Iran J Public Health, Vol. 45, Suppl. Issue No. 1, Feb 2016, pp.93-99

Original Article

Smart Co2 Detector Prototype Development to Enhance the Efficiency of Ventilation System in a Building

*Mohd Hanif MOHD ZIN, *Sharifah Norkhadijah SYED ISMAIL, Karmegam KARUPPIAH*

Dept. Environmental and Occupational Health, Faculty of Medicine and Health Science, Universiti Putra Malaysia, Serdang, Malaysia

***Corresponding Author:** Email: norkhadijah@upm.edu.my

(Received 20 Nov 2015; accepted 24 Jan 2016)

Abstract

Background: : This study developed a smart CO_2 detector, which attach to the general ventilation system to reduce the gas level.

Methods: Indoor air quality measurement was performed in five selected rooms between January 2015 to February 2015 using TSI Q-Trak™ Indoor Air Monitor 7575. The perceived indoor air quality conditions was gathered using questionnaires adopted from the Industrial Code of Practice (ICOP) of Indoor Air Quality 2010 by the Department of Occupational Safety and Health (DOSH). The AutoCad 2010 and Soldworks 2011 software were used to design and develop the CO_2 detector.

Results: The highest concentration of CO_2 was determined in the occupied tutorial room (1435 ± 62.6 ppm) followed by lecture hall 3 (1337.67± 14.6 ppm) and lecture hall 4 (1109 ± 4.0 ppm). The highest temperature was recorded in occupied tutorial room (29 ± 0.3 ºC) while the highest relative humidity was recorded in occupied lecture hall 4 (76 ± 3.1 %). All of these values exceed the ICOP standard level. Varying room temperature was the most common problem reported (n = 34, 22.7%) followed by unpleasant odors (n = 22, 14.7%) and drafty (n = 21, 14%). The CO_2 sensor attached to the general ventilation system triggers the ventilation system to regulate the air into the building more efficiently when CO^2 exceeds 800 ppm. The detector may stop the system when the pollutants level is back to normal.

Conclusion: The CO_2 detector system helps to regulate the air movement and reduce the CO_2 level.

Keywords: Carbon dioxide, General exhaust ventilation (GEV), Sick building syndrome (SBS), Indoor air quality

Introduction

Indoor air quality (IAQ) is defined as the air quality within and around buildings. It relates to the health and the comfort of building occupants. Carbon monoxide (CO), formaldehyde (HCHO), volatile organic compound (VOC), nitrogen oxides (NOx), respirable particulates matter (RPM), radon and asbestos are the indoor air pollutant (IAP). Carbon Dioxide (CO_2) is the common pollutants of indoor air in a building (1). These pollutants produce negative adverse health symptoms such as headaches, dizziness, irritated eyes, sneezing, coughing, difficult breathing and inability to work or study. High level of indoor CO_2 may produce symptoms of headaches, dizziness and sleepiness (2).

The source of indoor CO_2 is mainly from human's exhalation (3). "Although CO_2 is not considered to pose serious health risks to the occupants, elevated levels of CO_2 may serve as an indicator of insufficient ventilation" (4). High concentration of indoor CO_2 is lead to low amount of fresh air in the building. According to Industrial Code of Practice on Indoor Air Quality (ICOP 2010), Department of Occupational Safety and Health, Ministry of

Human Resources, Malaysia, ventilation performance indicator for CO_2 is 1000ppm or below per eight-hour time-weighted average airborne concentration. The concentration of indoor CO_2 under normal condition is 250-350 ppm. Occupants in a workplace tend to report drowsiness and lethargy when the CO_2 between 1,000 ppm to 5,000 ppm. Prolong exposures to high CO_2 is dangerous to human health. Serious injury, coma, even death could happen with the level of CO_2 exceed 40,000 ppm.

General ventilation (GV) system is a system that works within a building to regulate or improve the IAQ. This system is commonly used to supply fresh air to an enclosed space in a building to refresh, remove, or replace the contaminants such as fumes, dusts or vapors. General ventilation is also called as dilution ventilation. GV system captures the emissions at their source and removes them from the air by allowing the contaminant to be emitted into the workplace air and dilute the concentration of the contaminants to an acceptable level (5). Continuous running of ventilation system in a building is energy consumption. The ventilation system only can control the temperature by removing hot air and replacing outdoor air in building but not control the level of indoor pollutants (6). It has no detector to determine the level of pollutants and the efficiency of the ventilation system was not being measured. Theoretically, the programmed CO_2 detector triggers the ventilation system to regulate the air into the building more efficiently when the level of CO_2 exceeds the limit. The detector may stop the system when the pollutants level is back to normal. The CO_2 detector may reduce the energy consumption of the building and efficiently improve the IAQ. In order to achieve this objective, the level of CO_2 as a baseline information in the selected rooms of a building was measured. The smart CO_2 detector prototype was developed using the design software and fabricate as a product. The system that was developed in this study theoretically improves the IAQ level and reduces the energy consumption of the GV. This system contributes to the green technology.

Therefore, this study was aimed to develop a smart CO_2 detector, which can be attached to the general ventilation system of a building to enhance the system and to reduce the energy consumption.

Materials and Methods

This study was conducted from December 2014 to April 2015. The measurement of indoor CO_2, humidity and temperature was performed for three times using TSI Q-Trak TM Indoor Air Monitoring 7575 device. The measurement was conducted in occupied and unoccupied five selected rooms in the faculty between 10:00 am to 1:00 pm during fine sunny weather. The perceived indoor air quality conditions reported for the last three (3) months was gathered using questionnaires adopted from the Industrial Code of Practice of Indoor Air Quality 2010, Department of Occupational Safety and Health (DOSH), Ministry of Human Resources, Malaysia (7). AutoCad 2010 and Soldworks 2011 software were used to develop the CO_2 detector prototype. The prototype was designed as the conceptual designs based on the characteristics determined or specified by the researcher. The detail prototype design from the best conceptual designs was finalized. This detail design includes the simulation of the prototype, schematic diagram, each component design and full prototype design. Finally, the prototype of CO_2 detector from the detail design was fabricated as a product. Design verification test (DVT) method was used to verify the prototype function. The functional testing was used to test the completed prototype function and follow all sequences operation smoothly.

Results

Table 1 highlights the description of building involved in this study. Five rooms in the university building using centralized air-conditioning system unit were selected in this study. The system was maintained every month by the contractors and daily checking was done by the staff. The lecture halls were the biggest room, which can occupy more than 190 students at one time. The tutorial room has varied size, which meant for small discussion session. All lecture halls and tutorial rooms have no windows except they have four exit doors.

The lab and the management office have open able blind windows, which frequently open when the room is too cold or too warm. The highest rate of VDU usage is for the management office which all the staff use computer directly in their daily job scope. The characteristic of the rooms for example windows, type of ventilation unit, the VDU usage and size of the room are the factors that influenced the level of pollutants in IAQ.

Table 2 shows, the concentration of CO_2, temperature (ºC) and relative humidity (%) in each building.

Table 1: Building descriptions

Rooms	Size (m²)	Building block	Windows	Air supply	VDU use (%)	Occupants (N)
Lecture hall 3	10,000	Block A	No	Centralized	> 80	193
Lecture hall 4	10,000	Block A	No	Centralized	> 80	193
Tutorial room	4,100	Block A	No	Centralized	> 80	40
Lab	8,437	Block C lab	Openable blinds	Centralized	40-50	70
Management office	1,462	Block C	Openable blinds	Centralized	> 80	10

Note: All rooms are no smoking area and the building aged 9 yr old

The highest concentration of CO_2 was determined in tutorial room (with occupants) with the mean ± SD of 1435 ± 62.6 ppm followed by lecture hall 3 (1,337.67± 14.6 ppm) and lecture hall 4 (1,109 ± 4.0 ppm). The highest temperature was recorded in tutorial room 2 (29 ± 0.3 ºC, with occupants). Lecture hall 4 and lab were recorded with the highest relative humidity with the mean ± SD of 76 ± 3.1 % and 70 ± 0.5 % respectively. All of these values exceed the ICOP standard level as stated in the Table 2.

Table 3 shows the perceived indoor air quality conditions reported by 150 respondents for the last three (3) months in this study. Varying room temperature was the most common problem reported (n = 34, 22.7%) followed by unpleasant odors (n = 22, 14.7%), drafty (n = 21, 14%), dust and dirt (n = 17, 11.3%), and cold room temperature (n = 16, 10.7%). 10% (n = 15) of respondents reported warm room temperature and stuffy bad air (n = 11, 7.3%). Most of the problems occur in 2 to 3 times a week.

Table 2: The level of CO_2, humidity, and temperature in the building with and without occupants

	CO_2 (ppm)		Temperature (ºC)		Relative humidity (%)	
	Without occupants	With occupants	Without occupants	With occupants	Without occupants	With occupants
Lecture hall 3	[b] 891± 9.0	1338 ± 14.5	21 ± 0.1	25 ± 1.4	57 ± 0.6	56 ± 1.2
	[c] 882 – 900	1326 – 1354	21-23	24 – 27	55-57	55 – 57
Lecture hall 4	820 ± 14.0	1109 ± 4.0	25 ± 0.6	26 ± 0.0	71 ± 2.9	76 ± 3.1
	807 – 835	1105 – 1113	25 – 26	26-27	68 – 74	72 – 78
Tutorial room 2	815 ± 4.4	1435 ± 62.6	23 ± 1.3	29 ± 0.3	53 ± 3.3	65 ± 0.4
	812 – 820	1363 – 1479	21 – 24	29 – 30	49 – 56	65 – 66
OSH lab	601 ± 10.7	738 ± 26.6	23 ± 0.1	24 ± 0.1	66 ± 0.2	70 ± 0.5
	589 – 610	710 – 763	23 – 24	24-25	66-68	69 – 70
Management Office	624 ± 9.3	707 ± 3.8	25 ± 0.1	26 ± 0.5	48 ± 0.7	51 ± 1.0
	618 – 635	703 – 710	25-26	26 – 27	47 – 49	50 – 52
Reference values [a]	1000 ppm		23 – 26 ºC		40 – 70 %	

Note: [a] the reference value based on the acceptable limit in the Industrial Code of Practice on Indoor Air Quality 2010 (DOSH, 2010), [b] the mean ± SD, [c] range concentration

Table 3: The perceived indoor air quality conditions reported for the last three months

Variables	Report of variables		
	[a] Often (%)	[b] Sometimes (%)	None (%)
Varying room temperature	34 (22.7)	97 (64.7)	19 (12.7)
Unpleasant odor	22 (14.7)	95 (63.3)	33 (22.0)
Drafty	21 (14.0)	94 (62.7)	35 (23.3)
Dust and dirt	17 (11.3)	87 (58.0)	46 (30.7)
Dry air	16 (10.7)	105 (70.0)	29 (19.3)
Room temperature too cold	16 (10.7)	95 (63.3)	39 (26.0)
Room temperature too warm	15 (10.0)	108 (72.0)	27 (18.0)
Stale air	11 (7.3)	104 (69.3)	35 (23.3)

Note: [a] every week, [b] one times/month

Figure 1(a) shows the schematic diagram of the CO_2 detector functioning. All systems were programmed using the MPLAB C Language programming. Based on the ICOP (2010), CO_2 sensor was set to detect and trigger the alarm and the exhaust fan when the concentration exceeds 800 ppm. In addition, the sensor of humidity and temperature were also function to detect the value of humidity and temperature in percentage (%) and degree Celsius (°C) in the room. All values were appeared in the screen. Figure 1(b) shows the three dimensions (3D) drawing of a prototype detector that was placed in the building in the isometric view. The simulations of the system were built using the Solidworks 2011. The systems start from the detection of CO_2 by CO_2 sensor and sent the information to the programmed circuit board. The circuit board manipulate the information to trigger the exhaust fans after the concentration exceed the programmed limit which is 800ppm and above. The exhaust fans were stopped after the concentration lower than 800ppm. Figure 1(c) shows the CO_2 detector while its function.

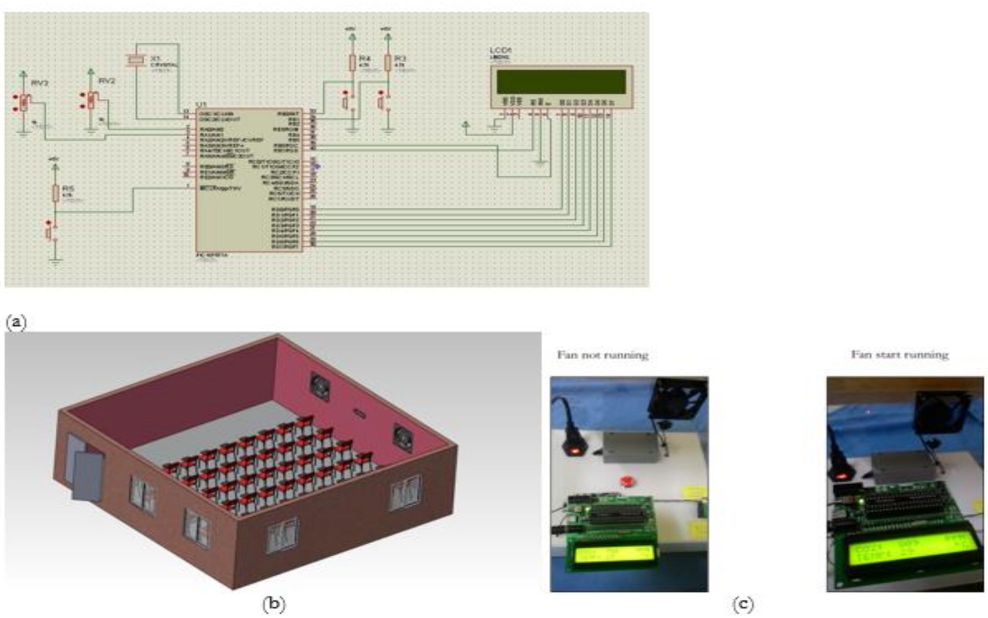

Fig. 1: (a) shows the schematic diagram of the CO_2 detector functioning, (b) three dimensions (3D) drawing of a prototype detector, (c) the CO_2 detector while functioning

Discussion

The CO_2 level in this study exceeds the acceptable limit of 1000 ppm of Industrial Code of Practice on Indoor Air Quality (ICOP 2010) and it is an indication of inadequate ventilation. High CO_2 in these rooms was possibly due to the inappropriate ventilation system, which leads to low outdoor air supply rates (8). The need to reduce energy consumption provides an incentive for low rates of ventilation that lead to high indoor CO_2 concentrations (3). Other factors that cause high CO_2 was possibly due to small room size and high number occupants at one time. In some condition, the level of CO_2 increased because of the physical activities level. Seated or quiet position is the lowest level of activity while exercise is the highest activity level produce CO_2 (9).

The temperature was recorded as high in the tutorial room, which exceeded the permissible range of 23 – 26 °C (7). This was possibly due to small space and high occupants in the room (3). Humans produce heat from their body naturally through the physical activity in the building (3). Humidity in lecture hall 4 also was recorded as the highest (>70%) and exceed the standard (7). This was possibly due to improper functioning of the ventilation system in the room. The number of occupant's plays important role that increased the humidity through the exhaled air. Relative humidity was also influenced by the room temperature because warmer air in the room can hold more moisture then colder air (10).

Varying room temperature was the most common problem reported followed by unpleasant odors, drafty, dust or dirt, dry air and cold room temperature. Varying room temperature was possibly occurred due to the improper function of air ventilation system in the room. Poor design, maintenance, and/or operation of the structure's ventilation system also may be at fault (11). Study by Aizat et al., (12) also indicates that air movement was associated with the complaints of varying temperature indoors. In addition, when the occupants lifestyle and activities are sedentary, they generally feel thermally neutral or cooler, with air movement being perceived as unacceptable at a temperature of up to 26ºC - 32ºC, even at low air movement (13). The room temperature will increase when total occupants increase (14). Study by Fadilah et al. also reported dizziness or light headed as the main symptoms among office workers between new and old building in UPM, Serdang (15). This was related to the increase of the occupants in the building. The study also has reported that the symptoms would be reduced by introduce the outdoor air supply into the building (15).

The CO_2 detector prototype detects the CO_2 concentration in a building. The detection sensor of CO_2 in the prototype triggered the system to switch on the GEV and regulate the air into the building. The system works with the voltage and alternative current 240V. The power supply that have transformer step down were used to convert alternative current 240V to direct current 12V to supply to the prototype system. Emergency stop-button was used in this system to enhance safety of the prototype. It used to cut off the current if something goes wrong while the prototype is running. The programmed Peripheral Interface Controller (PIC) and motor controller board were used to read the reading from the sensor of CO_2, humidity and temperature to produced instructions to switch on the fan and buzzer. The guideline from ICOP 2010 indicates that the occupant starts to report SBS symptoms at 1000 ppm CO_2. The programmed PIC and motor controller board were set to the concentration of 800 ppm CO_2 to ensure the ventilation rate in the building in good condition. The sensor of CO_2 was programmed to switch on the exhaust fan if the CO_2 exceed 800ppm. Once the CO_2 level back to normal range the exhaust fan stop running. The CO_2 sensor was calibrated using the Plug'N'Grow CO_2 sensor calibration kit. The CO_2 concentration of the detector system was measured concurrently with TSI Q-Trak device to check the validity of the detection system.

Conclusion

The research findings highlight, the highest concentration of CO_2 was determined in the room with occupants. High CO_2, which exceed the acceptable limit, is an indication of inadequate ventilation. The highest temperature was recorded in tutorial room was possibly due to small room size and high occupants. Lecture hall 4 was recorded with high humidity and was possibly due to the improper functioning of the ventilation system in the room. Varying room temperature was the most common problem of IAQ reported. While doing this research, we have observed some of the limitation. The CO_2 detector prototype in this study was mainly focused on the CO_2, temperature and humidity parameters. However, other indoor air quality parameters also influenced the IAQ of the building. These were not being considered in the present study due to limited time and resources. Future study maybe would consider other parameters included in the prototype to enhance the system of pollutants detection in the building. The present prototype is only for general ventilation GEV system, which can be, improved in future research for other type of ventilation system.

Ethical considerations

This research has received an ethical clearance from the Medical Research Committee, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia. Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

Acknowledgments

We would like to thank all subjects who volunteered to participate in this study. Special thanks to the Department of Environmental and Occupational Health, Universiti Putra Malaysia for giving various kinds of support in this research. Special thanks to Mr. Nor Mohamad Razif bin Nurani and Mr. Faizal Reza for their ideas and critical evaluations of this article. The authors declare that there is no conflict of interest.

References

1. Lee SC, Maureen C (1999). Indoor Air: Indoor air quality investigations on Five Classrooms, Denmark. *Indoor Air,* 9(2): 134–138.
2. Mohd Ezman Z, Juliana J, Nafiz S (2013). Indoor air quality and prevalence of sick building syndrome among office workers in two different offices in Selangor. *Am J Appl Sci,*10(1):1140-1147.
3. Satish U, Mendell MJ, Shekhar K, Hotchi T, Sullivan D, et al. (2012). Is CO_2 an indoor pollutant? Direct effects of low-to-moderate CO_2 concentrations on human decision-making performance. *Environ Health Perspect,* 120: 1671– 1677.
4. Mario C, Antonio M, Giuseppina N, Giovanni P (2014). A Dynamic Fuzzy Controller to Meet Thermal Comfort by Using Neural Network Forecasted Parameters as the Input. *Energies,* 7; 4727-4756.
5. Kelsey A, Batt R (2012). Effects of Local and General Exhaust Ventilation on Control of Contaminants. VENTILATION 2012 - The 10th International Conference on Industrial Ventilation, Paris, 17 - 19 September 2012. Institut National de Recherche et de Sécurité (INRS).
6. Chew BT, Yau YH (2014). Adaptive thermal comfort model for air-conditioned hospitals in Malaysia. *Build Serv Eng Res Technol,* 35 (1): 23-35.
7. Department of Occupational Safety and Health (DOSH) (2010). Industrial code of practice on indoor air quality. Ministry of Human Resources, Malaysia.
8. Robertson AS, Burge PS, Hedge A, et al. (1985). Comparison of health problems related to work and environmental measurements in two office buildings with different ventilation systems. *BMJ,* 291: 373–376.
9. Andrew KP (1997). Evaluating building IAQ and ventilation with indoor carbon dioxide. *ASHRAE*, 41: 39-48.
10. Seppanen OA, Fisk WJ, Mendell MJ (1999). Association of ventilation rates and CO_2 concentrations with health and other responses in commercial and institutional buildings. *Indoor Air,* 9(4):226-252.

11. ASHRAE (2004). Standard 55: Thermal environmental conditions for human occupancy. ASHRAE: Atlanta.
12. Aizat IS, Juahir H, Mohd Rafee B, Ahmad Zaid FA, Zulkapri I, Ismail Z, Katis S (2013). Gender, airborne chemical monitoring, and physical work environment are related to indoor air symptoms among nonindustrial workers in the Klang Valley, Malaysia. *Ther Clin Risk Manag,* 9: 87—105.
13. Toftum J (2004). Air movement – good or bad? *Indoor Air*, 14: 40-45.
14. Shirley JH, Burroughs HE (2004). *Managing indoor air quality*. 3rd ed. The Fairmont Press, Inc. Georgia, pp.: 191-263.
15. Fadilah RN, Juliana J (2012). Indoor air quality (IAQ) and sick buildings syndrome (SBS) among office workers in new and old building in university. *Health Environ J*, 3(2): 98-109.