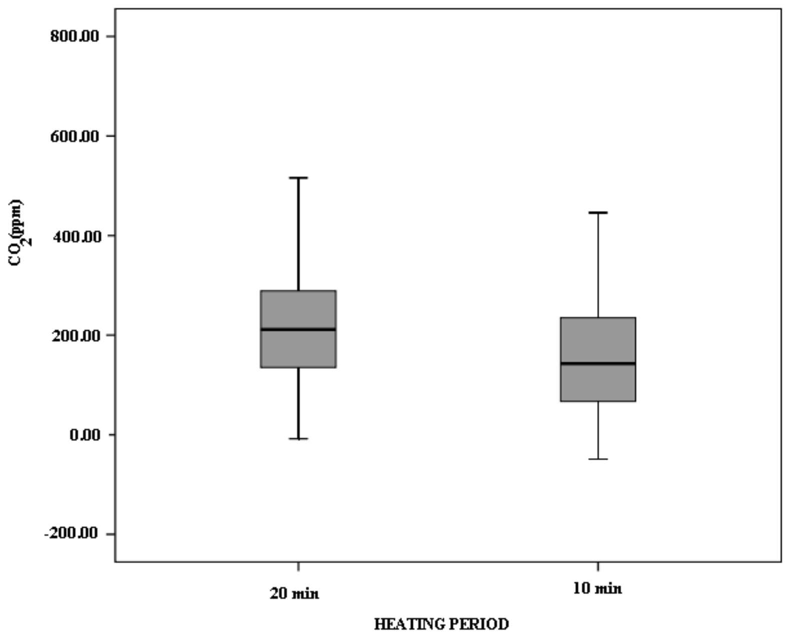

Figure 7. Mean CO_2 emissions for heating periods.

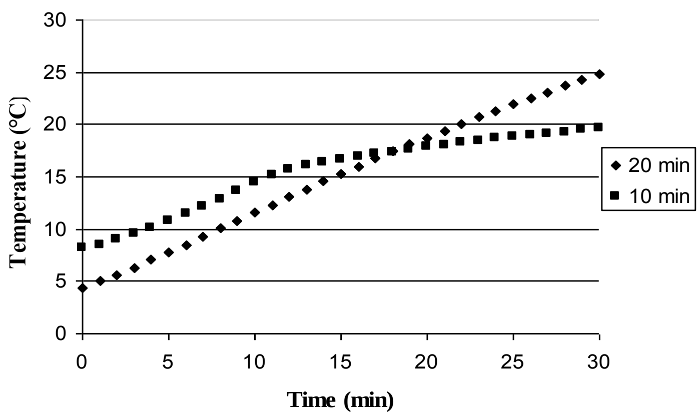

Figure 8. Change of cabin temperature with time and heating periods.

Table 5. Student-Newman Keul's Test of mass flow rates for 20 min heating period.

Mass flow rate	N	Subset		
		1	2	3
$\dot{m}_5$	30	155.533		
$\dot{m}_4$	93	191.666	191.666	
$\dot{m}_3$	63		227.619	227.619
$\dot{m}_2$	40			250.800
$\dot{m}_1$	84			251.583

Table 6. Student-Newman Keul's Test of mass flow rates for 10 min heating period.

Mass flow rate	N	Subset	
		1	2
$\dot{m}_5$	60	98.7667	
$\dot{m}_4$	93	138.3441	
$\dot{m}_3$	33	145.4545	
$\dot{m}_1$	33		313.5152
$\dot{m}_2$	60		330.8500

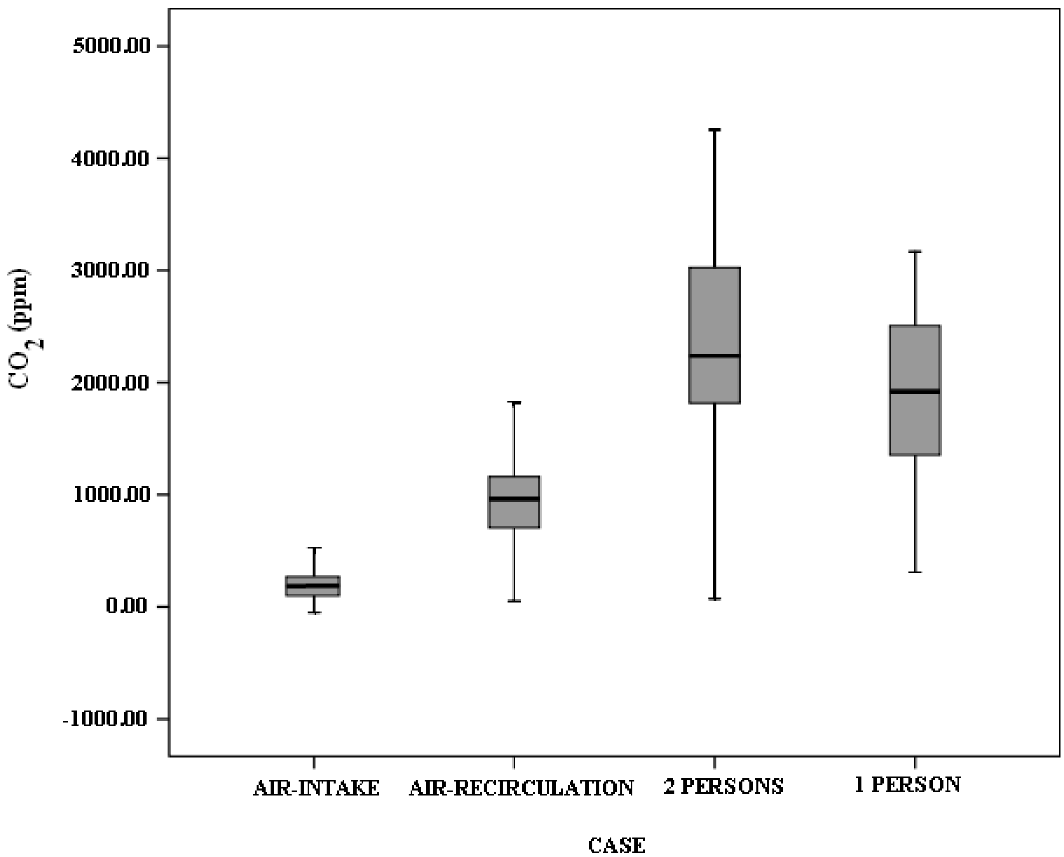

Figure 9. Mean CO_2 emissions for all cases.

Table 7. Student-Newman Keul's test of CO_2 emissions for all cases.

Case*	N	Subset			
		1	2	3	4
1	589	206.7657			
2	695		957.6892		
3	93			1895.2473	
4	93				2350.8710

Case* ; 1: Air-intake, 2: Air-recirculation, 3: 2 persons without AC, 4: 1person without AC.

Table 8. Student-Newman Keul's Test of mass flow rates for mass flow rates of all cases.

Mass flow rate	N	Subset					
		1	2	3	4	5	6
$\dot{m}_5$	90	117.688					
$\dot{m}_2$	100		298.830				
$\dot{m}_4$	447			547.644			
$\dot{m}_3$	313				718.134		
$\dot{m}_1$	334					830.3323	
$\dot{m}_0$	186						2123.0591

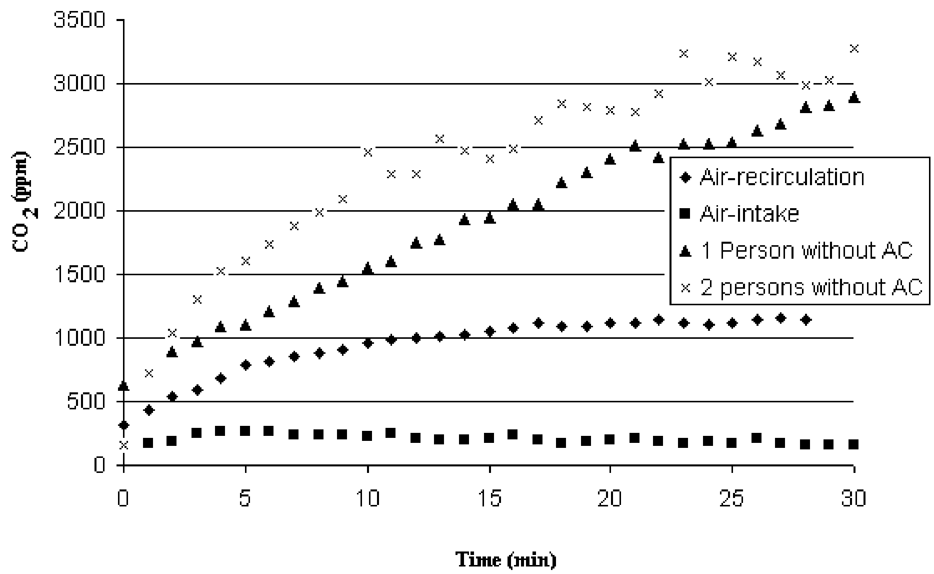

Figure 10. Change of CO_2 emissions with time and all cases.

ppm, which is 1.24 times greater than one occupant CO_2 emission mean.

2. The change of CO_2 emissions for occupant numbers with time is similar, both for the two person condition and the one person condition, CO_2 emissions increases with time.

3. Air circulation modes were also found significant. Air-recirculation mode has higher CO_2 emissions than that of air-intake mode. The mean CO_2 emissions of air-intake mode were 208.73 ppm and on the other hand, the mean CO_2 emissions of air-recirculation mode were 970.196 ppm, which is 4.65 times greater than the first case. It is not suggested that, to re-circulate the air for a 30 min period inside a car for the increase of CO_2 emissions inside the cabin.

4. The changes of CO_2 emissions for air circulation modes were significantly different. In air-recirculation mode, CO_2 emissions increased rapidly in the first 10 min and then stayed stable after 15 min, but in the air-intake mode CO_2 emissions changed not much and stayed stable with time. This result was also seen in the variance analysis (ANOVA) between two air circulation modes.

5. Both in air-recirculation mode and also in air-intake mode mass flow rates have affect on CO_2 emissions and higher mass flow rates have less CO_2 emissions. When we consider the ASHRAE 62.1, all the mass flow rates were comfortable for a 700 ppm CO_2 emission limit for air-intake mode. Although, $\dot{m}_2$ value is greater than $\dot{m}_1$ it had a greater CO_2 emission mean for air-intake mode.

6. Heating period of time were also significant, because when the driver adjusts the heater level he unconsciously changes the mass flow rate of air. Therefore, CO_2 emissions changes within the heating period of time.

20 min of heating period have less mass flow rates for the average of time, which has a mean of 215.79 ppm and, 10 min of heating period time have more mass flow rates, which has 192.79 ppm CO_2 emission mean.

7. From this study it is understood that CO_2 emissions inside a car varies directly from different mass flow rates.

8. We recommend that more experiment time with more participants, vent choices and cars will be better for the CO_2 emissions inside a car.

9. Applying a CO_2 emission sensor inside a car would trigger some ventilating functions to decrease the CO_2 emissions and will be better for specific conditions but in general it would be a new feature for modern cars.

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