Ventilation Efficiency and Carbon Dioxide (CO$_2$) Concentration

M. N. Halgamuge$^1$, T. K. Chan$^2$, and P. Mendis$^1$

$^1$Department of Civil & Environmental Engineering, The University of Melbourne
Parkville, VIC 3010, Australia

$^2$Faculty of Architecture, Building & Planning, The University of Melbourne
Parkville, VIC 3010, Australia

Abstract—In animals metabolic processes, involve complex organic molecules being broken down to simpler molecules, such as carbon dioxide and water. Carbon dioxide waste is removed from the body through respiration. Carbon dioxide content in fresh air is approximately 400 parts per million. In this study, we investigate the relationship between ventilation efficiency and carbon dioxide (CO$_2$) concentration. Carbon dioxide concentration can give an indication of the indoor air quality in indoor and enclosed environments. It serves as a measure of ventilation efficiency in areas where air-conditioning and mechanical ventilation is provided.

Our survey of various enclosed environments indicate that CO$_2$ levels may exceed the levels that have been suggested to cause occupants to grow drowsy, get headaches, or function at lower activity levels. Elevated levels of CO$_2$ are observed in public transport when filled almost to capacity and these concentrations remain for long durations.

1. INTRODUCTION

The most periodic found gases on the earth is carbon dioxide (CO$_2$) [1]. This produces from natural metabolism of living organisms and combustion processes. We inhale oxygen (O$_2$) and exhale carbon dioxide. Indoor CO$_2$ levels in general vary between 400 and 2000 ppm (parts per million) while outdoor CO$_2$ levels are 350–450 ppm and also heavily industrialized or contaminated areas may occasionally have a CO$_2$ concentration of up to 800 ppm. Moreover, with very heavy traffic area the levels of outdoor CO$_2$ are higher [1, 2].

Carbon dioxide levels are a replacement for measuring indoor pollutants. Unusually high indoor carbon dioxide levels may cause occupants to grow drowsy, get headaches, or function at lower activity levels. Prime indoor source of carbon dioxide is human. Indoor carbon dioxide levels indicates of the suitability of outdoor air ventilation relative to indoor occupant density. Indoor carbon dioxide level must be reduced to below 600 ppm to eliminate most indoor air quality complaints [3]. The US National Institute for Occupational Safety and Health (NIOSH) considers that indoor CO$_2$ concentrations that exceed 1,000 ppm suggest inadequate ventilation. The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) recommends that the CO$_2$ levels not exceed 1,000 ppm within an occupied space [4].

2. METHODOLOGY

Three carbon dioxide sensor nodes were designed measure indoor gas concentrations, store these measurements in memory, and to operate at low battery powered voltages. These sensor nodes will eventually be coupled with wireless radio devices to be deployed as wireless sensor nodes in the near future and must therefore operate for long periods of time with minimum power consumption. The CDM4161 carbon dioxide sensor module from Figaro Engineering Inc., Japan was selected for its high selectivity to CO$_2$, compact size, low power consumption and maintenance free operation. The sensor detection range of 400 to 4,000 ppm is the concentrations that are of interest in many indoor environments. The sensor output is then connected directly to the analog-digital convertors of an ATmega128 micro-controller. The node is powered from six AA-sized alkaline batteries providing 9.0 V supply voltage and regulated to 5.0 V for both the ATmega128 and sensor module.

The sensor requires a warm-up period of two hours after the module is powered up. By assuming that the baseline level represents fresh air (400 ppm of CO$_2$), actual CO$_2$ concentrations are calculated based on the difference between the baseline level and the current sensor output. As a result, accurate readings cannot be expected if an accurate baseline is not provided. If the module is warmed up in an environment where the CO$_2$ concentration is higher than normal fresh air, the baseline will represent a polluted level. Power to the module should be on at all times. Since the
baseline is memorized in a microcomputer, if the power should be cut off, the memory would be lost and operation would resume from the warm-up process. The module is designed for indoor use and should be protected from exposure to rain, wind, sun and heat radiation.

This preliminary investigation was focused on examining the air quality in three indoor environments: Public spaces, private home, and public transport.

3. RESULTS & DISCUSSION

The three sensor nodes were deployed into two lecture theatres at the university one was a large 250 seat theatre with an older air-conditioning system, and another was a newly refurbished 120 seat theatre with a modern air-conditioning system. Measurements were commenced in the first theatre at 12.00 noon with a class of 100 students for a period of approximately 1 hour and 50 minutes. The sensors were placed at desk height (approximately 800 mm from the floor level) at the front, middle and rear of the theatre. As the lecture theatre was occupied prior to this session, the CO₂ concentration in the theatre was between 500 and 800 ppm at the start of the data collection period. The results indicate that the CO₂ level in the middle of the theatre reduced to 400 ppm after 1 hour, but the levels at the rear and front initially increased to a maximum of 700 and 900 ppm, respectively, before gradually reducing to a steady level of 600 and 800 ppm during the second hour of the session. As the front of the theatre was much lower than the rear, the denser CO₂ was concentrated at the front and remained at a level between 700 and 800 ppm event though the levels at the middle and rear have improved as shown in Figure 1.

Similar measurements in a newly refurbished lecture theatre indicate that the ventilation was adequate for an audience of 30 students as shown in Figure 2. The three sensors were placed in the empty theatre before the commencement of the class, and confirmed that the levels of CO₂ were similar to that of the ambient environment. Carbon dioxide levels increased from 400 to levels between 600 and 800 ppm once the students entered the theatre and remained at these levels throughout the 80 minute session. It can be seen that the ventilation at the rear of the theatre was less efficient with CO₂ concentration at approximately 800 ppm whereas the concentration at the front and middle was only 600 ppm.

In order to examine the levels of carbon dioxide in various public transport modes, a sensor mode was carried into a typical tram. The CO₂ sensor was placed near at approximately foot level (approximately 80 mm above the floor level) at the front of the tram. The sensor was brought into the tram when it was almost full with passengers as indicated by a high CO₂ reading of 1150 ppm immediately upon entry as shown in Figure 3. The CO₂ concentrations gradually declined from the peak of 1150 to 600 ppm as passengers alighted from the trains and air exchanged with the exterior through the opening and closing of the doors at each stop. This elevated CO₂ level indicate that although the tram was equipped with a ventilation system, the CO₂ concentration only showed some improvements when more than half the passengers have alighted from the tram.

Similar measurements were carried out in a room located on second floor of a two-storey de-
Figure 2: CO\textsubscript{2} concentrations at the engineering faculty.

Figure 3: CO\textsubscript{2} concentrations in a typical tram.

Figure 4: CO\textsubscript{2} concentrations in a room with a single adult occupant.
tacked house. The CO₂ measurements were taken from 9:30 pm to 9:00 am in following day to investigate the efficiency of the natural ventilation system present within the room. This room was not mechanically ventilated or air-conditioned. This room was occupied by a single adult who was sleeping in the room from 9:30 pm until 4:30 am. It is clear that the CO₂ concentration increased immediately at 9:30 pm until it reached a steady state condition at about 11:00 pm as shown in Figure 4. The maximum CO₂ concentration was constant at 580 ppm for the entire duration until 4:30 am when it started to decrease gradually to the ambient level of 400 ppm. This result clearly indicates that CO₂ levels within a room in a house can increase significantly if the windows and door are kept closed.

4. CONCLUSION

The results clearly indicate that the CO₂ concentrations can give an indication of the indoor air quality in these indoor and enclosed environments. It serves as a measure of ventilation efficiency in areas where air-conditioning and mechanical ventilation is provided. This preliminary investigation has shown that in an older lecture theatre, CO₂ levels may exceed the levels that have been suggested to cause occupants to grow drowsy, get headaches, or function at lower activity levels. Similar investigations in public transport have shown that elevated levels of CO₂ are present when the tram is near to capacity and these concentrations remain for long durations.

Although the monitoring of CO₂ in a house has indicated that the concentration has not reached unhealthy levels, it will be worth comparing this result with the effects of forced ventilation. Future work will focus on the deployment of a number of wireless sensor nodes equipped with CO₂, temperate and humidity sensors to investigate a range of air quality parameters in similar spaces and to develop strategies for managing indoor air quality concerns with these novel sensor technologies.

REFERENCES