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NATURAL VENTILATION EFFECT ON CO2 CONCENTRATIONS IN CLASSROOMS, WAKAYAMA UNIVERSITY, JAPAN

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ABSTRACT: Using a portable CO_2 sensor, the CO_2 concentration in a classroom at Wakayama University was measured and "natural ventilation", the open door or window effect was evaluated based upon the number of persons, room size, door or window condition and CO_2 concentration. Under no ventilation condition in the classroom, increase of CO_2 concentration was 2,000 to 4,000 ppm after 90 minutes and CO_2 production per person per hour due to respiration was 0.005 to 0.015 m^3/hour/person during a lecture. Comparing CO_2 concentration under no ventilation condition with under natural ventilation condition, effect of natural ventilation to reduce CO_2 concentration per open space size was calculated. The amount of CO_2 gas exchanged outside through doors or windows by natural ventilation was in agreement with the amount of CO_2 gas produced by respiration in the room when sizes of open doors or windows were 2.3 to 12.8 m^2 or ratios of total room volumes per open door or window sizes were 40 to 180 m.

Keywords: Carbon dioxide, classroom, ventilation, respiration

1. INTRODUCTION

CO_2 concentrations in classrooms using air conditioners are based on the Japanese School Environmental Standard. The Ministry of Education, Culture, Sport, Science and Technology propose that the CO_2 concentration in classrooms be less than 1,000ppm [1]. Classrooms are likely to have a high number of person present and regularly ventilating classrooms is not commonly done at Universities. In addition, buildings in recent years often have high air tightness because of improvements in building technologies [2].

Recently, reducing the use of air conditioners has been practiced to save electricity. However ventilation fans work in conjunction with air conditioners in recently constructed buildings. In most classrooms at Wakayama University, a ventilation fan does not work separately with an air conditioner. In particular, air conditioners are not used during spring and autumn time because of moderate temperatures, thus CO_2 concentration was thought to be high. The purpose of this study was to evaluate the "natural ventilation" effect of opening a door or window.

2. METHOD

CO_2 gas measurement in the air was performed in the room at a private house in August and October 2014, and in a classroom at the faculty of Systems Engineering at Wakayama University from December 2013 to January 2015. The room size of the private house was 23.5 m^2 with 6 tatami mats. The size of the classrooms were 1,297 m^2 for A101, 430 m^2 for A103, 413m^2 for A104, 522 m^2 for A202, 416 m^2 for A203, 286 m^2 for A204, 551 m^2 for B101, and 260 m^2 for B202 and B203 as shown in Table 1. For all classrooms both air conditioners and ventilation worked together. The size of the door and window in the classroom were 1.9 m^2 and 1.5 m^2. A portable sensor, GCH-2018, was used for measuring CO_2 concentrations in the air as shown in Fig1. The measuring place was in the center of the room for the private house and at the back side at 80 cm in height of the each classroom.

Table 1 Room size of house and classroom

Room name	Size m^3
Private house	23.5
A101 classroom	1,297
A103 classroom	430
A104 classroom	413
A202 classroom	522
A203 classroom	416
A204 classroom	286
B101 classroom	551
B202 classroom	260
B203 classroom	260

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3. RESULTS

3.1 House Room under No Ventilation Condition

Fig.2 shows CO_2 concentrations in the room under quiet conditions after the windows and doors were closed. CO_2 concentrations in the air

Fig. 1 Portable sensor**, GCH-2018**

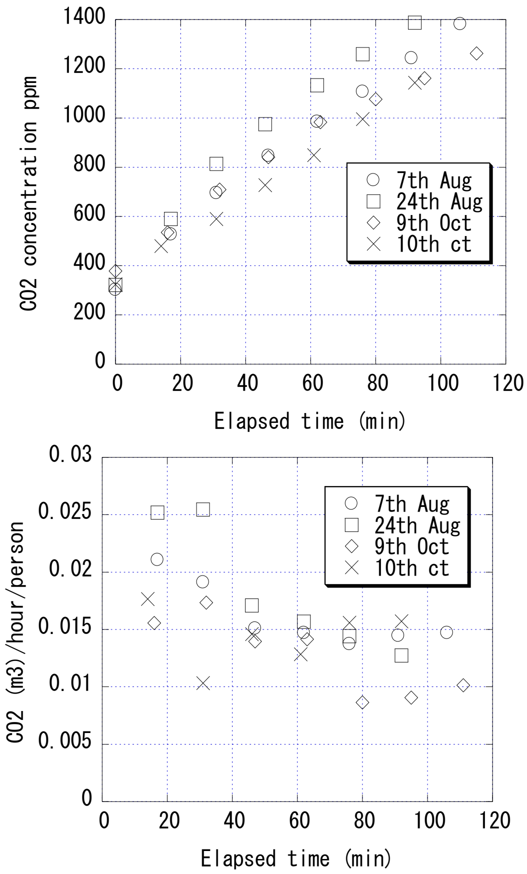

Fig.2 CO_2 concentration in room and production per hour per person under no ventilation condition in the private house.

increased from 300 to 1,300 ppm at 100 minutes each time. The results showed that CO_2 concentration in the air with no air conditioner reached over 1,000 ppm and ventilation was necessary for normal life. From the results, CO_2 production in the room per hour per person by respiration was calculated as the following equation.

CO_2 production = CO_2 concentration change × room volume /(time ×person number) (1)

The CO_2 production per hour per person decreased 0.02 to 0.01 m^3/hour/person with time as shown in Fig.2. The calculated values with 56 kg weight and 175cm in height were average values per hour per person under normal conditions [2]. The decrease with time was thought to depend on the respiration activity of humans. High CO_2 production per hour per person from the start of measurements till the 40 minute mark was thought to be due to the still high respiration activity for preparation of experiment.

3.2 Classroom on University under No Ventilation Condition

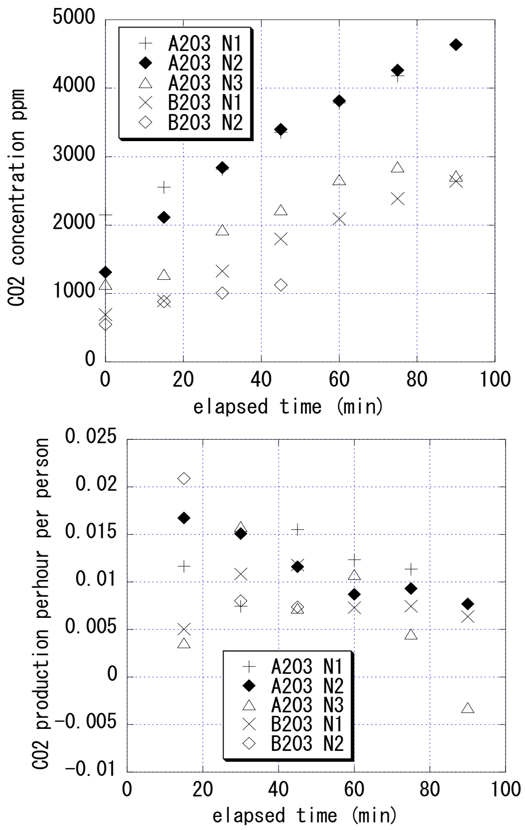

Fig. 3 CO_2 concentration and production per hour per person in classroom (A203, B203) with no air conditioner and closed doors and windows from autumn 2013 to spring 2014.

Fig. 3 shows that CO_2 concentration and CO_2 production in the classroom during a lecture with no air conditioner after the windows and doors were closed from 2013 to June 2014 for the A203 and B203 classrooms. The CO_2 concentrations increased with time and were over 2,000 ppm after one lecture time of 90 minutes. Maximum values reached over 4,000 ppm with 80 persons and a 416

m^3 volume. CO_2 production values in the classroom decreased with time as well as the private room and they were lower than those in the private room.

Fig.4 shows CO_2 concentration and CO_2 production per hour per person in classroom (A101, A103, A104, A202, A203, A204, B101) with no air conditioner and closed doors and windows from spring 2014 to autumn 2014. CO_2 concentrations increased with time and were over 1,500 ppm after one lecture time of 90 minutes. Maximum value reached over 3,000 ppm with 110 persons and a 522 m^3 volume. Therefore, the CO_2 concentration of the classroom with no ventilation reached over 1,000 ppm which was the recommended maximum value. During spring and autumn seasons, air conditioners are not employed because temperatures in the classroom are moderate. Therefore, the ventilation fan did not work because it was on the same switch of the air conditioner. As a result, in spring and autumn high CO_2 conditions were sometimes observed.

CO_2 production values in the classroom were 0.005 to 0.015 m^3/hour/person, lower than those in the private room. Both CO_2 classroom production

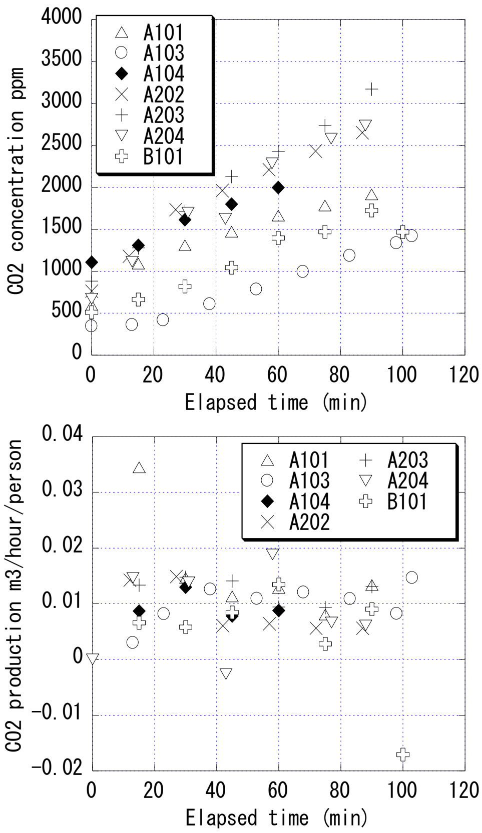

Fig. 4 CO_2 concentration and CO_2 production per hour per person in classroom (A101, A103, A104, A202, A203, A204, B101) with no air conditioner and closed doors and windows from spring 2014 to autumn 2014.

values in fiscal 2013 and 2014 were lower than those in the private room. One possibility was because of exchanging air when some students entered into the room through the door.

3.3 University Classroom with One Open Door (1.9 m^2)

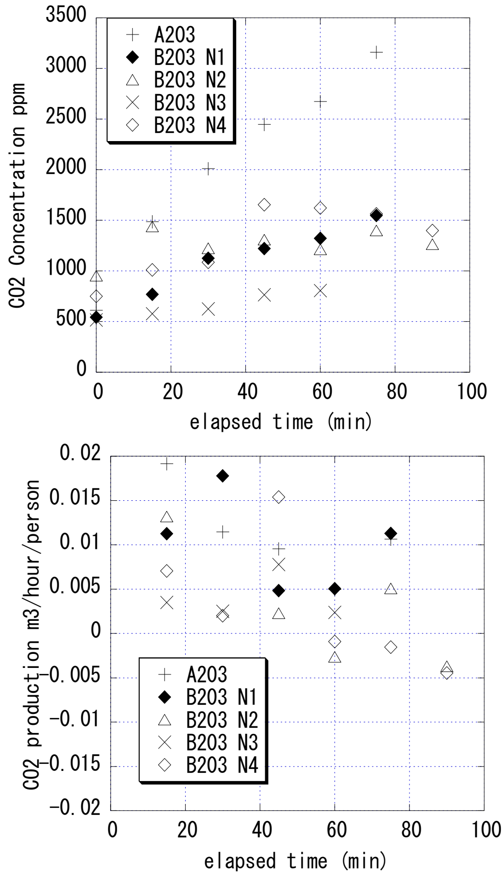

Fig. 5 CO_2 concentration and CO_2 production per hour per person in classroom (A203, B203) with no air conditioner and one open door from autumn 2013 to spring 2014

Fig.5 shows CO_2 concentration and CO_2 production per hour per person in classroom (A203, B203) with no air conditioner and one open door from autumn 2013 to spring 2014. The CO_2 production in Fig.5 included wind ventilation through door and the total open space was 1.9 m^2. CO_2 concentrations increased with time and were over 1,000 to 3,000 ppm after one lecture time of 90 minutes. Maximum value reached over 3,000 ppm with 76 persons and a 416 m^3 volume. CO_2 concentration depended on room size and number of people however the CO_2 production per hour per person in classroom was calculating from person number and room size and it was directly evaluated each time.

CO_2 production values in the classroom under one open door decreased with time as well as the private room and they were lower than those values in the classroom under the condition of closing doors and windows. Even though some CO_2 production values were less than 0 after 60 minutes, CO_2 concentration in the classroom exceeded 1,000 ppm after 90 minutes.

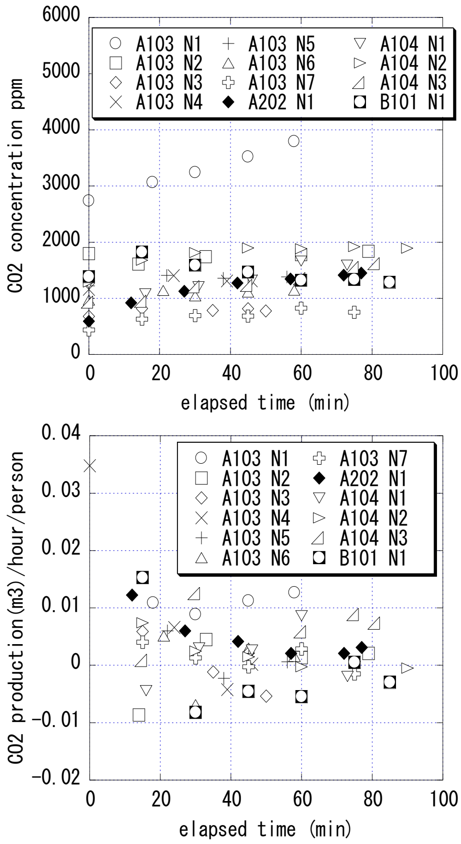

Fig. 6 CO_2 concentration and CO_2 production per hour per person in the classroom (A103, A202, A104, B101) with no air conditioner and one open door from spring 2014 to autumn 2014

Fig.6 shows CO_2 concentration and CO_2 production per hour per person in classroom (A103, A202, A104, B101) with no air conditioner and one opened door from spring 2014 to autumn 2014. The CO_2 production in Fig.6 included wind ventilation through door and the total open space was 1.9 m^2. The CO_2 concentrations increased with time and increases were over 1,000 ppm after one lecture time of 90 minutes. Maximum value exceeded 4000 ppm with 43 persons and 430 m^3 volume. Therefore, CO_2 concentration in a classroom with one open door for ventilation exceeded 1,000 ppm which was the recommended maximum value. Therefore, wind ventilation by opening one door was not enough ventilation to reduce CO_2 concentration.

CO_2 production values with one open door varied from –0.01 to 0.015 m^3/hour/person. The difference of CO_2 production values between one door being open and no door being open was small therefore one door being open had little effect in reducing CO_2 concentration.

3.4 University Classroom with One Open Door (1.9 m^2) and one Open Window (1.5 m^2)

Fig.7 shows CO_2 production per hour per person in classroom (B101, B203, A202, A204) with no air conditioner and one open door and one open window. The CO_2 production in Fig.7 included wind ventilation through door and window and the total open space was 3.4 m^2. The CO_2 production values were variable with half of values were minus values showing a CO_2 concentration decrease and plus showing a CO_2 concentration increase. Therefore, wind ventilation by opening one door and one window was not enough ventilation for reducing CO_2 concentration in the classroom.

The difference of CO_2 production values between one door being open and one door and one window being open was small therefore one window being open had little effect in reducing CO_2 concentration.

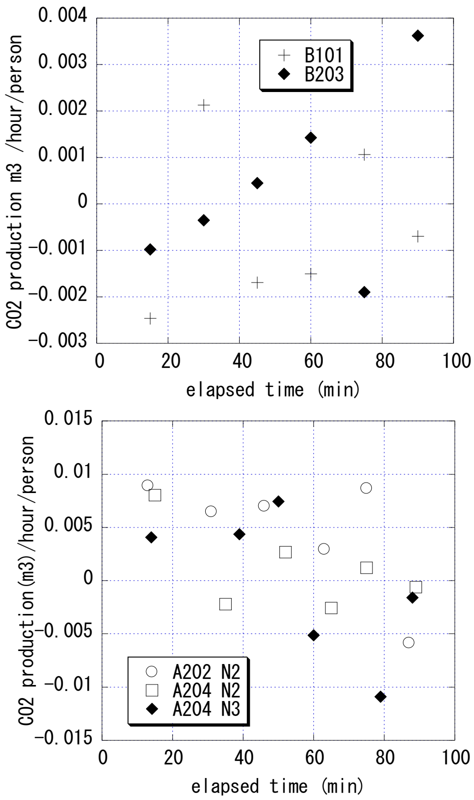

Fig. 7 CO_2 production per hour per person in classroom (B101, B203, A202, A204) with no air conditioner and one open door and one open window.

3.5 University Classroom with One Open Door (1.9 m^2) and Two Open Windows (3.0 m^2)

Fig. 8 shows CO_2 production per hour per person in classroom (A103, A204, B202) with no air conditioner and one open door and two open windows. The CO_2 production in Fig.8 included wind ventilation through door and window and the total open space was 4.9 m^2. CO_2 production values varied with most of the values being minus values. Therefore, wind ventilation by opening one door and two windows was enough ventilation for reducing CO_2 concentration in the classroom and then over 5 m^2 of the total open space area was necessary for reducing CO_2 concentration.

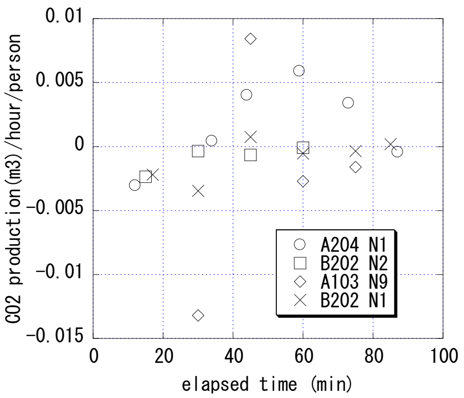

Fig. 8 CO_2 production per hour per person in classroom (A103, A204, B202) with no air conditioner and one open door and two open windows.

3.6 University Classroom with One or Two Open Windows (1.5 to 3.0 m^2) or Two Open Doors (3.8 m^2)

Fig. 9 shows CO_2 production per hour per person in classroom (A103, A202, A203, A204) with no air conditioner, no open door and one or two open windows. The CO_2 production in Fig.9 included wind ventilation through windows and the total open space was 1.5 to 3.0 m^2. Most of the CO_2 production values were plus. Therefore, wind ventilation by opening one or two windows was not enough ventilation for reducing CO_2 concentration in the classroom.

Fig. 10 shows CO_2 production per hour per person in classroom (B202, B203) with no air conditioner and two open doors. The CO_2 production in Fig.10 included wind ventilation through doors and the total open space was 3.8 m^2. Most of the CO_2 production values were plus. Therefore, wind ventilation by opening two doors was not enough ventilation for reducing CO_2 concentration in the classroom.

4. DISCUSSION

Table 1 shows CO_2 production 1/1,000 m^3 /hour/person at the 15 minute mark (beginning of lecture) and the 75 minute mark (end of lecture). The calculated CO_2 production per hour per person in classroom was various and it was thought to vary with open space area. The open size of the door and window were 1.9 and 1.5 m^2. The window was facing outside and the door was facing the floor. Comparing each CO_2 production value under the condition of closing door and window, most CO_2 production values from the small size, private house room with 23.5 m^2 to the big classroom, A101 with 1,297 m^2 were 0.010 to 0.015 m^3/hour/person not depending on time and room size. These were a little lower than the average production values of respiration under relaxed condition.

CO_2 production value was thought to vary with classroom character, door and window ventilation effect and airtightness. Then, the difference of calculated CO_2 production per hour per person under between no wind ventilation condition and wind ventilation condition, D, was calculated for each classroom as shown in Table 1. The calculated difference per ventilation space area, D/a, was also listed in Table 1.

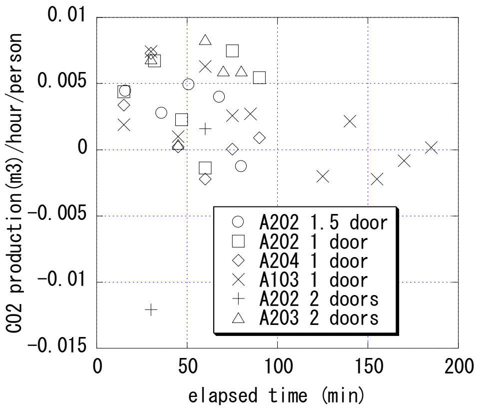

Fig.9 CO_2 production per hour per person in classroom (A103, A202, A203, A204) with no air conditioner and no open door and one or two open windows.

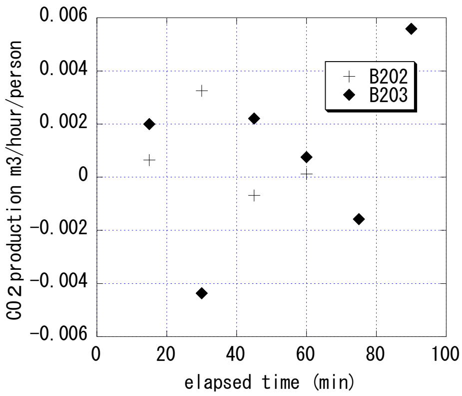

Fig.10 CO_2 production per hour per person in classroom (B202, B203) with no air conditioner and two open doors.

For A103, the difference (D) of door and wind ventilation compared with no door and window were 1.0 to -13×1/1,000 m^3/hour/person and the difference per unit size of door and window (D/a) were -0.5 to 5.8 (average 2.6) × 1/1,000 m/hour/person/size. D/a shows effect to reduce CO_2 concentration by natural ventilation of door or window. Minimum open space size of door and window for natural ventilation to keep uniform CO_2 concentration was the CO_2 production per hour per person with no wind ventilation / (D/a). For A103, the original CO_2 production with no ventilation was 2.0 to 11 (average 6.5)×1/1,000 m^3/hour/person. Then for A103, the minimum open space size to keep uniform CO_2 concentration was 6.5 (average)×1/1,000/ 2.6 (average) ×1/1,000, 2.5 m^2. The room size per open space size for natural ventilation was 430 m^3/2.5 m^2, 170 m.

As well as for A104, the difference (D) of door and wind ventilation compared with no door and window were 6.0 to 8.5×1/1,000 m^3/hour/person and the difference per unit size of door and window (D/a) were 3.2 to 4.5 (average 3.9)×1/1,000 m/hour/person/size. Similarly, as for A104, the original CO_2 production with no ventilation was 9.0 ×1/1,000 m^3/hour/person. Then minimum open space size to keep uniform CO_2 concentration was 9.0×1/1,000/ 3.9 (average) ×1/1,000, 2.3 m^2. The room size per open space size for natural ventilation was 413 m^3/ 2.3 m^2, 180 m.

For A202, the difference (D) of door and window compared with no door and window were -2.0 to 5.0 ×1/1,000 m^3/hour/person and the difference per unit size of door and window (D/a) were -0.6 to 1.6 (average 0.78) ×1/1,000 m/hour/person/size. As for A202, the original CO_2 production with no ventilation was 6.0 to 14 (average 10) × 1/1,000 m^3/hour/person. Then minimum open space size to keep uniform CO_2 concentration was 10 (average) × 1/1,000/ 0.78 (average)×1/1,000, 12.8 m^2. The room size per open space size for natural ventilation was 522 m^3/12.8 m^2, 40m.

As for A203, although the difference (D) of one door compared with no door and window were -8.0 to 3.0 × 1/1,000 m^3/hour/person and the difference per unit size of door and window (D/a) were -4.2 and 1.6 ×1/1,000 m/hour/person/size, D/a was minus at the 15 minute mark and then D/a was selected to be 1.6 ×1/1,000 m/hour/person/size at the 75 minute mark. As for A203, the original CO_2 production with no ventilation was 8.0 × 1/1,000 m^3/hour/person at the 75 minute mark. Then the minimum open space size to keep uniform CO_2 concentration was 8.0 ×1/1,000/ 1.6 ×1/1,000, 5.0 m^2. The room size per open space size for natural ventilation was 416 m^3/ 5.0 m^2, 83 m.

For A204, the difference (D) of door and wind ventilation compared with no door and window were 4.0 to 18×1/1,000 m^3/hour/person and the difference per unit size of door and window (D/a) were 0.8 to 8.0 (average 3.9) ×1/1,000 m/hour/person/size. As for A204, the original CO_2 production with no ventilation was 7.0 to 15 (average 11)×1/1,000 m^3/hour/person. Then the minimum open space size to keep uniform CO_2 concentration was 11 (average)×1/1,000/ 3.9 (average)×1/1,000, 2.84 m^2. The room size per open space size for natural ventilation was 286 m^3/ 2.84 m^2, 100 m.

For B101, the difference (D) of one door, one door and one windows compared with no door and window were 9.0 to 31×1/1,000 m^3/hour/person and the difference per unit size of door and window (D/a) were -4.7 to 9.1 (average 1.3) × 1/1,000 m/hour/person/size. As for B101, the original CO_2 production with no ventilation was 2.0 to 6.0 (average 4.0) ×1/1,000 m^3/hour/person. Then the minimum open space size to keep uniform CO_2 concentration was 4.0 (average) ×1/1,000/ 1.3(average)×1/1,000, 3.1m^2. The room size per open space size for natural ventilation was 551 m^3/ 3.1 m^2, 180 m.

For B202 or B203, the difference (D) of one door, one door and one window, one door and two windows, and two doors compared with no door and window were -3.0 to 16 ×1/1,000 m^3/hour/per/person and the difference per unit size of door and window (D/a) were -1.5 to 4.1 (average 2.3) ×1/1,000 m/hour/person/size. As for B202 or B203, the original CO_2 production with no ventilation was 7.0 to 13 (average 10) ×1/1,000 m^3/hour/person. Then the minimum open space size to keep uniform CO_2 concentration was 10 (average)×1/1,000/ 2.3 (average)×1/1,000, 4.4 m^2. The room size per open space size for natural ventilation was 260 m^3/ 4.4 m^2, 60 m.

As a result, the minimum open space size to keep uniform CO_2 concentration and the total room volume per open door or window size for each room was estimated to be 2.5 m^2 and 170 m for A103, 2.3 m^2 and 180 m for A104, 12.8 m^2 and 40 m for A202, 5.0 m^2 and 83 m for A203, 2.8 m^2 and 100 m for A204, 3.1 m^2 and 180 m for B101, and 4.4 m^2 and 60 m for B202.

5. CONCLUSION

The CO_2 concentration in a classroom at Wakayama University was measured using a portable CO_2 sensor and then, maximum CO_2 concentration reached over 4,000 ppm in the classroom after 90 minutes because air conditioner was not used under moderate temperature in particular spring and autumn and then ventilation fans did not work in conjunction with air conditioners. Therefore, to reduce CO_2 concentration by natural ventilation, opening door and window was important and it is necessary to estimate how much open space of door and window for keeping uniform CO_2 concentration.

From the number of persons, room size, door or window open space and CO_2 concentration, CO_2 production per person per hour in the room due to respiration was estimated to be 0.01 to 0.02 m^3/hour/person for a private house and 0.005 to 0.015 m^3/hour/person for a classroom during a lecture. The minimum open space size of door or window for natural ventilation and ratios of total room size per open door or window size to keep uniform CO_2 concentration was also calculated to be 2.3 to 12.8 m^2 and 40 to 180 m respectively comparing CO_2 concentration under a closed door and window condition with under opening door and window condition.

Table 1 CO_2 Production (1/1,000 m^3 /hour/person)

Room Size m^3	Time (min)	CO_2 Production 1/1,000 m^3 /hour/person No DW	1D 1.9 m^2	1D + 1W 3.4 m^2	1D + 2W 4.9 m^2	1W or 2W 1.5~ 3 m^2	2D 3.8 m^2
private House 23.5	15	15~ 25					
	75	13~ 16					
A 101 1297	15	34					
	75	8.0					
A 103 430	15	2.0	-9.0 ~15			2.0 1.3	
	D		-1.0			-0.5	
	D/a		-0.5			-0.3	
	75	11	-2.0 ~2.0		-2.0	3.0	
	D		11		13	8.0	
	D/a		5.8		2.7	5.3	
A 104 413	15	9.0	-5.0 ~8.0				
	D		6.0				
	D/a		3.2				
	75	9.0	-1.0 ~0				
	D		8.5				
	D/a		4.5				
A 202 522	15	14	12	9.0		4.0	
	D		2.0	3.0		10	
	D/a		1.0	0.9		1.6	
	75	6.0	3.0	8.0		-2.0 ~7.0	
	D		3.0	-2.0		1.0	
	D/a		1.5	-0.6		0.3	
A 203 416	15	4.0~ 17	19				
	D		-8.0				
	D/a		-4.2				
	75	4.0~ 12	11				
	D		3.0				
	D/a		1.6				
A 204 286	15	15		4.0~ 8.0	-3.0	3.0	
	D			9.0	18	12	
	D/a			2.6	3.7	8.0	
	75	7.0		-11 ~1.0	3.0	0	
	D			12	4.0	7.0	
	D/a			3.5	0.8	4.7	
B 101 551	15	6.0	15	-25			
	D		-9.0	31			
	D/a		-4.7	9.1			
	75	2.0	1.0	1.0			
	D		1.0	1.0			
	D/a		0.5	0.3			
B 202 B 203 260	15	5.0~ 21	3.0~ 13	-1.0	-3.0		1.0~ 2.0
	D		5.0	14	16		12
	D/a		2.6	4.1	3.3		3.2
	75	7.0	-2.0 ~12	-2.0	0		-2.0
	D		-3.0	9.0	7.0		9.0
	D/a		-1.5	2.6	1.4		2.4

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