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Effect of Recirculation on Air Quality in a Car Compartment

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ABSTRACT

The quality of air in a car's compartment is an important factor affecting passengers' comfort and also the driver's ability to focus throughout his driving trip. In this work, air quality related to the level of carbon dioxide (CO_2) and relative humidity (RH) in a car's compartment was studied. Two mode of ventilation were considered: (a) 100% recirculation air mode and (b) intermittence of recirculation and fresh air mode (mixed mode). It was found that the concentration of CO_2 under the full re-circulation mode reached 2500 ppm just in one hour after the trip started. Under the same condition, the RH decreased with temperature, from 58% to 42% in one hour. For mixed mode, when fresh air was selected 15 minutes after the trip started, the concentration of CO_2 reduced to a range of 700 ppm to 1000 ppm. However, as expected, the RH started to increase because the air surrounding had high humidity. This study gave an insight on suitable interval for interchange of air recirculation and fresh air modes in order to maintain acceptable level of comfort in a car.

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INTRODUCTION

Air quality in car's compartment is important in ensuring comfort and good focus of the driver. Heating, Ventilation and Air-Conditioning (HVAC) systems are normally designed to fulfill this requirement. However, people often spend long time in the automobile during commuting and leisure. Therefore indoor environment in car compartment could be regarded as a kind of residential environment that is equipped with HVAC system (Yokoyama, Iwashita, Yoshinami, Nagayama, & Nakagawa, 2007). Notable characteristics of a car compartment include, for example, sensitiveness to the atmospheric environment and functionality for driving performance.

Study on the quality of air indoor has been very limited; e.g. by Yokoyama *et al*. (Yokoyama, Iwashita, Yoshinami, Nagayama, & Nakagawa, 2007) and Nakagawa *et al*. (Nakagawa, Iwashita, Yoshinami, Nagayama & Yokoyama, 2007). On the other hand, there are plentiful of reports available on study of indoor air quality in buildings; for example in the work by Sulaiman *et al*. (Sulaiman, Isa, Raskan, & Harun, 2013) and Harun *et al*. (Harun, Buyamin, Othman, & Sulaiman, 2013).

The decision for choosing either fresh air or recirculation air mode for car compartment environment may involve similar process as in buildings, in which one would select recirculation modes when he feels discomfort (Nakagawa, Iwashita, Yoshinami, Nagayama & Yokoyama, 2007). Carbon dioxide content in air may be used as an indicator of the appropriateness of air recirculation because its concentration relates to the number of people in a building and the building's general ventilation rate.

Outdoor air contains about 330 parts per million (ppm) or about 0.033 percent carbon dioxide (Government of Alberta, 2012). However, when people breathe in a confined space, oxygen from the air is inhaled and carbon dioxide is exhaled, and if recirculation air is selected, the carbon dioxide content would increase to a level far higher than that of the outdoor air. If carbon dioxide concentration becomes too high, the air gets stale and the occupants will not feel comfortable. Complaints usually begin when carbon dioxide concentrations reach about 800 ppm and become more common when carbon dioxide exceeds 1000 ppm. If the level of carbon dioxide is too high, more fresh air would be required to dilute the carbon dioxide content (Government of Alberta, 2012) and (Federal Regulations, 2000).

The objective this work was to assess the air quality in car compartment as a result of choice of air circulation mode. The study was conducted by measuring the level of carbon dioxide (CO_2), relative humidity (RH), and temperature in a traveling car under tropical weather.

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Methodology:

In this work, a compact sedan car with an estimated compartment volume of 3 m^3 was selected. The conditions of air in the car compartment were measured when the car was traveling along countryside road between Ipoh and Lumut in Malaysia (4.2°N) mainly westward. The weather during the test was hot and humid. The distance travelled was approximately 100 km at an average speed of 70 km/h. The weather during the test, which was held between 9.30 am and 11.30 am, was sunny with scattered thin clouds in the sky in the month of January. During this study, the car was occupied with three persons including the driver. The measured conditions were CO_2 content, relative humidity (RH), and dry bulb temperature.

The set point temperature of the car compartment's air-conditioner was set at 26°C. The average supply air flow rate from each of air-conditioner outlets, located on the dashboard, was measured to be 3.8 m^3/min. Two ventilation modes were selected; i.e. 100% recirculation and intermittence of recirculation and fresh air modes. Table 1 shows descriptions of the measurement instruments and their accuracies. A Telaire 7001 portable CO_2 – temperature monitor was used to monitor the indoor CO_2, dry bulb temperature and relative humidity. The maximum readable value of carbon dioxide content was 2500 ppm. The data was analyzed by the software provided by the instrument's manufacturer. The instrument was mounted on the middle of the rear seat about 30 cm from the floor. Care was taken to ensure that the instrument was not directly exposed to sun radiation so that only air temperature was measured.

Table 1: Measured parameters.

Parameter	Instrument	Accuracy
CO_2 content	Telaire 7001	± 50 ppm
Relative Humidity, RH	Telaire 7001	± 2.5% (10%-90% RH)
Temperature (°C)	Telaire 7001	± 1°C

Different than centralized air-conditioning systems for buildings, which allow slight fresh air intake for return air system, most car air-conditioning systems do not allow such feature while in recirculation mode. Consequently, under the air recirculation mode the car interior would experience accumulation in the content of carbon monoxide due to exhalation by the occupants in the fully confined space.

The different modes tested in this study are shown in Table 2. Also shown in Table 2 are the durations and actual times of the tests. The full re-circulation test refers to the condition during which air recirculation was in place from start until end of test (60-minute duration). During this period, no fresh air was introduced. The intermittence test refers to regular switching between fresh-air mode and re-circulation mode. The intermittence mode started with fresh air at 10.30 am and followed by switching to recirculation and 100% fresh air at a 15-minute interval. The total duration for intermittence test was 60 minutes.

Table 2: Test conditions.

Test	Duration (minutes)	Time
Full Re-circulation	60	9.30 am – 10.30 am
Intermittence:		
a. Fresh air b. Re-circulation c. Fresh air d. Re-circulation	15 × 4	10.30 am – 11.30 am

RESULTS AND DISCUSSION

The results are divided into three sections, which look into the dry bulb air temperature, relative humidity, and CO_2 content.

A. Air Temperature:

Shown in Fig. 1 and Fig. 2 are variations of the dry bulb air temperature in the car compartment with time throughout the test under the full recirculation and intermittence modes, respectively. It must first be noted that the sudden drop and rise in temperatures in the graphs were erratic probably due to signal interference and might also be caused by sudden change in the environment conditions.

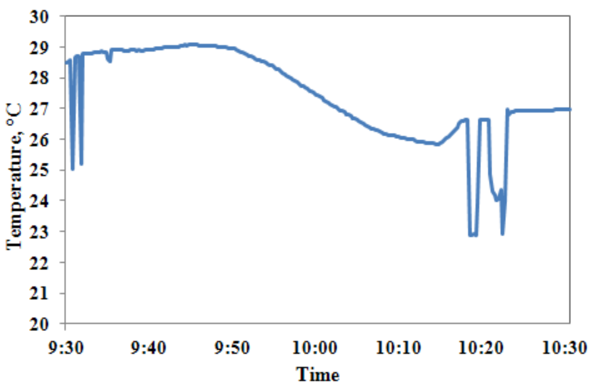

Fig. 1: Variation of dry bulb air temperature with time for full-recirculation test between 9.30 am and 10.30 am

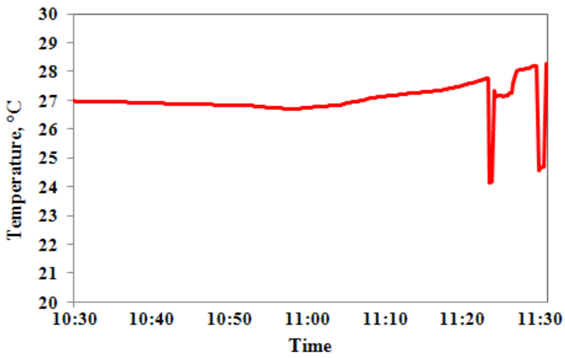

Fig. 2: Variation of dry bulb air temperature with time for intermittence test between 10.30 am and 11.30 am

It is shown in Fig. 1 that the air temperature was at 28.5°C at the start of test. During the first 20 minutes, the air temperature increased gradually to 29.1°C most probably due to the heat gain from occupants of the compartment. Approximately at 10.13 am the air temperature reached a minimum value of about 26°C, which was the same as the set point temperature.

In Fig. 2, for the intermittence test, the temperature is shown to be steady at around 27°C for the next 30 minutes before the raising up to 28°C until end of test. At 10.30 am, when the intermittence test was started, fresh air was introduced. Nevertheless, did sudden increase in the indoor air temperature was not displayed, implying that the air-conditioning system was already at steady state. Furthermore, the measurement sensor was located on the rear seat of the car that the transient effect, due to sudden in the air intake configuration could not be detected. The slight increase in the air temperature at 11.00 am was probably in response to the external heat gain condition, which probably changed significantly at that time; for example the outdoor air temperature would be expected to be higher as it reached closer to noon.

Overall, it is shown in Fig. 1 and Fig. 2 that the air temperatures under both full re-circulation and intermittence tests were acceptable as they were very close to the set point temperature. The exceptionally higher temperature at the start of full recirculation test was understandably due to the transient effect, which could have been reduced by starting the test only after a quasi-steady state condition has been reached.

B. Relative Humidity (RH):

Shown in Fig. 3 and Fig. 4 are variations of relative humidity (RH) of air in the car compartment with time throughout the test under the full recirculation and intermittence modes, respectively. Different than temperature results, the graphs are shown in both figures to be fluctuating all the time at about ±1%. This was suggested to be caused by the high sensitivity of the sensor to RH. Despite the fluctuations, the trends of variations of RH with time are clearly displayed.

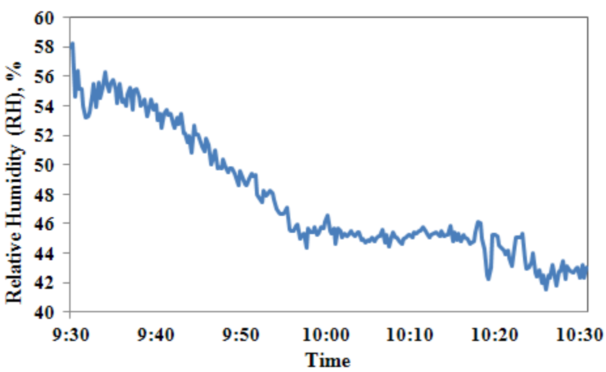

Fig. 3: Variation of relative humidity (RH) with time for full-recirculation test between 9.30 am and 10.30 am

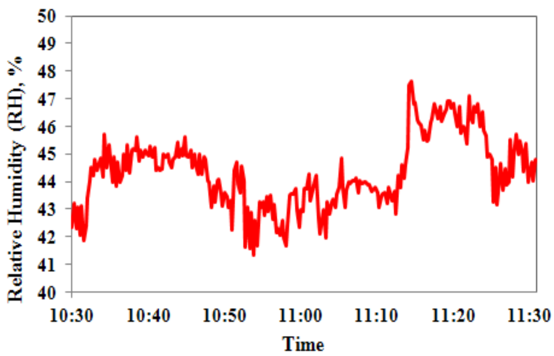

Fig. 4: Variation of relative humidity (RH) with time for intermittence test between 10.30 am and 11.30 am

Like in Fig. 1, the RH in Fig. 3 is shown to start at a high value (about 58%) mainly owing to the fact that was the start time of the test and thus the significant transient effect is displayed. Therefore, right after the air-conditioning system was turned on the RH dropped significantly. It took about 30 minutes from the start of test for the RH to display a steady condition (at about 45%). The remainder 30 minutes saw a quite constant RH ranging between 42% and 46%, which was anticipated since no fresh air was taken and thus almost no change in the amount of vapor in air. The source of vapor would come only from the occupants (passengers) and would be regarded as very small in quantity. Overall, the RH in Fig. 3 kept decreasing with time.

The RH in Fig. 4 increased when fresh air was introduced at the start of intermittence test (10.30 am). This was expected because the high humidity from the outdoor air, at an average RH of 74% - 80% (Director General Meteorological Services, 2011), would affect the moisture content in the car compartment. A quite significant pattern of increase and decrease in RH is displayed in Fig. 4. However, the highest RH recorded was only about 47%, which was small as compared to the results in Fig. 3. This implied that the cooling coil of the air-conditioner was highly capable in condensing almost 100% of the water vapour from the fresh air intake.

Generally, Fig. 3 and Fig. 4 show that the RH under both tests were quite consistent despite the change in the air ventilation mode. As explained for the temperature results, the higher RH at the start of full recirculation test was avoidable. The result implied that the air-conditioning system functioned well in delivering air at suitable RH under full recirculation and intermittence test. No attempt was made to observe the trend for a very long operation under the 100% fresh air mode.

C. ***Carbon Dioxide (CO_2) Content:***

Fig. 5 and Fig. 6 display the variations of Carbon Dioxide (CO_2) content in air of the car compartment with time throughout the test under the full recirculation and intermittence modes, respectively. It must be noted that the maximum readable CO_2 content was 2500 ppm (limitation of equipment), and thus explain the reason why the graph lines look flat at 2500 ppm. In actual fact, the actual value may be higher than 2500 ppm. However, since 1000 ppm would be regarded the upper limit of healthy condition, the equipment limitation should be acceptable in determining on the quality of air in the compartment.

Fig. 5 showed that the level of CO_2 was readily high (2500 ppm or higher) and unhealthy at the start of test. It was not clear why there was a drop in the measurement between 9.55 am and 10.20 am. One reason could be due to disturbance on the data logger since the value dropped tremendously down to 500 ppm.

During the intermittence test, as shown in Fig. 6, the CO_2 content decreased when the fresh air mode was selected. This happened because of the dilution effect caused by introduction of fresh air. The patterns results were similar between the 15-minute intervals of switching of recirculation and 100% fresh air modes. Interestingly, the 15-minute duration of introduction of fresh air was just enough to bring down the CO_2 content to the recommended upper limit value (DOSH, 2005).

The reduction in CO_2 content shown in Fig. 6 was as high as 1500 ppm. Thus, it can be suggested that if the initial value of the CO_2 content were low, it would not be difficult to maintain a healthy indoor content in the car. Therefore, long exposure of the car interior to fresh air prior to the start of journey would be highly recommended; for example by opening all the windows and selecting the air intake to 100% fresh air.

It is also worth noting that it took only 15 minutes after changing to full recirculation mode for the car interior to gain 1500 ppm of CO_2 content, consequently resulting in to unhealthy indoor condition. Therefore, it would be recommended that 100% fresh air mode be maintained whenever possible, although the tradeoff would be poorer energy conservation. Another consideration would be for car manufacturers to design systems that can allow small intake of fresh air as in building air-conditioning systems.

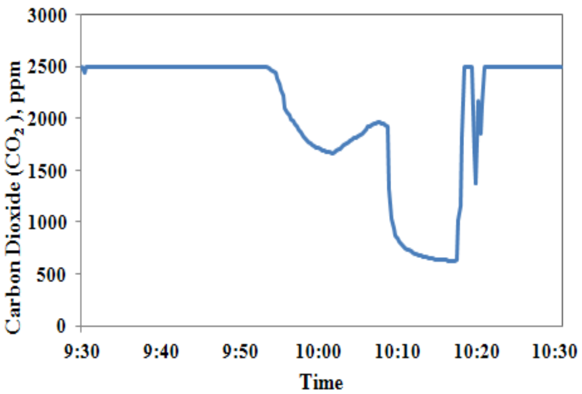

Fig. 5: Variation of Carbon Dioxide (CO_2) in ppm with time for recirculation test between 9.30 am and 10.30 am

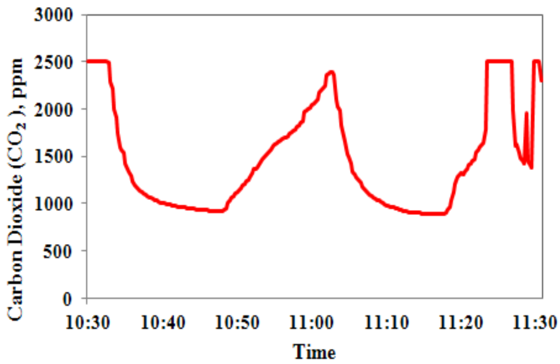

Fig. 6: Variation of Carbon Dioxide (CO_2) in ppm with time for intermittence test between 10.30 am and 11.30 am

Conclusion:

A study on indoor air quality of a car compartment was conducted, while the vehicle was traveling on roads. The study was important in assessing the suitability of air condition vis-à-vis passengers' comfort and health. From the study, the following conclusions are made:

1. The temperature and relative humidity were observed to be acceptable during the study that they fell within the expected set point values.
2. The CO_2 content was observed to be high in the car compartment at the start of test. Ventilation with 100% fresh air and opening of windows at the start of every journey would be recommended for healthy indoor environment.
3. The rise in CO_2 content can be as high as 1500 ppm in just 15 minutes after changing from 100% fresh mode to full recirculation mode. This implies that full recirculation would result to unhealthy indoor condition. To some extent, this could be a factor contributing to poor drivers' alertness in long distance journeys, apart from fatigue.
4. For journeys that take more than one hour, the selection of mixed mode (alternate between 100% fresh air and full recirculation) would be highly recommended in addressing the issues of passengers' comfort and also energy conservation.

One important recommendation that car manufacturers and respective authorities would want to consider is to add minimal fresh air intake even under full recirculation mode; a concept that has been long applied in centralized air-conditioning systems for building.

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REFERENCES

Director General Meteorological Services, 2011. "Temperature & Relative Humidity Range, Country: Malaysia".

DOSH, 2005. Department of Occupational Safety and Health Ministry Resources, Ministry of Human Resources, Malaysia, Code of Practice on Indoor Air Quality, Putrajaya

Federal Regulations, 2000. Classes of comparable automobiles, Country: U.S. "Title 40- Protection of Environment", Section., 600: 315-82.

Government of Alberta, 2012. "General Health – Occupational Health and Safety Bulletin", Canada.

Harun, H., N. Buyamin, M.A. Othman and S.A. Sulaiman, 2013. A Case Study on Indoor Comfort of Lecture Rooms in University Buildings, Applied Mechanics and Materials, 393: 821-826.

Nakagawa, J., G. Iwashita, Y. Yoshinami, H. Nagayama and Y. Yokoyama, 2007. "Fundamental Study on The Ventilation Rate and VOCS Concentration in The Car Compartment", 6^{th} International Conference on Indoor Air Quality, Ventilation & Energy Conservation in Buildings IAQVEC, Sendai, Japan.

Sulaiman, S.A., N. Isa, N.I. Raskan and N.F.C. Harun, 2013. Study of Indoor Air Quality in Academic Buildings of a University, Applied Mechanics and Materials, 315: 389-393.

Yokoyama, Y., G. Iwashita, Y. Yoshinami, H. Nagayama and J. Nakagawa, 2007. Fundamental Study on Particles, Ultra-Fine Particles and Ozone in The Car Compartment, 6^{th} International Conference on Indoor Air Quality, Ventilation & Energy Conservation in Buildings IAQVEC, Sendai, Japan.