DIAGNOSIS OF INDOOR AIR QUALITY AND VENTILATION DESIGN UTILIZING EXPERT SYSTEM

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ABSTRACT

This research is aimed to improve indoor air quality (IAQ) in the building by using the expert system (ES) based on the artificial intelligence (AI). The diagnosis tool of IAQ and ventilation design tool corresponding to 9 kinds of pollutants were developed. For diagnosis the concentration calculated from pollution generation rate and outdoor air is compared to the standard. For designing, the ventilation rate is provided from allowed concentration and pollutant generation rate. This paper explains the view of the systems corresponding to 11 rooms and some examples using "standard house" of AIJ(1) and "HASS102" of Japanese ventilation standard(2).

INTRODUCTION

While insulated and air-tightened house is spreading to realize energy conservation and comfort mainly in northern part of Japan, IAQ problem may occur in these buildings. Sick Building Syndrome (SBS) and Multiple Chemical Sensitivity (MCS) are typical issues that the indoor chemical represented by Formaldehyde and Volatile Organic Compounds (VOC) causes, therefore the proper ventilation is required. Guidelines for these materials were made recently in Japan, and the data for a standard of each material is being prepared. However it is not easy for the construction company, housing builders, etc. to design the ventilation rate which satisfies the standard, because special knowledge should be necessary in advance.

This study explains a ventilation design tool which can be used easily by designer with graphical user interface (UI) and without many requisites.

METHODOLOGY

(1)OVERVIEW

There is the relationship between the allowed pollutant concentration, the pollutant generation rate, and the ventilation rate as figure 1. Indoor pollutant concentration is located in the center. For three surrounding terms. One term is derived by using other two terms, in order to diagnose, design, etc. for diagnosis the concentration is calculated from pollutant generation rate and ventilation rate, and it is compared to the standard. For designing the ventilation rate is provided from allowed concentration and pollutant generation rate. Also to find the allowable pollutant existence, the other two factors are used for calculation similarly.

(2)STRUCTURE OF EXPERT SYSTEM

The expert system consists of following parts.
1) Knowledge base : necessary knowledge for ventilation calculation is stored as subroutines in the form of production rule. Values for the allowed concentration, etc. are referred from literatures. Visual Basic for Application (VBA) is used for the expression of the knowledge and for the description of system.
2) Inference engine : reasoning is forward and the numerical value is calculated by Excel and VBA routine.
3) User interface : the interface enables users to input conditions in rooms and ventilation rates.
4) Interface for knowledge acquisition : it is easily modified afterwards with graphical UI.

While general development shell is not so suitable for the ventilation design, this system which a ventilation designer could use for diagnosing and ventilation designing in terms of indoor air quality was built by using the spread sheet that is more familiar to designers.

(3)POLLUTANTS IN THE SCOPE

The pollutant dealt in the system is nine species; 1) CO_2, 2) CO, 3) Dust, 4) Formaldehyde, 5) TVOC, 6) NO_2, 7) SO_2, 8) Radon, 9) Asbestos as shown in table 1 based on HASS102 (SHASE)(2), etc(3).

For allowed concentration and the amount of pollutant generation rate, the standard of each pollutant is classified into three levels in this paper.
1) house standard : standard for the occupation in room
2) public standard : mainly in cases of school, the library, a standard for the public facilities

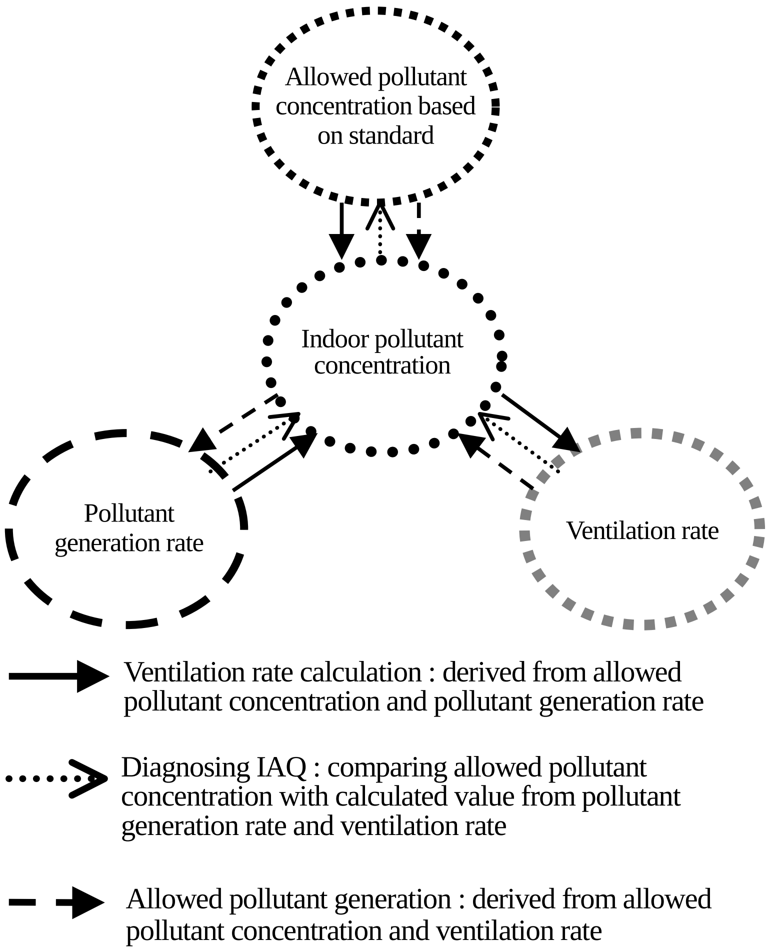

Figure 1 Relationship of ventilation rate, pollutant generation rate, and allowable

Table 1 Main generation source and standard of pollutant

name of pollutant (unit)	main generation source	house standard	public standard	lobar standard
1.CO_2 (m^3/m^3)	open combustion equipment for gas and kerosene gas burner, smoking	0.001	0.0015	0.005
2.CO (m^3/m^3)	open combustion equipment for gas and kerosene, smoking	0.00001	0.00002	0.00005
3.Dust (mg/m^3)	smoking, cleaning(used a vacuum cleaner)	0.15	0.2	2
4.Formaldehyde (m^3/m^3)	particleboard, ceiling tile, smoking, adhesive of building material and furniture, open combustion equipment	0.00000008	0.0000002	0.000001
5.TVOC ($\mu g/m^3$)	artificial building material and furniture, building equipment	300	300	300
6.NO_2 (m^3/m^3)	open combustion equipment for gas and kerosene, smoking	0.00000021	0.000003	0.000005
7.SO_2 (m^3/m^3)	open combustion equipment for gas and kerosene	0.00000003	0.00000012	0.000005
8.Radon (Bq/m^3)	soil, concrete, plaster board	100	150	1000
9.Asbestos (f/l)	insulation, fire resistive material, sound absorbing material	0.1	2	10

3) labor standard : a standard for the labor environment in cases of the office, the factory
The values of each pollutant are from some literatures[3]. All the data is included into the knowledge base.

For generation rate, an example of CO_2 from an inhabitant is indicated in table 2. CO_2 generation rates are provided at five working levels, e.g. the time of the rest, extreme light work, light work, inside work, and heavy work.
Also, for the combustion equipment, it is classified into municipal gas, liquefied petroleum gas, kerosene, and LP gas, corresponding to generation from sources in table 1.

(4)HOUSE AND OCCUPANT BEHAVIOR

The house to be designed is the standard house of AIJ, shown in figure 2. The standard house has two floors and height of each floor and ceiling is 2.7m and 2.4m respectively. THe floor area is 125m^2. Ventilation system is natural supply and mechanical exhoust and has air change rate of 0.5ach.

A life pattern of grandfather, grandmother, fathre, mother and two school children of six people family were presumed at 20 o'clock on the weekday. The pattern refers to the result of the national life investigation fone by NHK[4].

DIAGNOSIS OF IAQ

(1) PROCEDURE OF DIAGNOSIS

When a diagnosis is done, we need to know the ventilation rate, the pollutant generation rate, allowable concentration and procedure is shown in figure 3 as following.
1) input data : ventilation rate, number of inhabitant, working level, and heating equipment, etc.
2) calculation : with input data, the indoor pollutant concentration is calculated with ventilation rates for respective houses that are provided by multizone air flow code COMIS (IEA-ANNEX23)[5](figure 2).
3)comparison : comparing allowable concentration with the calculated pollutant concentration, diagnose is executed.

Calculating concentration in the diagnosis process (left of the figure 3) is based on flow expression of eq. (1) by using input ventilation rate.

$$M_i + \sum_{j=0}^{R\max} C_i \times Q_{ji} - \sum_{j=0}^{R\max} C_i \times Q_{ij} = 0 \quad \cdots\cdots\cdots (1)$$

M_i : *pollutant generation rate*
C_i : *pollutant concentration*
Q_{ji} : *ventilation rate to room j from room i*
Q_{ij} : *ventilation rate to room i from room j*

The consequent process is to calculate the inverse matrix, to input the pollutant concentration of each room from the pollutant generationrate of the person, the equipment, etc., and to select the room compared to the standard. Next, it is to calculate the pollutant concentration of each room by the matrix production of the input pollutant generation rate matrix and the ventilation rate matrix.

Finally diagnosing is executed. This system judges each pollutant room by room, and graphical out put with colors can be demonstrated for user to understand the result clearly.

(2) EXAMPLE RESULT

An example of diagnosis on CO_2 with house and ventilation shown in figure 2 is indicated in figure 4. For a condition, mother is cooking as light work using gas burner in kitchen, grandmother and father are having a meal i.e. extreme light work in dining, grandfather is taking a bath as light work in bathroom, and children are studying as extreme light work for each bedroom1 and 2.
As result in graphical expression, in Japanese room, wash room, guest room, and 2F toilet CO2 concentration is under 1000ppm, and it satisfies house standard. On the other hand it is over 1500ppm, public standard, in hall, 1F toilet, bathroom and bedroom1 & 2. Pollutant concentration becomes 6160ppm in kitchen, dining and living, and even it couldn't satisfy labor standard.

VENTILATION DESIGN

(1) PROCEDURE OF DESIGN

Procedure is shown in figure 3. When ventilation rate is designed, it is necessary to know the pollutant generation rate, the connection between room (if air can flow enough the room) and allowed concentration. Design procedure is divided into 3 phases.
1) input data : number of room, room classification, pollutant generation rate, possible flow path, etc.
2) calculation : calculate the necessary ventilation rate of each room from input data, and establish ventilation rate between rooms and flow paths
3) decision of flow path and ventilation rate :

Table 2 CO_2 generation rate from inhabitant

Degree of work	RMR	CO_2 generation rate [m^3/h]
1.at the time of the rest	0	0.013
2.extreme light work	0 - 1	0.022
3.light work	1 - 2	0.030
4.inside work	2 - 4	0.046
5.heavy work	4 - 7	0.074

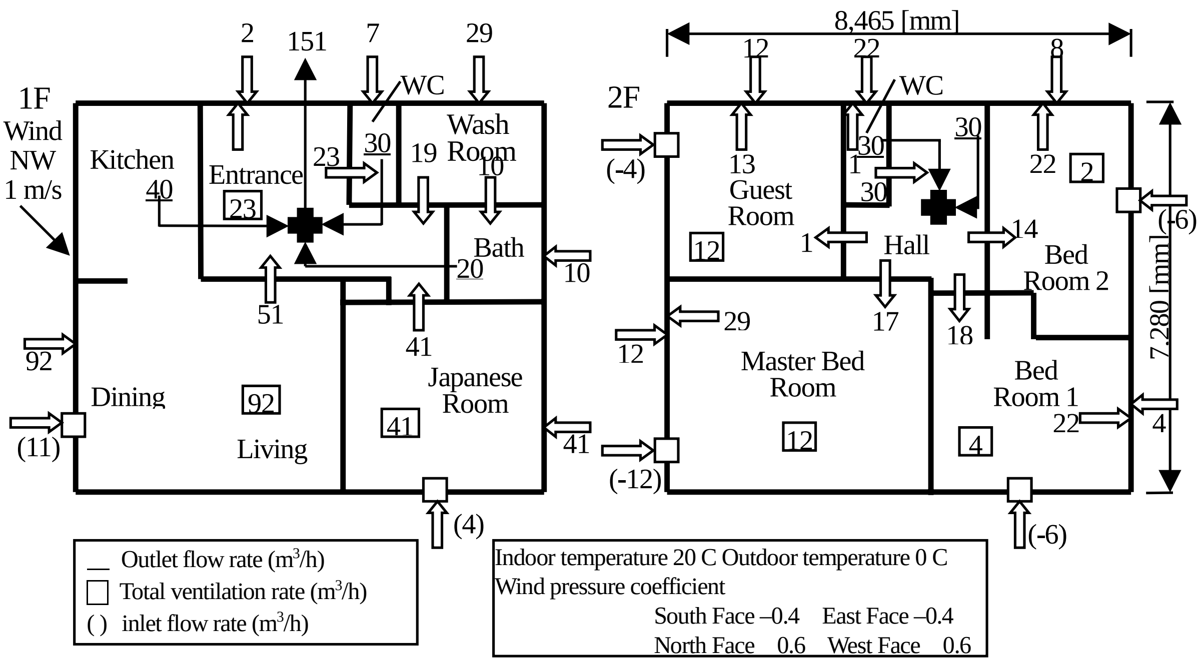

Figure 2 Plan of ‘Standard House’

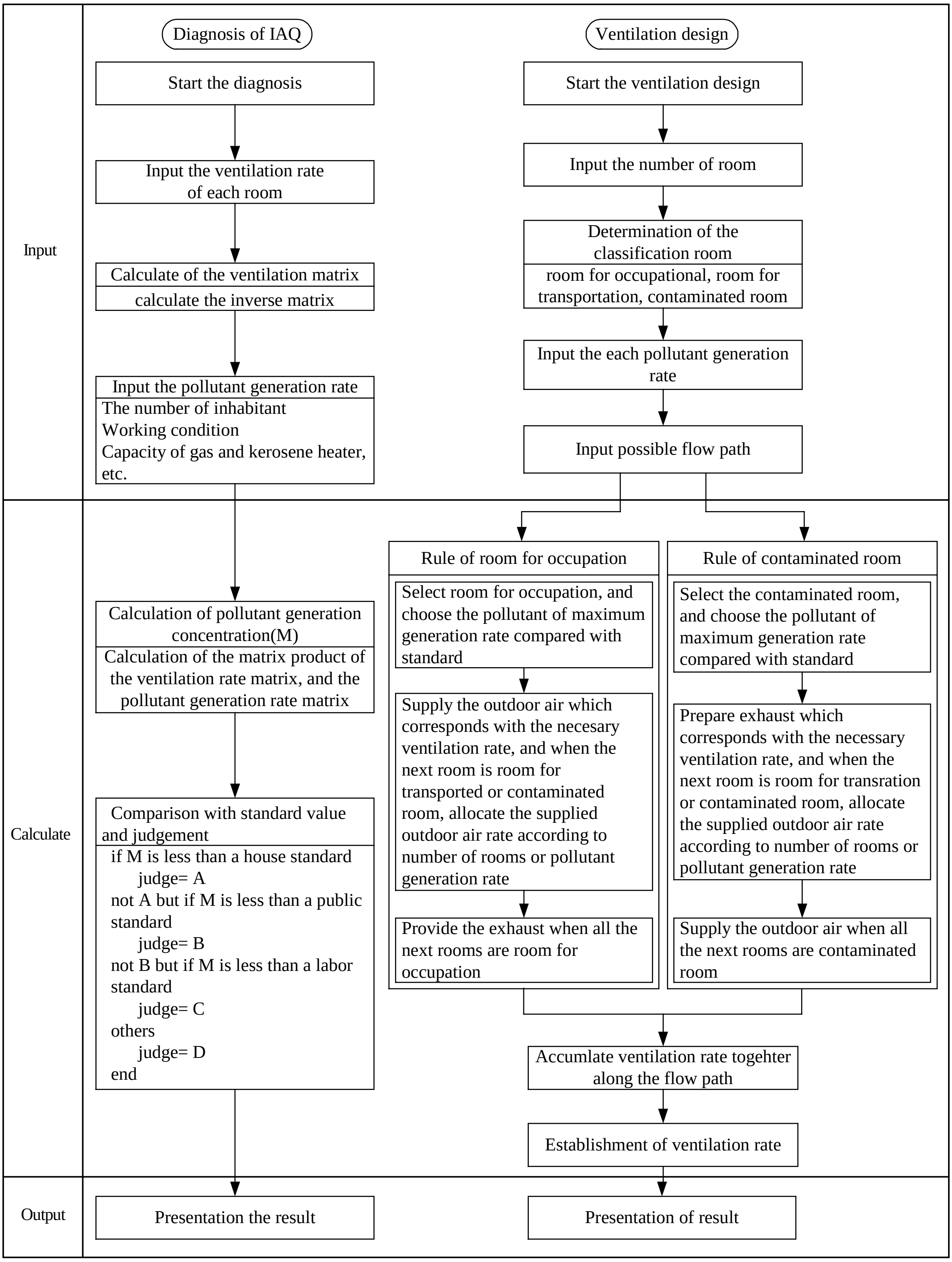

Figure 3 Flow chart of IAQ diagnosis and ventilation design

accumulation ventilation rate along the flow path and calculation of designed ventilation rate

Here is the calssification of rooms in phase 1.
1) room for occupation : living room, dining room, bedroom, etc. for long time occupation
2) room for transportation : entrance, corridor, hall, etc. for human transportation and no pollutant generation
3) contaminated room : kichen, toilet, bath, etc. with possible contaminant generation

The production rule of this system is subdivided into 2 parts over phase 2 and 3.
1) the routine of calculating the mutual ventilation rate between the room from the necessary ventilation rate of the room for occupation
2) the routine of calculating the exhausting rate from the necessary ventilation rate of the contaminated room.

For the former it is to introduce the outdoor air which corresponds with the necessary ventilation rate to the room for occupation, and to provide ventilation route and rate in the order of “the outdoor air -> room for occupation (-> room for transportation) -> (contaminated room) -> outdoor air”. On the other hand, exhaousted air corresponds with the necessary ventilation rate from the contaminated room. Ventilation route and rate is provided in the order of “the outdoor air <- contaminated room (<- room for transportation <- room for occupation) <- outdoor air”. As for various pollutants which occur in each room, various the maximum generation rate is considered by comparing with the standard value (HASS102 ventilation standard).

An example of production rule for the room for occupation is shown in figure 5. Supplied outdoor air is decided from rule 0 to rule 2. Destination and the amount of air going out from rooms are decided from rule 3 to rule 4.

(2) EXAMPLE RESULT

An example of ventilation design is shown in figure 6 using same conditions to diagnosis shown in figure 2 except ventilation rates. Outdoor air is more needed than the given rate at the diagnosis example not to exceed allowed CO_2 concentration. Outdoor air enters the badrooms, 20m^3/h each and living, 561.4m^3/h and is exhausted from kitchen, 599.88m^3/h. Also outdoor air is supplied into bathroom, 33m^3/h and almost same amount is directly exhausted to outside, 34.52m^3/h. This result estimated reasonable flow path and air flow rates.

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CONCLUSIONS

IAQ diagnosis and ventilation design tool with graphical UI is developed and corresponds to 9 contaminants. Also diagnosis and ventilation are demonstrated according to CO_2 using a house of 9 rooms and a life pattern based on broad survey. The system reveals the capability of diagnosis of IAQ and ventilation design considering air flow rate and flow path.
To develop system included life pattern into data base with synthetically diagnosis and ventilation rate design for various life pattern is scheduled.

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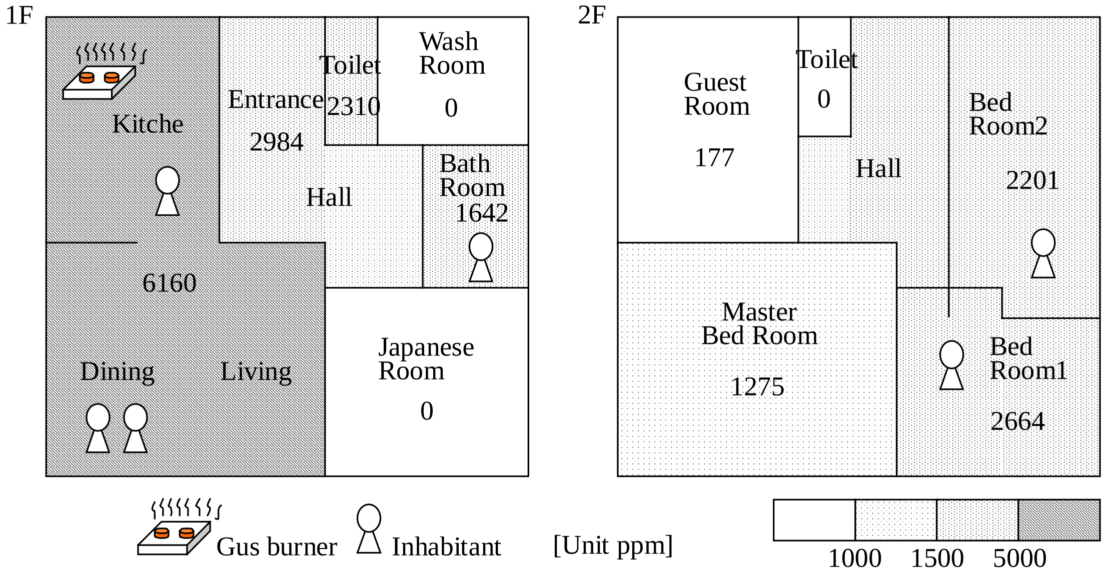

Figure 4 Result of diagnosis IAQ

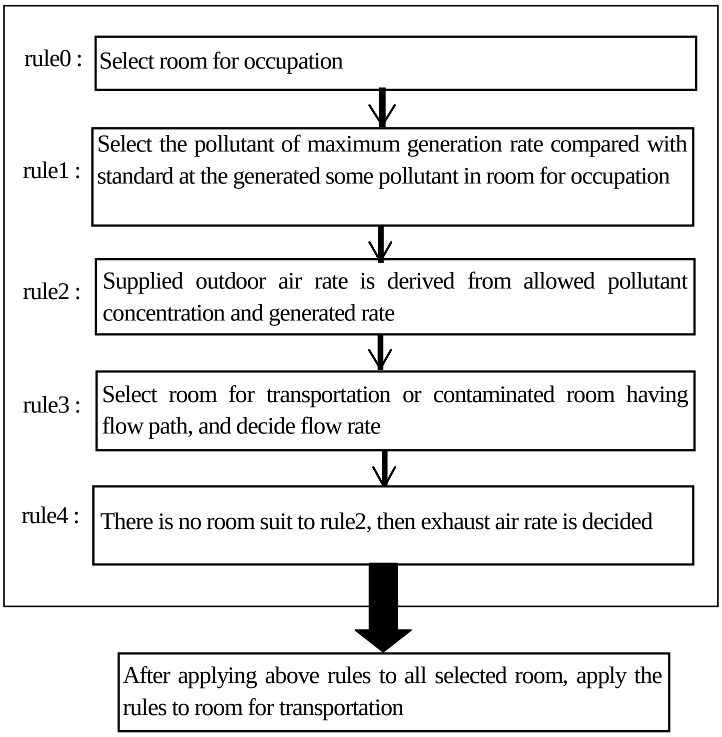

Figure 5 An example of production rule

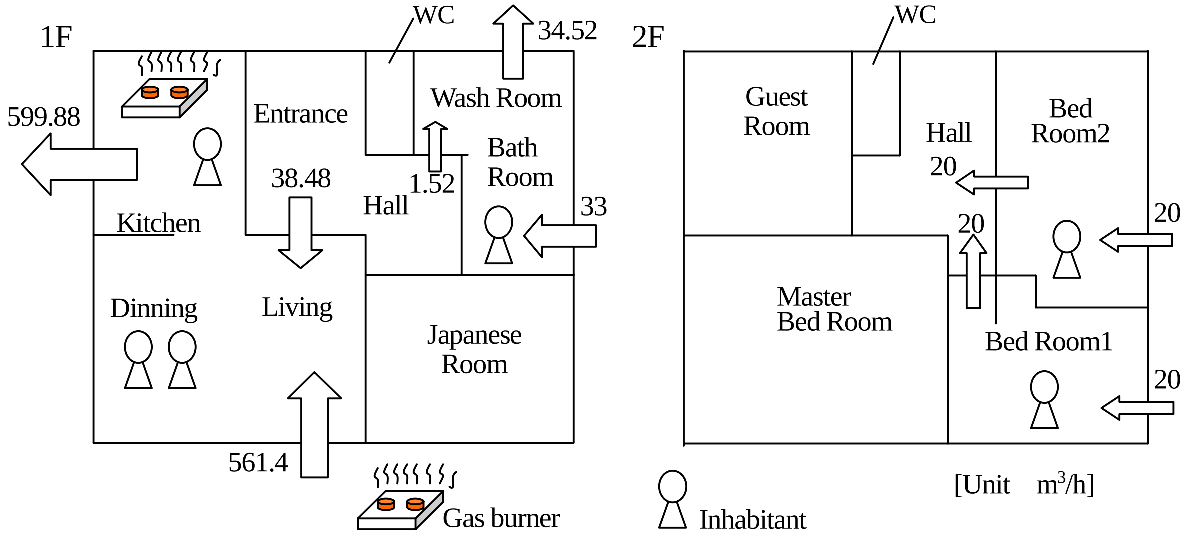

Figure 6 Result of ventilation design