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The Impacts of Elevated Carbondioxide (CO_2) on Users' Comfort in Residential Building at Bawak-Sabo, Auchi, Nigeria

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This research work establishes the effects of CO_2 on users' comfort in residential building with specific residential neighborhood in Bawak Sabo as the study area. There is an existing complaint of sneezing, tiredness, sweating and headache at dawn from resident of this neighborhood documented in a medical report of a medical hospital within the community. The research is set to investigate the cause of these problems. The methodology adopted was the combination of experimental-field survey and review of existing literature. Measurement of CO_2 concentration was conducted in a given 10% sample population (cases). Measurement was taken in tenement and bungalow accommodation of varied room sizes (9.0m^2 and 12.6 m^2 floor area), population (one to two occupants per room) and window opening adjustment. Measurements were taken 8 hours day time and twilight with varied user activity and ventilation rate respectively. The results show that CO_2 concentration was higher in rooms with larger numbers of persons. CO_2 concentration was closely related to room size and density and increased rapidly when doors and windows were locked. Elevated carbondixoide was low in bungalow accommodation with more numbers of window openings in comparison with tenement accommodation. Differential levels of CO_2 concentration have negative impacts on the users' in ways such as shortness of breath, sneezing sweating and increased breath rate among others. It was concluded that CO_2 concentration was responsible for the reported discomfort experienced by Bawak-Sabo residents.

Keywords: *CO_2 concentration, Window opening, Users' comfort, Bawak-Sabo, Daytime, Twilight*

1. Introduction

Carbondioxide (CO2) is a major greenhouse gas. The gas is not harmful, but higher concentration causes carbondioxide poisoning and intoxication. Indoor CO2 concentration is an important factor to evaluate the level of ventilation in buildings. Studies have shown that outdoor CO2 concentration is about 400ppm, higher in urban centres(ASTM, 2014; Persily, 1997; and Seppanen et al., 2006).Increases of outdoor CO2 concentration in cities are due to high use of fossil-fuel energy and industrialization.

However, indoor CO2 concentration is higher in comparison to the outdoor and increases in indoor CO2 is significantly depends on the number of occupants in an apartment. Using CO2 as an indicator of ventilation, indoor CO2 concentrations is recommended to be maintained at or below 1,000 ppm in schools and 800 ppm in offices (ASHRAE, 2010).

It is very important to measure indoor CO2 concentration for maintaining acceptable ventilation comfort in residential buildings. Accurate measurement outdoor and indoor CO2 concentration is useful to design Demand Controlled Ventilation System (DCV) in buildings. Having established the importance of concentrated CO2 in residential buildings, this simulated the research study to measure elevated CO2 using 8-hour for daytime and twilight at Bawak-Sabo, Auchi for various apartments and occupant's density. The output of the research will be applied to determine the correlation between high-elevated CO2 using different ventilation mechanisms and occupancy densities. Overall impacts would be tested whether it has negative effects on occupants' health.

2. Research methodology

The methodology adopted was the combination of experimental-field survey and literature review of existing literature. Field survey method included measurement and interview. Measurement of CO_2 concentration was conducted in a given 10% sample population (cases) with valuable primary data. Interview conducted in the given studied population provided the needed primary feedback of users experience under varied CO_2 concentration.

2.1. Population of the study

The population of the study comprises majorly of students but with sprinkling adult local populace, who lived in owner occupied bungalows. There are 30 numbers of residential dwellings. This is categorized as follows:

i. Bungalow – 10 buildings x 5rooms /building/5 occupants, Room type measuring: (3.6 m x 3.6 m) of floor area 12.96 m^2, two window opening (.1.2 m x 1.2 m) located adjacent to the other, fitted with sliding windows located on the external wall for ventilation.(fig.4)

ii. Self-contained – 20 buildingsx10 room/ building

There are two distinct room sizes in the self-contained buildings:

i. Room type 1: measuring (3.0 m x3.0 m), of floor area 9 m^2, excluding kitchen and toilet floor area of ($1.2m^2$) each. The room window opening (0.6 m x 1.2m), the kitchen (0.6 mx 0.6 m) and toilet (0.6 mx 0.6 m) are fitted with sliding windows located on the external wall for ventilation.(Fig. 2)

ii. Room type 2: measuring (3.6 m x3.6 m), of floor area ($12.96m^2$), with separate kitchen and toilet floor area of $1.44m^2$ each. The room opening (0.9 x 0.9m), the kitchen (0.6 m x0.6 m) and toilet (0.6 m x 0.6m) are fitted with sliding windows located on the external wall for ventilation (Fig.4). 50 % of the self-contained rooms had 2persons per room while remaining 50% had one occupant each. Adult of both sex totaling 350 persons drawn from healthy population lived in the studied area. The average headroom was 2.9m high.

2.2. Sampling technique

Purposive sampling method was used because; it allows a researcher select only such items or subjects that suit his or her purpose. Thus, 5 rooms (10%) out of 50 rooms in bungalow building and 20 rooms (10%) of self-contained building were selected in the studied area. The 20- self-contained buildings contain 10 rooms each per block. 50% of the rooms had 2 occupants per room and the remainder (50%)-1 occupant per room.

2.3 . Instrument for data collection

This research work is purely scientific. The essential instrument for data collection is by experiment. Experiment was conducted using CO_2 Meter AZ-0004 with specific user population, sample buildings, readings were obtained based on meters log and accurate calibration. Measurement accuracy of the instrument ± 40ppm ±3%

2.4 . Validity of the instrument

The instrument was calibrated to determine its actual resolution and accuracy before used for measurement on the field. The logger was adjusted to appropriate setting. The recommended mounting technique, distance, applied altitude, temperature, humidity and pressure were applied. The sample spaces were structured and the population well-being was technically selected to justify valid result. The following steps were taken to reduce any element of measuring errors:

2.4.1. CO_2 meter location

CO_2 transmitter (logger) was located off where person may breathe directly into the sensor. CO_2 transmitter (logger) was located off intake and exhaust duct or near windows and door ways Wall mounted sensor was applied in demand controlled ventilation (DVC) which is best for accurate reading measurement on ventilation effectiveness than duct mounted sensor.

2.4.2. Automatic baseline calibration (ABC)

Automatic baseline calibration was employed in the study within the period of experiment. Each morning before the experiment, the indoor CO_2 level return to equilibrium with outdoor concentration. This was possible because the period between 6p.m and 8a.m no occupant was present in the sample building. Therefore the loggers detect minimum CO_2 level and compute a new baseline of 400ppm. Automatic calibration was suitable in this study and its errors were minimized

2.4.3. Altitude Compensation

As gas pressure declines exponentially, fewer CO_2 molecules enter the fixed NDIR sensor chamber at high attitude, despite the relatively constant 400ppm CO_2 in the troposphere. Failure to set the correct elevation could result in CO_2 concentration error of 1-5% or more depending on the elevation when the wind is steady and the pressure fairly constant. To avoid altitudinal influence, ground floor areas of sample buildings were used.

2.4.4. Differential measurement to improve relative accuracy

To reduce the impact of calibration errors, two CO_2 loggers were deployed for differential measurements. Differential measurements values are the best indicator for ventilation performance and additive co_2 internal source calculation.

2.5. Data collection and analysis

Reading of CO_2 meters was recorded accurately. The following factors were considered in during the data collection:

Key consideration before and during measurement:

- Established rooms Altitude in building using digital altimeter.
- Established daytime and Twilight CO_2 reading with varied windows and door conditions.
- Establish Twilight CO_2 reading with varied windows and door conditions.

- Achieve CO_2 equilibrium in rooms prior to first reading.
- Restricted visitor's access to room under investigation at measurement time to prevent CO_2 concentration fluctuation.
- Detail of effect of CO_2 was kept away from volunteer to avoid premeditated response and fear factor that could affect result.
- Medical personnel were handy for medical
- Private power generator with energy saving bulb were deployed and used at twilight.
- No artificial ventilator utilized. Figs 1-5 indicate different classes of accommodation and occupant (Room type) considered for this research

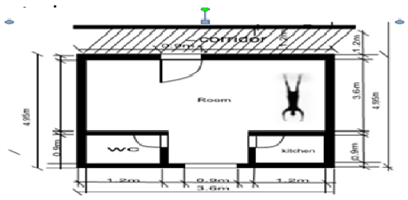


Figure 1. Accommodation with an occupant

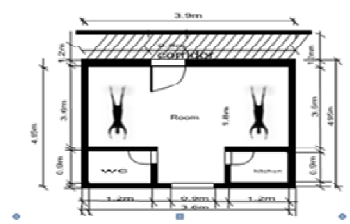


Figure 2. Accommodation with (2) occupants

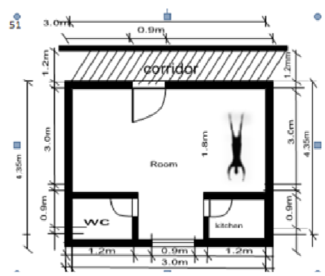


Figure 3. Accommodation with an occupant

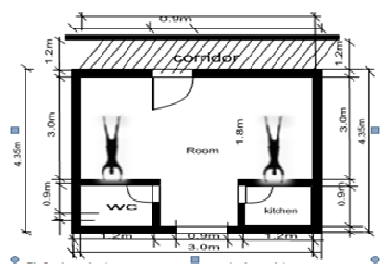


Figure 4. Accommodation with two occupants

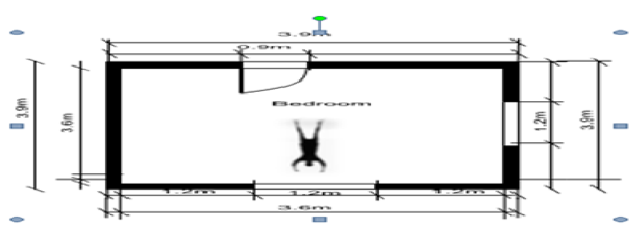


Figure 5. A typical bedroom in bungalow accommodation with one occupant.
Source: Researchers field work 2016

2.4 . Comparison of CO_2 meter and estimated carbondioxide

Carbon dioxide concentrations in rooms with persons after a time (t) were estimated as follows:

$$C = \left(\frac{q}{nv}\right)\left[1 - \frac{1}{ent}\right] + (C_o - C_i)\left(\frac{1}{ent}\right) \tag{1}$$

Where:

C = carbon dioxide concentration in the room (m^3/m^3);q = carbon dioxide supplied to the room (m^3/h)V = volume of the room (m^3);e = the constant 2.718.;n = number of air shifts per hour (1/h) t=time (hour, h); c_i =carbon dioxide concentration in the inlet ventilation air (m^3/m^3); c_0 =carbon dioxide concentration in the room at start, t =0 (m^3/m^3); CO_2 Concentration Calculator; q -Carbon dioxide supplied to the room (m^3/h); V -Volume of the room (m^3); n -Number of air shifts per hour (1/h);t -Time (hour, h); c_i -carbon dioxide concentration in the makeup air *) (m^3/m^3) C_0 -carbon dioxide concentration in the room at start, t = 0 (m^3/m^3)

3. Results and discussion

The concentration of the exhaled CO_2 after 8hrs of measurement from logger was summarized above with minimum log 417 ppm and maximum log 14487 ppm respectively (Tables 1 and 2). This study challenges conventional acceptability that CO_2 concentrations of 1000 ppm are acceptable occupational limits in the living environment. It shows that CO_2 concentrations of 690 ppm are acceptable occupational limits in the living environment. However, test learning ability against CO_2 concentration was not tested, but it clearly shown impaired cognitive and decision-making abilities, which could impact student reasoning and test score.

Table 1a. 8-hr CO2 readings for one occupant in without exhaust vent.(Case 1-5)

Time	ACH	Rep	CO_2	CO_2	CO_2	CO_2	CO_2	CO_2	CO_2	CO_2
Daytime	1.00	R	739	739	739	739	739	739	739	739
Twilight	1.00		567	567	567	567.0	567.0	567.0	567.0	567
Twilight	0.67		723	1046	1369	1692.0	2015.0	2338.0	2661.0	2984
Twilight	0.33	S	1206	2012	2818	3624.0	4430.0	5236.0	6042.0	6848

Table 1b. 8-hr CO2 readings for Two occupant without exhaust vent.(Case 6-10)

Time	ACH	Rep	CO_2	CO_2	CO_2	CO_2	CO_2	CO_2	CO_2	CO_2
Daytime	1.00	R	1221.0	1221.0	1221.0	1221.0	1221.0	1221.0	1221.0	1221
Twilight	1.00		882.0	882.0	882.0	882.0	882.0	882.0	882.0	882
Twilight	0.67		1192.0	1984.0	2773.0	2561.0	4353.0	5146.0	5934.0	6726
Twilight	0.33	S	2161.0	3922.0	5683.0	7444.0	9205.0	10695.0	12726.0	14487

Table 1c. 8-hr CO2 readings for One occupant without exhaust vent.(Case 11-15)

Time	ACH	Rep	CO_2	CO_2	CO_2	CO_2	CO_2	CO_2	CO_2	CO_2
Daytime	1.00	R	589.0	589.0	589.0	589.0	589.0	589.0	589.0	589
Twilight	1.00		471.0	471.0	471.0	471.0	471.0	471.0	471.0	471
Twilight	0.67		579.0	758.0	937.0	1116.0	1295.0	1474.0	1653.0	1832
Twilight	0.33	S	704.0	1006.0	1309.0	1612.0	1915.0	2218.0	2521.0	2824

Table 1d. 8-hr CO2 reading for Two occupant without exhaust vent(Case 16-20)

Time	ACH	Rep	CO_2	CO_2	CO_2	CO_2	CO_2	CO_2	CO_2	CO_2
Daytime	1.00	R	926.0	926.0	926.0	926.0	926.0	926.0	926.0	926
Twilight	1.00		690.0	690.0	690.0	690.0	690.0	690.0	690.0	690
Twilight	0.67		905.0	1409.0	1914.0	2419.0	2924.0	3429.0	3934.0	4439.0
Twilight	0.33	S	1578.0	2756.0	3934.0	5112.0	6290.0	7468.0	8646.0	9824.0

Table 1e: 8-hr CO2 readings for one occupant without exhaust vent.(Case 20-25)

Time	ACH	Rep	CO_2	CO_2	CO_2	CO_2	CO_2	CO_2	CO_2	CO_2
Daytime	1.33	R	505	505.0	505.0	505.0	505.0	505.0	505.0	505
Twilight	1.33		417	417.0	417.0	417.0	417.0	417.0	417.0	417
Twilight	0.67		579	758.0	937.0	1116.0	1295.0	1474.0	1653.0	1832
Twilight	0.33	s	704	1006.0	1309.0	1612.0	1915.0	2218.0	2521.0	2824

Table 2. Effects of CO_2 on users of residential building in Bawak, Sabo, Edo State

	Summary of 8-hour CO_2 reading for daytime and twilight and effect on occupants based on interview and observation.								
Case 1-5	Daytime	741	741	741	741	741	741	741	741
	Effect			COGNITIVE			IMPAIRMENT		
	Twilight	567	567	567	567	567	567	567	567
	Effect	N /I	N /I	N /I	N /I	N /I	N /I	N /I	N /I
	Twilight	742	1050	1369	1692	2015	2338	2661	2984
	Effect	CI	CI	CD	PV	PV	PV	PV	PV
	Twilight	1208	2012	2818	3624	4430	5236	6042	6848
	Effect	CI	PV	PV	PV	UH	UH	SUB/A	SUB/A

Case 6-10	Daytime	1221	1221	1221	1221	1221	1221	1221	1221
	Effect	COGNITIVE IMPAIRMENT							
	Twilight	887	887	887	887	887	887	887	887
	Effect	COGNITIVE IMPAIRMENT							
	Twilight	1198	1984	2773	3561	4353	5146	5934	6726
	Effect		PV	PV	PV	UH	UH	UH	SUB /A
	Twilight	2161	3922	5683	7444	9205	10965	12726	14487
	Effect	PV (breath rate)		UH	SUB /A	SUB/A	SHR	SHR	SHR
Case 11-15	Daytime	589	589	589	589	589	589	589	589
	Effect	N /I WITHIN COMFORT LIMIT ,EFFECTIVE VENTILATION							
	Twilight	471	471	471	471	471	471	471	471
	Effect	N /I WITHIN COMFORT LIMIT ,EFFECTIVE VENTILATION							
	Twilight	579	760	939	1118	1298	1474	1653	1832
	Effect	NI	CI	CI	CI	CI	CD	PV	PV
	Twilight	706	1008	1306	1612	1915	2218	2521	2824
	Effect	CI	CI	CI	PV	PV	PV		
Case 16-20	Daytime	933	933	933	933	933	933	933	933
	Effect	COGNITIVE IMPAIRMENT							
	Twilight	690	690	690	690	690	690	690	690
	Effect	(N/I) UPPER COMFORT LIMIT(N/I)							
	Twilight	910	1409	1914	2419	2924	3429	3934	4439
	Effect	CI	CD	POOR VEVTILATION					UH
	Twilight	1578	2756	3934	5112	6290	7468	8646	9824
	Effect	CD	PV	PV	UH	SUB/A	SUB/A	SUB/A	SUB/A
Case 21-25	Daytime	505	505	505	505	505	505	505	505
	Effect	N /I WITHIN COMFORT LIMIT ,EFFECTIVE VENTILATION							
	Twilight	417	417	417	417	417	417	417	417
	Effect	N /I WITHIN COMFORT LIMIT ,EFFECTIVE VENTILATION							

Source: Field study, 2016

CI - Cognitive impairment characterized by loss of memory; **PV**- poor ventilation characterized by *Sweating, Increased Breath Rate, sneezing (suffocation) Fatigue .and drowsiness;* **N /I** - No impact; **CD**- cognitive dysfunction, *Stale Air , Inability to Assimilate and Concentrate;* ***UH****- unhealthy, characterised by Odour, Increase Breath Rate, dizziness;* ***SUB/A****- submarine air, characterized by Odour, Gasping for Breath, Increase Breath Rate,*

3.1. Shortness of breath

Concentration of high CO_2 in the breathing zone (case 6) depletes the level of fresh air quality in the personal breathing zone (Fig.8, 9; Table 1,2). The re-inhalation of exhaled CO_2 in the breathing zone occurs frequently due to poor air change rate or ventilation the re-inhalation of CO_2 through the nostril at the PBZ into the lungs deprived the body of the needed oxygen fuel to balanced metabolism and oxygenation of the brain and body cell. In a room of 26.1 m^3, with air volume 26.1m^3 comprising of 76 % nitrogen, 21% oxygen and 0.04% carbon dioxide. 21 % of 26.1m^3 amount to 5.4m^3 volume of oxygen in the room. At every one hour respiration, 0.3m^3 of air mix is taken out of room air and returned through inhalation and exhalation respectively. At every one hour, 21% of 0.3m^3 of inhaled air contains 0.06m^3 of oxygen by volume taken out of total 5.4m^3 oxygen constituent into the lungs, converted within the body system and exhaled as CO_2. Since 0.06m^3 oxygen withdrawn only 0.013m^3 of the 0.3m^3 of exhaled air contain carbon dioxide (4%) the difference (0.045m^3) diffuses into the blood stream for circulation and body metabolism. For eight hour respiration devoid of fresh air supply or air change of 0.3ACH,corresponding to closure of all windows and door , the total volume of oxygen consumed by conversion and metabolism amounts to (0.06m3x8h) =0 .48m^3 . On the other hand under the above condition, the volume of exhaled CO_2 after eight hour amount to (.013 m3x8h) =.104m^3. Thus substitution of .104m^3 CO_2, consumption and conversion of 48m^3 oxygen offset the oxygen balance in the room by 9%.

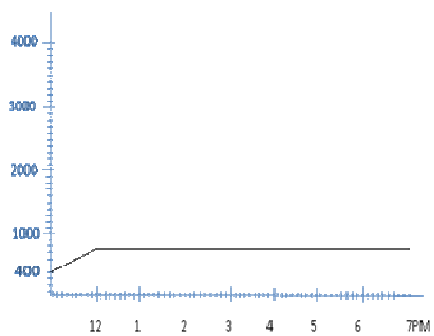


Fig 6. Case 1-5, ACH(1/h),Twilight–CO_2 ppm

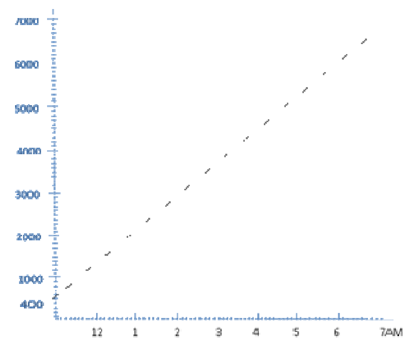
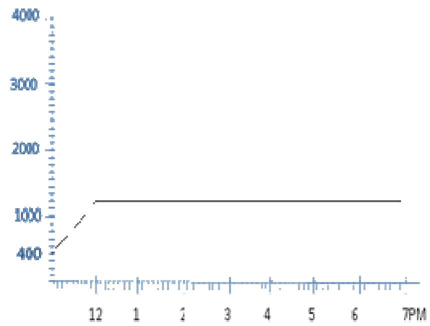


Fig 7. Case 1-5, ACH(0.33/h), Twilight–CO_2ppm

In general, each time a person exhale into an enclosed indoor air with no air change the injected CO_2 increases the concentration of CO_2 of indoor air quality (Figs 8-13). The implication of this depleted oxygen quotient results in concentration of CO_2 in re-inhaled air in the lungs. The occupants increased breathing rates to supply oxygen to the blood for oxygen balance thus resulting in the occupant discomfort associated with gasping for breath, sneezing (suffocating).



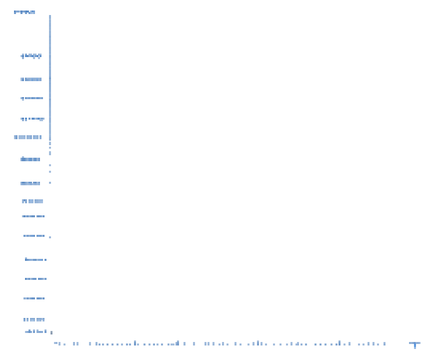
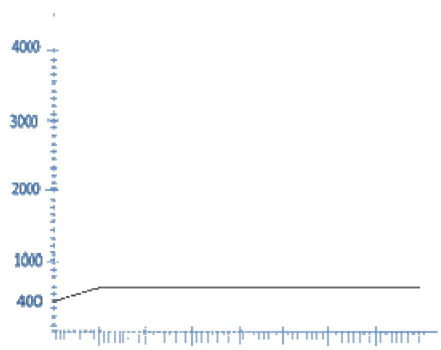


Fig. 8: Case 6-10: ACH(1/h): Daylight-CO_2(ppm)

Fig.9:Case 6-10: ACH (0.33): Twilight CO_2



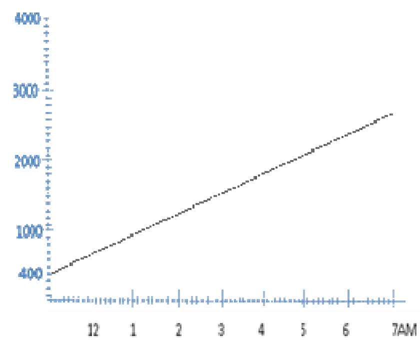


Fig.10. Case 11-15:ACH(1): Daytime CO_2(ppm)

Fig.11. Case 11-15:ACH(0.33): Twilight CO_2(ppm)

3.2. Thermal discomfort

3.2.1. Sweating

The evaluation of discomfort level at operation temperature during the time of measurement of case study was compared with heat index model (Figs 6-15). The connection between CO_2 and thermal discomfort was established as CO_2 and metabolism**.** The metabolic rate of human being at sleep is 0.8 met. which is the energy released due to body activity. The energy released expressed in watt or the energy released can also be expressed as heat. Heat produced from the body increases the air temperature in and around the breathing zone of an occupant at sleep. The breathing zone at sleep is the region 1.0 m above the sleep datum, heat due to metabolism steadily increases over 8 hour period of investigation. Body metabolism increases body discomfort in this breathing zone. The linkage between CO_2 and metabolism at sleep is the impact or effect of CO_2. Similarly at sleep the concentration of CO_2 injected or exhaled into the breathing zone.

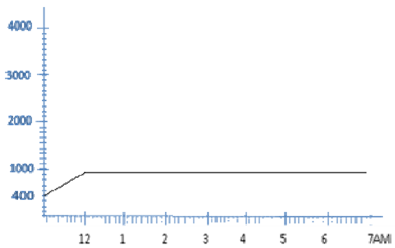


Fig.12: Case 16-20:ACH(1): Daytime CO_2(ppm)

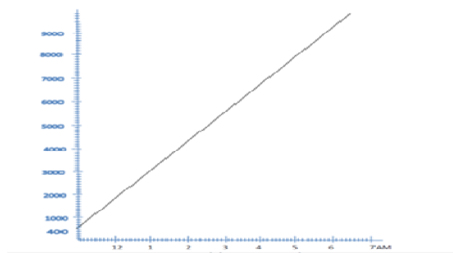


Fig.13: Case 16-20:ACH(0.33): Twilight CO_2(ppm)

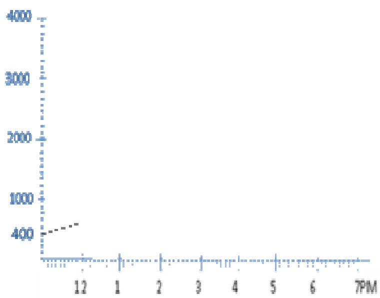


Fig.14: Case 21-25:ACH(1.33): Daytime CO2(ppm)

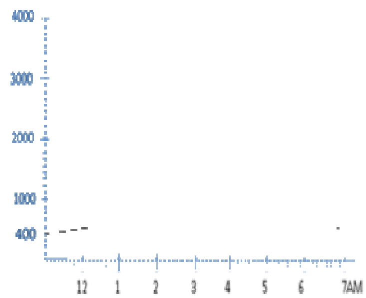


Fig.15: Case 21-25:ACH(1.33): Twilight CO2(ppm)

3.3. Investigating indoor air quality

The indoor air quality was investigated in terms of the ventilation effectiveness, based on the CO_2 concentration in the breathing zone (BZ). The ventilation effectiveness was a measure of the effectiveness of the window supply-airflow into breathing zone for removal of CO_2 or other pollutants. The actual window opening is 7%, whereas, the effective window (Sliding window) opening is 3.5% for type I room. However, 4.63% and 9.26 % were estimated for sliding and actual window openings for type II room with the computed ventilation rate of 0.085m^3/s per occupant respectively. These estimations fall short of minimum ASHARE standard of 5% model for the sliding window openings. In general ventilation rate should keep carbon dioxide concentration below 690ppm to create indoor air quality condition acceptable to most individual.

4. Conclusion

Carbondioxide (CO_2) concentration exists in the buildings, with higher concentration in rooms with larger numbers of persons. CO_2 concentration was closely related to room size and density. CO_2 concentration increased rapidly when doors and windows were locked. Its concentration was observed to be low in bungalow accommodation associated with more numbers of window opening in comparison with tenement accommodation. Thus different levels of CO_2 concentration affected users comfort negatively manifested by shortness of breath, sneezing sweating and increased breath rate among others. Generally, this research hereby establishes that CO_2 concentration was responsible for the reported discomfort experienced by Bawak resident and users' of residential buildings at large. The possibility of closing their window and door at night was high due to fear which should be addressed in future research.

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