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Commuter exposure and indoor–outdoor relationships of carbon oxides in buses in Hong Kong

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Abstract

The exposure of bus commuters to carbon monoxide (CO) and carbon dioxide (CO_2) in various bus routes in Hong Kong has been studied. The buses under investigation travel in the city of Hong Kong and involve both air-conditioned and older buses without air-conditioning. The in- and out-vehicle concentrations of both pollutants were measured simultaneously using portable samplers. It is found that the exposure level of CO_2 inside the air-conditioned vehicle is strongly dependent on the number of passengers but not on the driving environment. During the measurement, it is found that the CO_2 level can reach up to a dangerous 10 times that out-vehicle when the air-conditioned bus is full. On the other hand, it was found that the CO and CO_2 levels for a non-air-conditioned bus remain low due to better air exchange between in- and out-vehicle.

Keywords: Indoor–outdoor relationships; Commuting; Exposure; Carbon monoxide; Carbon dioxide

1. Introduction

People in urban areas spend a considerable amount of commuting between their workplace and homes. In fact Jenkins et al. (1992) had shown that urban people spend 7% of their daily time commuting. Thus, exposure to urban pollutants during commuting has become a concern to the general public (Chan et al., 2002; Chan and Chung, 2003). Traffic-related exposure is known to contribute considerably to the daily total human exposure (Chan et al., 1999). This is especially true during peak traffic hours where most vehicles are idling or moving slowly (Ott, 1990). Studies have also related this exposure to increased respiratory problems, mortality and loss of productivity (Dockery and Pope, 1994). Complaints of nauseas, dizziness and respiratory problems in buses are commonplace nowadays especially after prolonged commuting.

Amongst the many modes of transportations in Hong Kong, public buses remain the most popular mode, contributing almost half of the total passenger commuting services in Hong Kong every day (Chan and Wu, 1993; Transport Department, 2001). Thus, understanding the human exposure to traffic pollutants in buses and its indoor–outdoor (IO) air quality relationship will be very important in understanding our total exposures.

A number of works have been devoted to commuters' exposure inside vehicles or public transport. Gee and Raper (1999) studied the exposure of bus commuters and cyclist to respirable suspended particulate (RSP) in Manchester while Van Wijnen et al. (1995) and Chan et al. (2002) examined the commuters' exposure to RSP in various public transports. Bevan et al. (1991) studied the exposure to RSP while commuting bicycle in both urban and suburban routes. Praml and Schierl (2000) performed a 4-year survey and found that particulate exposure in buses and trams in München depended on external sources and factors like out-vehicle concentration and road traffic. Rudolf (1990) measured the in- and out-vehicle pollutants of a vehicle on a highway, whereas Chan et al. (1991, 1993–1995) did a series of investigation on the commuter exposures in various

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commuting environments in Taipei and Boston. Berg-Münch and Fanger (1983) studied the connexion between ventilation, in-vehicle pollution level and body odour. Adams et al. (2001a, b, 2002) measured and analysed the personal exposure levels of carbon and particulate matters in transport microenvironments.

A number of researchers have performed investigations on carbon monoxide (CO) and carbon dioxide (CO_2) exposures in commuting due to its apparent connexions with motion sicknesses and nauseas. For example, Colwill and Hickman (1980) and Flachsbart et al. (1987) measured the CO exposures by drivers and commuters. Despite these measurements, the sources of these pollutants remain unclear and there are no apparent strategies for a commuter to minimize his/her exposure to these two pollutants. It is thus interesting to understand how the concentration level of these two pollutants varies with some related factors like traffic, driving environment and number of passengers, to name just a few.

The present field study was undertaken to understand the various out-vehicle effects on the penetration of pollutants into a bus. As in Chan and Chung (2003), the indoor–outdoor air quality relationships (IO) gives an indication of the sources and penetration of out-vehicle pollutants into the vehicle. We shall thus study the IO ratio of CO and CO_2 for a bus under different ventilation conditions and number of passengers. The two ventilation systems to be considered are natural ventilation (windows opened) and air-conditioned.

2. Methodology

Measurements were conducted during the period January–March 2002, which was the winter and spring season in Hong Kong when variation of weather is relatively small. Samplings of both pollutants inside the bus were performed in the middle of the passenger compartment using the portable IAQCALC carbon oxides sampler. The measurement was made on an empty seat to avoid direct measurement of human's breath. Out-vehicle pollutants were measured by the same sampler located in a light-goods vehicle that followed closely the bus. The tubings were connected to the ambient environment as in Chan and Chung (2003) through the sky-window. This is to avoid direct suction from the exhaust pipes of the bus. All measuring equipment sets were carefully calibrated and compared before and after the measurements and gave readings to the accuracy of 0.5% of each other. Throughout the sampling, the time, the duration, the traffic conditions, the number of passengers and surrounding environments were recorded. Data were taken every 2 min to reduce the response time. Meteorological conditions were also noted from data acquired from Hong Kong Observatory for reference purpose.

Passenger service rates and the route environment are used as the selection criteria of the bus routes under investigation. The routes chosen represent some of the most travelled bus routes in the region. These routes transverse the major corridors and represent distinctively the driving environment: country side and urban areas. In Hong Kong almost 80% of the buses belong to air-conditioned types with engines following the Euro II or Euro III standards. Non-air-conditioned buses are used mostly in the suburbs where the passenger numbers are generally lower.

Quality assurance procedures were included during the field sampling following the standard procedures applied by the United States Environmental Protection Agency in its own research with this kind of monitoring equipment as in Spengler et al. (1988). To ensure samplings reflect the true situation and not by peculiar issues, all trips were made at least in duplicate for objectivity. Due to contractual reasons and agreements, the bus routes and bus types cannot be disclosed.

3. Results and analysis

3.1. Urban bus routes

Figs. 1a–c show the variation of CO and CO_2 concentration levels along a popular bus route from the Hong Kong Island to Kowloon. The route involves an air-conditioned bus travelling inside urban street canyons and a cross-harbour tunnel in between. An immediate observation is that there exists strong correlation between the number of passengers inside the bus with the in-vehicle CO_2 level. In fact the correlation coefficient between the two is extremely high ($R = 0.9422$), showing the strong connexion between the two. This also agrees with a similar work conducted by Leutwyler et al. (2002) on RSP in coaches. Out-vehicle ambient CO_2 level is relatively constant except for a very minor surge just outside the tunnel as explained in Chan and Chung (2003). It can thus be seen from the variation of IO ratio for CO_2 that the main source of this pollutant arises almost solely from the presence of human. When the bus was almost full, the CO_2 level reached an alarming level of more than 10 times that out-vehicle (3900 ppm), which is close to concentration of concern of the World Health Organization (American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE), 2001) and exceeded the Level 2 of the Recommended Indoor Air Quality Objectives of Hong Kong (Environmental Protection Department, 1999). Obviously this has to do with two factors: limitation of air velocity to avoid discomfort and the lack of exhaust or dilution paths in a completely sealed bus compartment.

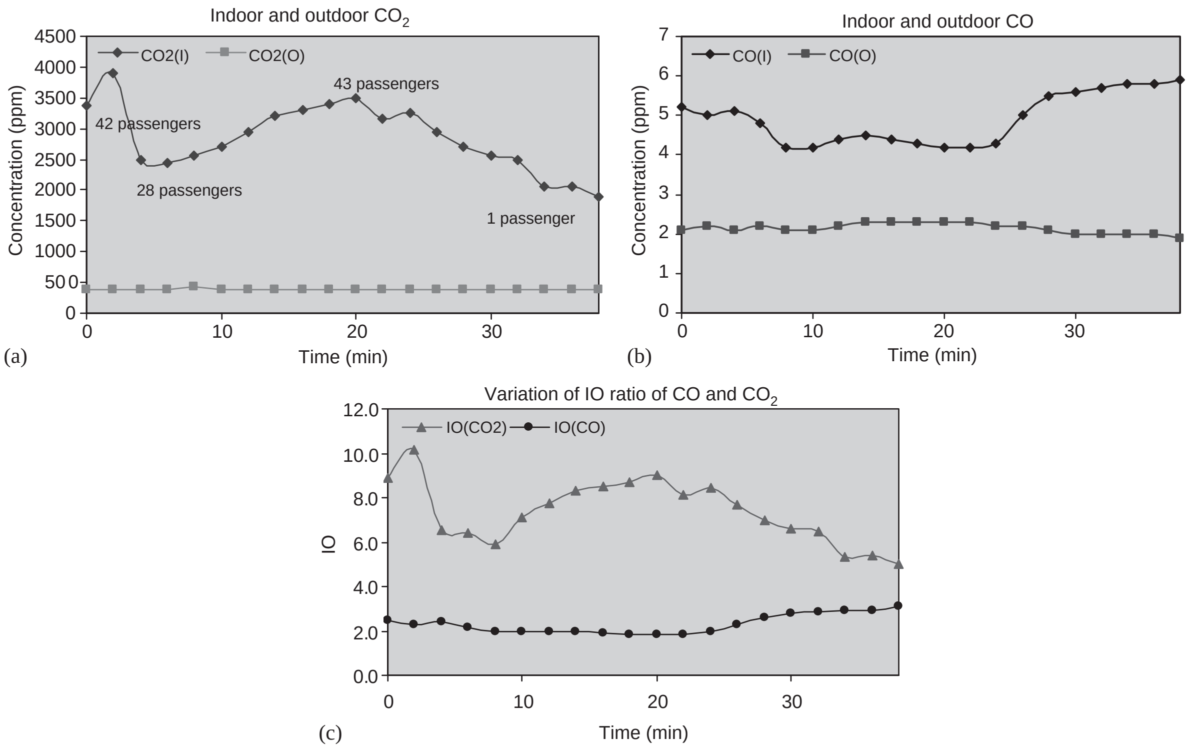

Fig. 1. Variation of pollutant concentration characteristics of an air-conditioned bus on an urban route: (a) in-vehicle pollutant, (b) out-vehicle pollutant and (c) IO value.

The in-vehicle CO level is less alarming but is similarly concerning. Carbon monoxide is likely to come from outdoors, originating from emissions from other vehicles. In-vehicle CO level is constantly 2.5 times higher than that in an urban street canyon. The in-bus CO level fluctuates around 5 ppm which is one-fifth of the acceptable short-term exposure range (ASTER). However, it is interesting to note that the correlation between the number of passengers and CO level is low ($R = -0.6245$), while the IO ratio shows very little variation due to the relatively small change in CO level throughout the journey.

Another trip on an air-conditioned bus was made along another urban route (Figs. 2a–c). It can be seen that despite the fact that the bus was commuting along a similarly heavy traffic route (readily seen from the comparable out-vehicle CO and CO_2 levels), the in-bus pollutant level is far different. This is due to the fact that this journey was taken with fewer passengers (30 during its peak). From this and the IO variation, it can be seen that the in-vehicle CO_2 level is almost solely dependent on the number of passenger while the in-vehicle CO level is not. Again it must be noted that the in-bus CO_2 level is again many times higher than that out-vehicle while CO is slightly lower, despite still higher than out-vehicle. It can be seen from this that air-conditioned bus is not a properly ventilated vehicle in terms of removing in-vehicle pollutants.

Figs. 3a–c show the specified pollutant levels for a bus journey without air-conditioning. Most of the windows were opened during the trip. From the IO graph and comparing it with the previous graphs, it can be interpreted that CO is mostly generated out-vehicle while CO_2 is generated in-vehicle. The fact that CO_2 level still responds to the number of passengers but with a much smaller correlation coefficient ($R = 0.3395$) shows that air exchange between in- and out-vehicle is good and that the pollution is much diluted as can be seen from the variation of both CO and CO_2 levels. For CO, which is an out-vehicle pollutant, its IO value fluctuates around the value of unity indicating the constant exchange between in- and out-vehicle. Relatively speaking, a non-air-conditioned bus seems to be much better ventilated than an air-conditioned bus with significantly lower CO and CO_2 levels and lower IO value.

3.2. Countryside bus routes

Figs. 4a–c show the variation of in- and out-vehicle CO and CO_2 levels in an-air conditioned bus journey to the countryside. Apparently the in-vehicle

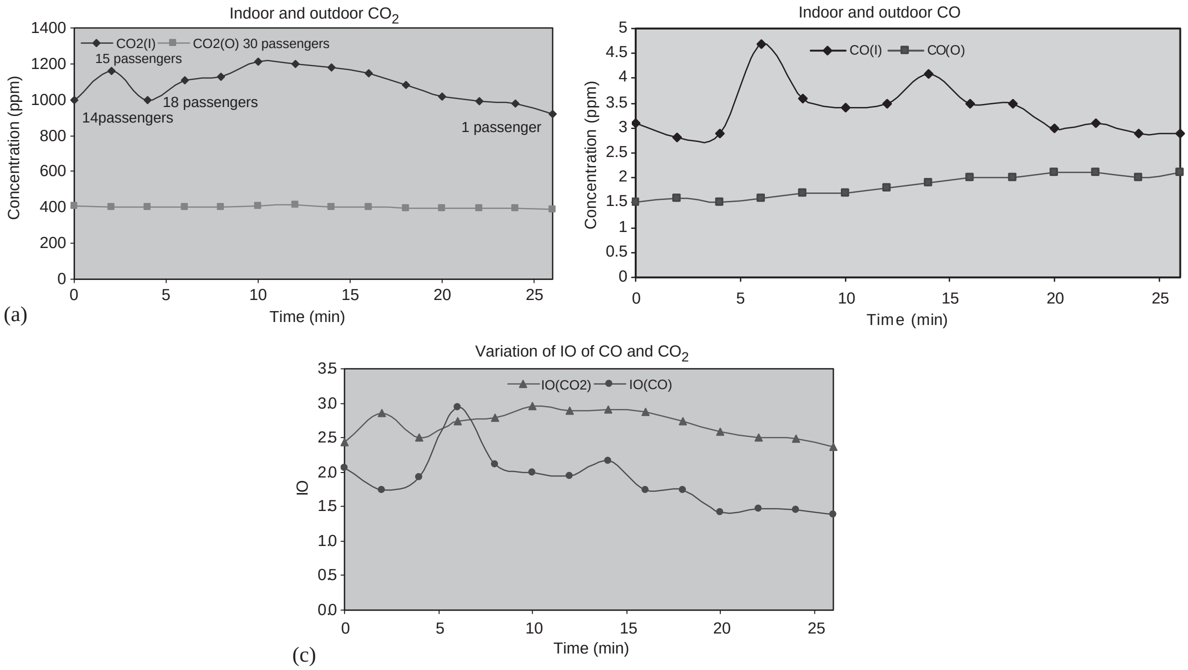

Fig. 2. Variation of pollutant concentration characteristics of an air-conditioned bus on an urban route: (a) in-vehicle pollutant, (b) out-vehicle pollutant and (c) IO value.

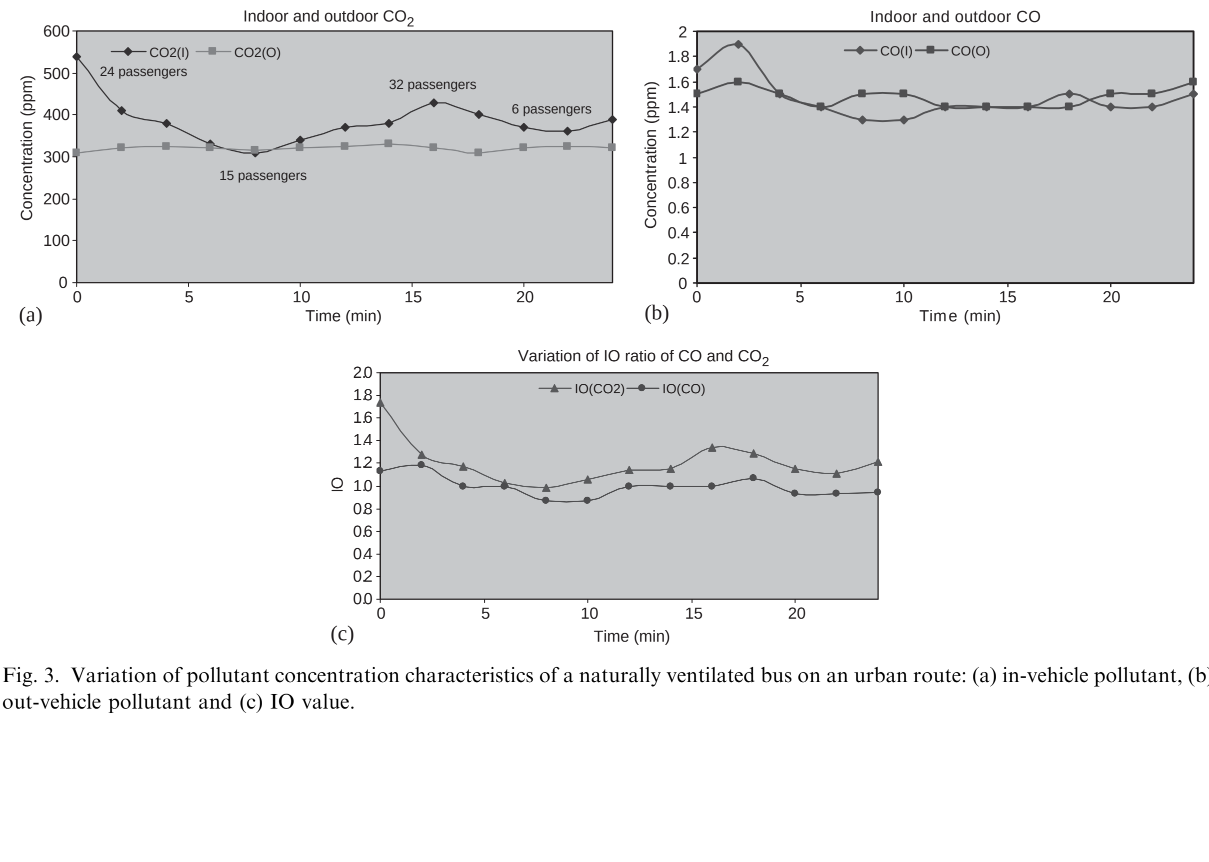

Fig. 3. Variation of pollutant concentration characteristics of a naturally ventilated bus on an urban route: (a) in-vehicle pollutant, (b) out-vehicle pollutant and (c) IO value.

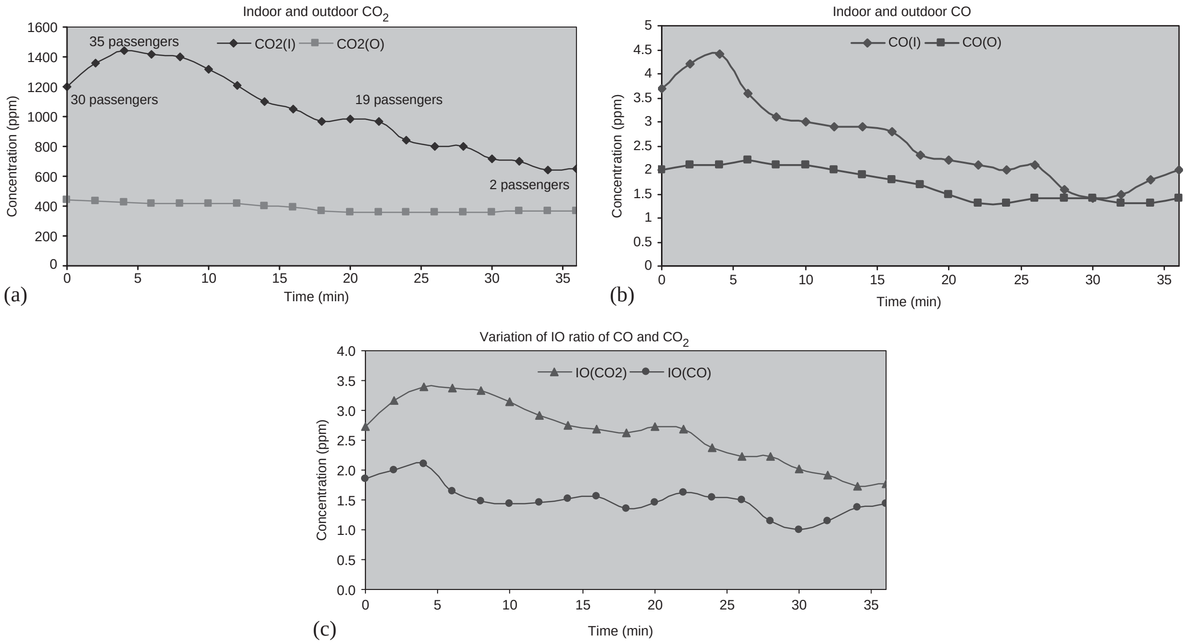

Fig. 4. Variation of pollutant concentration characteristics of an air-conditioned bus on a countryside route: (a) in-vehicle pollutant, (b) out-vehicle pollutant and (c) IO value.

microenvironment seemed unaffected by the out-vehicle environment, as the pollution level by the end of the journey is comparable with that in an urban trip. The number of passengers and its number variation is similar to the previous trip in the urban corridor and insignificant difference is observed between the pollution level between them. Cleaner air is available in out-vehicle, thus both pollutants in the out-vehicle are of a lower concentration compared with the urban setting. Nevertheless in-vehicle CO_2 level was still 2.5 times higher than that out-vehicle whereas the IO fluctuates around 1.5 for CO. As in previous cases, the CO_2 level is dependent on the number of passengers ($R = 0.8584$), while the correlation for CO is also surprisingly high ($R = 0.6290$).

Another trip in the countryside was made with a non-air-conditioned bus. Figs. 5a–c show the variation of in- and out-vehicle CO and CO_2 levels of the trip. The low CO and CO_2 levels indicate thorough exchange of air between in- and out-vehicle during the journey. This is further supported by the fact that the IO ratio of the two pollutants remains only slightly higher than unity throughout. This is understandable as air movement inside the passenger compartment is less. It must again be noted that the correlation between the in-vehicle pollution level and the number of passengers remain high (0.9353 for CO_2 and 0.6324 for CO). The trend and the magnitude of the IO variations are similar to that trip made in the urban setting. This seems to suggest again that the ambient environment has little to do in affecting the in-vehicle pollution level.

4. Conclusions

The exposure of bus commuters to CO and CO_2 in various bus routes in Hong Kong has been studied. The buses under investigations travel in the city of Hong Kong and involve both air-conditioned and older buses without air-conditioning. The in- and out-vehicle concentrations of both pollutants are measured simultaneously using portable samplers. It is found that the exposure level of CO_2 inside the air-conditioned vehicle is strongly dependent on the number of passengers but not on the driving environment. During the measurement, it is found that the CO_2 level can reach up to a dangerous 10 times that of out-vehicle when the air-conditioned bus is full. The pollution level measured also exceeded many health guidelines for in-vehicle environment and poses a serious health concern to frequent or long-journey traveller. This is especially important when long-journey trips are becoming more popular with most of these buses fully occupied. On the other hand, it was found that the CO and CO_2 levels for a non-air-conditioned bus remain low due to better air exchange between in- and out-vehicle.

With respect to the mentioned dangerous level of CO_2 accumulated inside the bus, there seems to be a need to

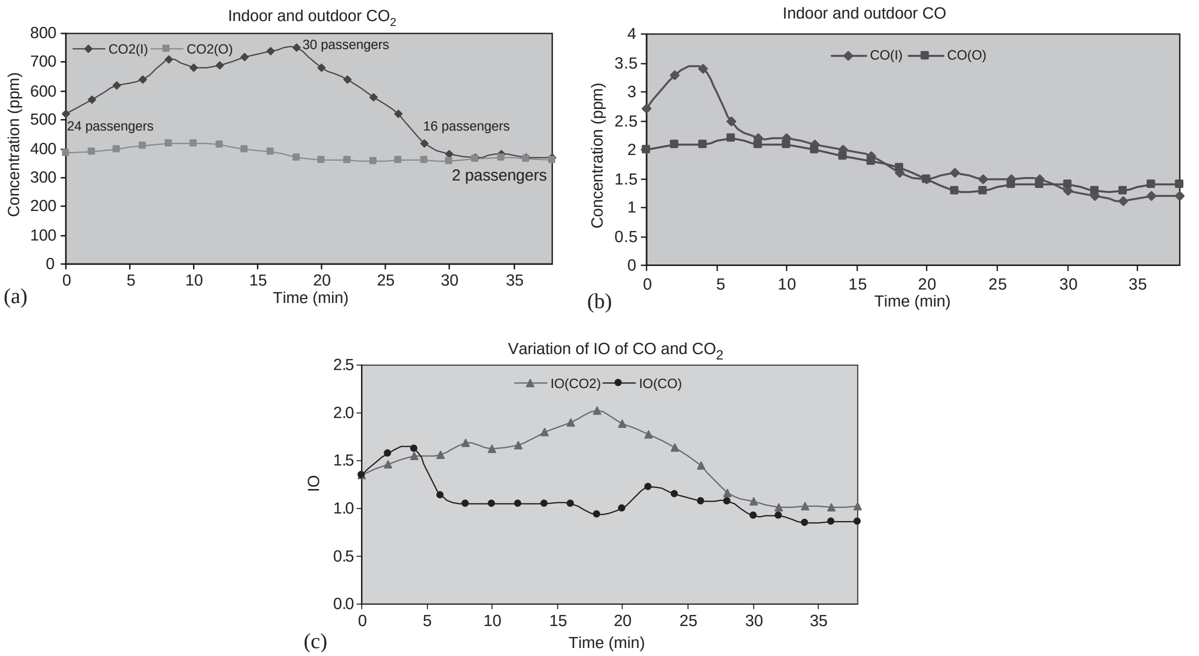

Fig. 5. Variation of pollutant concentration characteristics of a naturally ventilated bus on a countryside route: (a) in-vehicle pollutant, (b) out-vehicle pollutant and (c) IO value.

establish protocols to maintain the air quality inside a bus. While criteria for air quality have been developed and thoroughly studied for the in-vehicle environment, in-vehicle has received relatively little attention. This is coupled with the fact that many people spend considerable amount of time commuting in buses especially in the urban areas. Many buses do not have a proper ventilation system in terms of pollutant dilution and most windows cannot be opened at all for proper fresh-air exchange. Much work is expected to be done in this area in the near future.

Acknowledgements

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