"VENTILATION SIMULATOR"

〈Countermeasure against Novel Coronavirus-Tool to Simply Estimate the Adequacy of Ventilation〉

[Detailed Explanation and Description of its Usage]

April 25, 2020

Expert Community of Occupational Hygiene & Ergonomics,
Japan Society for Occupational Health

In order to prevent the collective occurrence of mass infection by the novel coronavirus, it is important to evade the close situations (so-called "Three Cs"), that is, closed space with poor ventilation, crowded place with a large number of people, and close-contact setting with conversation or utterance at the vicinity. As for the first one on "ventilation", the Expert Community of Occupational Hygiene & Ergonomics, the Japan Society for Occupational Health has prepared a tool "Ventilation simulator (hereinafter referred to as "this simulator") that allows simplified estimation of the adequacy of ventilation of a room. Occupational health professionals (occupational physicians, occupational nurses, technical specialists, etc.), safety/health supervisors responsible for safety and health in business establishment, persons in charge of human affairs/general affairs, as well as others concerned are expected to use this simulator to estimate the performance of the ventilation of rooms inside the business establishment, and on the basis of simulation results, to conduct necessary improvements, so as to eliminate the "closed space with poor ventilation".

When using this simulator, you are kindly requested to pay adequate attention to the points to be noted for use, as well as the disclaimer set out in this document.

1. Points to be noted for use of this simulator
  (1) For this simulator, use the Microsoft EXCEL 2010 or later versions.
  (2) Declaration (declaration of a state of emergency), instruction or proposal issued by the government, local authorities and the expert conference for countermeasures against infection of the novel coronavirus shall have priority over the "estimation results" obtained by this simulator. For instance, if request for self-restrain is made due to a declaration of a state of emergency for the service in the workplace, sales activities or meetings, the self-restrain shall be observed, irrespective of the result of this simulator. That is, the simulator shall be used only for activities or in areas where such request is not made, or under conditions where such request for self-restrain is released.
  (3) This simulator estimates the adequacy of ventilation on the basis of preconditions such as the complete mixture of air inside the room and the design value of the ventilator. So that, depending on various conditions including the actual air flow and the operation condition of

the ventilator, the result thus obtained may differ from the one corresponding to the actual situations.

(4) Estimation with this simulator is made on the basis of the status of the ventilator. First, check if the room is provided with a ventilator or not, and also if it is operated. In principle, be sure to operate it, and set at “Strong” if setting “Strong-weak-quiet” is made available, before performing estimation. “Ventilation” here means taking-in of external air, while air conditioners or fans for home use that simply circulate air are not considered as “ventilator”.

(5) This simulator allows the estimation to be made without the ventilation rate (design value or actual value) of the room, but better estimation is obtained if it is known. The ventilation rate at the time of design may be obtained generally by asking the administrator of the building or the facility, or the monitoring center or the maintenance company of the building.

(6) Since this simulator is intended only for indoor ventilation use, it cannot be used for outdoor service.

(7) Even if this simulator provides a good result, it is still necessary to conduct at the same time the other countermeasures against infection prevention. That is, the two of the “Three Cs”: “Crowded place with a large number of people” and “Close-contact setting with conversation or utterance in the vicinity” shall be observed separately. For instance, even in a very well-ventilated room, overcrowding or conversation without keeping a social distance should be avoided. Moreover, be sure to perform the infection prevention measures such as coughing etiquette and hand washing.

2. Background of “ventilation simulator and the basic concept

(1) In the field of occupational hygiene and architecture, it is a common practice to use the concentration of carbon dioxide (CO_2) inside the room as an indicator to evaluate the adequacy of indoor ventilation. That is, the use of a “ventilation model”, which assumes that the generation of CO_2 at a certain rate from the persons inside the room which is ventilated at a certain rate and that the gas is completely mixed and exhausted, allows the concentration of CO_2 in the room to be estimated. As this model is employed for occupational hygiene engineering and architectural environmental engineering, this simulator also uses this model.

(2) According to the “The ventilation to improve “poor-ventilated closed spaces” in commercial facilities (the Ministry of Health, Labor and Welfare; March 30, 2020), “If the standard for the Building Control Law (concentration of CO_2 equal to the standard value of 1,000 ppm, which corresponds to the ventilation rate of 30m^3/h/person) is met, such a space is not regarded as “poor-ventilated closed space”. This simulator is designed also in line with this basic concept.

(3) Since this simulator is intended to estimate “the adequacy of indoor environment from the viewpoint of ventilation”, its result is not to directly evaluate the elimination capability by ventilation of airborne droplets generated by persons inside the room, or the degree of possibility for the virus infection inside the room.

3. Design of simulation model and parameters

（1） Definition of variables and parameters

C : Indoor CO_2 concentration (ppm; parts per million)

C_e: CO_2 concentration in exhaled breath (assumed as 46,000 ppm in the simulator)

C_o: CO_2 concentration in outdoor fresh air (assumed as 400 ppm)

G: Total CO_2 generation rate（m^3/h）

k: Coefficient of aspiration

Expiratory volume depends on physical activity level, therefore, the volume is obtained by multiplying expiratory volume at the standard condition by coefficient k, summarized in the following table

(Table1 has been installed in the “Ventilation simulator”.)

Table 1 Coefficient of aspiration (k)

State of activities	k	Examples
Standard	1	General clerical work (seated)
Very slight movement	2	Frequent telephone talks, meeting with active utterance, light stretching, running machine (slow walking: 3 to 4 km/h)
Light movement	3	Light work, radio gymnastics, stretch, running machine, a little fast walking: about 6 km/h)
Exercises (light to heavy)	5	Muscle training, running machine, (jogging: about 9 km/h), sports in general, muscular work

m: Air exchange rate (number of air exchanges per hour)

n: Number of persons in a room

n_p: Designed number of persons in a room

Q: Room ventilation rate (m^3/h) J

Q_f: Designed room ventilation rate per floor area (m^3/m^2・h)

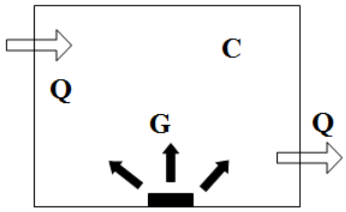
Q_p: Designed ventilation rate per person (m^3/h・person)

R: Exhaled breath volume per person at rest (0.39 m^3/h (6.5 L/min) while seated)

S: Floor area of a room (m^2)

t: Time elapsed (h)

V: Room volume (m^3)

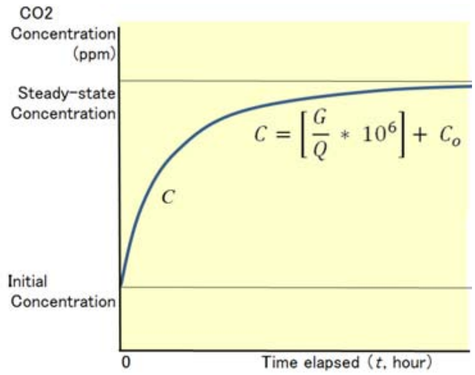


(2) Ventilation model and equation

Based on the standard one-box well-mixed room model (complete mixing throughout the room with constant CO_2 emission and ventilation rate), indoor CO_2 concentration can be described by the following equation and the figure (right).

It should be noted that the equation should not be used in the situation where there is CO_2 source(s) other than occupants in the room.

$$C - C_o = \frac{G}{Q}\left(1 - e^{-\frac{Q}{V}t}\right) * 10^6$$



< Indoor CO_2 Concentration >

Steady-state indoor CO_2 concentration (C) is obtained by substituting t with infinity.

$$C = \left[\frac{G}{Q} * 10^6\right] + C_o \quad \cdots (1)$$

CO_2 generation rate (G) is obtained by the following equation.

$$G = C_e * n * R * k * 10^{-6}$$

$$= n * k * 0.01794 \quad \cdots (2)$$

By combining equations (1) and (2), equation (3) is derived.

$$C = \left[\frac{n * k * 0.01794}{Q} * 10^6\right] + 400 \quad \cdots (3)$$

Room ventilation rate (*Q*) is calculated by the method explained in the next section.

(3) Calculation of the room ventilation rate (*Q*)

Equations for calculation should be selected based on the availability of information on room conditions such as presence or absence of ventilation, ventilation rate etc.

Equations are summarized in Table2

Table 2 Equations corresponding to the status of ventilation

Ventilator equipped?	Ventilation rate available?	Cases	Parameters to calculate room ventilation rate	Equations for CO_2 concentration
Yes	Available	(A)	Room ventilation rate (Q)	(3)
		(B)	Air exchange rate (m)	(3), (4)
		(C)	Designed ventilation rate per person (Q_p), and Designed number of persons in a room (n_p)	(3), (5)
	Not available	(D)	Designed room ventilation rate per floor area (Q_f)	(3), (6)
No (*)	—	(E)	Air exchange rate (m)	(3), (4)

* "No" includes "out of service".

Room ventilation rate (Q) for each case (A to E) can be calculated as shown below.

[Important notes]

In general, the designed ventilation rate represents to the maximum capacity of the equipped ventilators. If the ventilators are not operated at the maximum capacity, the designed ventilation rate should not be used for calculation. Instead, estimated actual ventilation rate should be used.

(A) When the room ventilation rate (Q) is available,

- Use room ventilation rate (Q). (Enter Q value directly in the simulator.)

(B) When the air exchange rate (m) is available,

- Use air exchange rate (m). (Enter m value directly in the simulator.)
- Room ventilation rate (Q) is obtained by the following equation.

$$Q = V * m \quad \cdots (4)$$

(C) When the designed ventilation rate per person (Q_p), and the designed number of persons in a room (n_p) is available,

- Use these two values. (Enter two values directly in the simulator.)
- Room ventilation rate (Q) is obtained by the following equation. J

$$Q = Q_p * n_p \quad \cdots (5)$$

(D) When the ventilators are installed, and the room ventilation rate (Q) is not available,

- Depending on the room type, use the designed room ventilation rate per floor area (Q_f), summarized in the following Table. If the appropriate room type is not listed in the Table, choose the closest situation.

(Table 3 has been installed in the “Ventilation simulator”.)

Table 3 Designed room ventilation rate per floor area of the typical room types

Room type	room ventilation rate per floor area Q_f （m^3/m^2・h）*1
Office (office room, conference room diverted from office room, other rooms)	7.2
Meeting room (designed only as a conference room) *2	30
Detached house, condominium, retail store (shop), convenience store	9
Barber shop, beauty shop	6
Department store (general sales floor), supermarket	20
Theater, cinema, banquet hall	37.5
Restaurant (seat interval: wide) ex: high quality restaurant	17.7
Restaurant (seat interval: narrow) ex: drinking spot, family restaurant, café	30

*1: Ventilation rate per person is set to be 30m3/h; The society of heating, air-conditioning and sanitary engineers of Japan, SHASE-S standard, HASS 102 1972

*2: A room designed as a dedicated meeting room only; This excludes meeting rooms converted from office rooms or open floors.

- Room ventilation rate (Q) is obtained by the following equation.

$$Q = Q_f * S \quad \cdots (6)$$

（E）When the ventilators are not installed in the room, including ventilators are out of service,

- Use the air exchange rate (*m*) in the following table 4.

  (Table 4 has been installed in the “Ventilation simulator”.)

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Table 4 Estimated air exchange rate (*m*)

Estimated air exchange rate*	Room type
0.5	Concrete buildings
1	Wooden building (Western style room)
2	Wooden building (Japanese style room)
3	Old wooden building
5	Building with window and door always open

* Determined by referencing literature (8)-(10)

- Room ventilation rate (Q) is obtained by the following equation.

$$Q = V * m \quad \cdots (4)$$

(4) Calculation of the indoor CO_2 concentration

Indoor CO_2 concentration will be calculated by equation (3), using the room ventilation rate (*Q*) obtained from cases (A) to (E) mentioned above.

(Also, refer to the equations in Table 2)

$$C = \left[\frac{n * k * 0.01794}{Q} * 10^6 \right] + 400 \quad \cdots (3)$$

4. Estimation of the adequacy of ventilation

The following countermeasures for each classification are recommended, where the “Classification for the adequacy of ventilation” corresponding to the predicted indoor CO_2 concentration is set as in the table below. If, after obtaining an estimation result, input conditions are changed, for instance, the number of persons in the room is reduced, another estimation may be made.

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Table 5: Classification for the adequacy of ventilation

Classification for the adequacy of ventilation	Corresponding CO_2 concentration (ppm*)	Explanation and recommended countermeasures
Good	1,000 or less	Good, so maintain this condition
Fairly good	1,000 to 1,500 or less	Acceptable limit; windows should be partially opened from time to time (for about several minutes per hour)
Poor	1,500 to 2,500 or less	Open the windows for several minutes per every 30 minutes (full open), or refrain from using the room
Very poor	2,500 to 3,500 or less	Always keep the windows open (full open), or refrain from using the room
Extremely poor	More than 3,500	Refrain from using the room

* Explanation of each numerical value

1,000 ppm: Standard value specified in the Building Control Law and the Office Health Standard Regulation of the Industrial Safety and Health Law

1,500 ppm: Value recommended by the School Health Law

2,500 ppm: Determined in a comprehensive way in consideration of the following viewpoints: 1. Intermediate value of 1,500 and 3,500; 2. Literature stating that for a concentration exceeding 2,500 ppm, an adverse effect is clearly observed for the decision-making function of persons in the room; 3. That predicted CO_2 concentration reaches 2,800 ppm under the following condition, "amount of ventilation per person of 30 m3/h, twice the designed number of persons in the room, and a meeting with active utterance (k=2)"

3,500 ppm: The design standard value of the Air Conditioning and Health Engineering Standard (SHASE-S102-2011 Ventilation Standard), as well as the Canadian Indoor Air standard value

5. Estimation examples of the adequacy of ventilation

On the assumption of an office room (5 m x 10 m, designed number of 10 persons, designed ventilation rate of 30 m3/h), the adequacy of ventilation was estimated for several model situations, as shown in the following table.

For a CO_2 concentration of 1,000 ppm under the standard condition (office work, 10 persons in the room), the adequacy estimation of ventilation is classified as "Good". For the number of persons in the room of 1.5 times or 2 times the designed number, the CO_2 concentration and estimation result will be "1,300 ppm, fairly good" and "1,600 ppm, poor", respectively. On the other hand, even for the same number of persons in the room, the CO_2 concentration and estimation result will be "1,600 ppm, poor" in case of a meeting with active utterance (coefficient of aspiration k=2), and "2,200 ppm, poor" in case of a buffet-style party (k=3), respectively. Also, for a meeting with active utterance (*k*=2) having twice the number of persons in the room, the result will be “2,800 ppm, very poor”. As mentioned above, even for the same office room, it is possible to estimate, under what sort of use, the estimation result will turn to “closed space with poor ventilation”.

Table 6: Estimation examples of the adequacy of ventilation
(assuming a room of 5 m x 10 m x 2.6 m high)

Situation	Number of persons inside: *n*	Aspiration coefficient: *k*	Designed ventilation rate: *Qp* (m3/h/person)	Room ventilation rate: *Q* (m3/h)	Predicted CO_2 concentration: *C* (ppm)	Classification for the adequacy of ventilation
Office work, standard condition	10	1	30 (10*)	300	1,000	Good
Office work, 1.5 times the designed number of persons	15	1	30 (10*)	300	1,300	Fairly good
Office work, 2 times the designed number of persons	20	1	30 (10*)	300	1,600	Poor
Meeting with active utterance/Buffet-style party	10	2	30 (10*)	300	1,600	Poor
Buffet-style party	10	3	30 (10*)	300	2,200	Poor
Meeting with active utterance, 2 times the designed number of persons	20	2	30 (10*)	300	2,800	Very poor

(*Designed number of persons)

6. Disclaimer

(1) This ventilation simulator has been made by the Expert Community of Occupational Hygiene & Ergonomics, of the Japan Society for Occupational Health, with the copyright being the proprietary of the above.
Users of this simulator shall observe the copyright law and the related regulation, and shall not redistribute it without permission of the copyright holder. Its use or distribution for profit, distribution of a revised one, or distribution in combination with other products are also prohibited.

(2) Users shall take full responsibility for the use of this simulator. The copyright holder and the preparer shall not assume any guarantee or responsibility for the users.

7. Reference documents

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