Performance evaluation of four ventilation systems regarding IAQ and energy use for Japnaese climate conditions

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ABSTRACT

The purpose of this paper is to evaluate the performance of 4 kinds of ventilation systems from the point of view of indoor air pollution and energy need during heating season under Japanese conditions by numerical simulation. TVOC was selected to characterize the indoor air quality impact to residents. The results show that in the case of mechanical exhaust ventilation system, TVOC level is the highest among all the systems. Mechanical central supply and exhaust ventilaton system shows its advantages for minimizing energy consumption and maintaining an acceptable indoor air quality.

KEYWORD

Air quality, Energy, Numerical simulation

INTRODUCTION

As residential houses have been built more and more airtight to reduce energy consumption, it results in decreased level of natural ventilation rate and the problem of indoor air quality will occur. On the other hand, except for the traditional indoor air pollutant such as CO_2, CO, etc., the potential adverse health effects of exposure to total volatile organic compounds (TVOC) are becoming an increasingly important issue in recent days. Therefore, in this paper, TVOC was selected to characterize the indoor air quality impact to residents.

Numerical simulations under various conditions by the means of COMIS model were carried out in order to evaluate the performance of various ventilation systems to determine the optimum indoor environment with sufficient energy conservation.

SIMULATION METHODS

Model House and Climate Condition

A Japanese two storey single family house proposed by AIJ (Architectural Institute of Japan) was used in this calculation[1]. The floor plan is shown in Figure 1. The total volume of this house is about 297m^3. In this paper, two levels of airtightness performance of building envelope were given as 2.0 and 5.0 cm^2/m^2. The amount of leakage was uniformly distributed over all the exterior

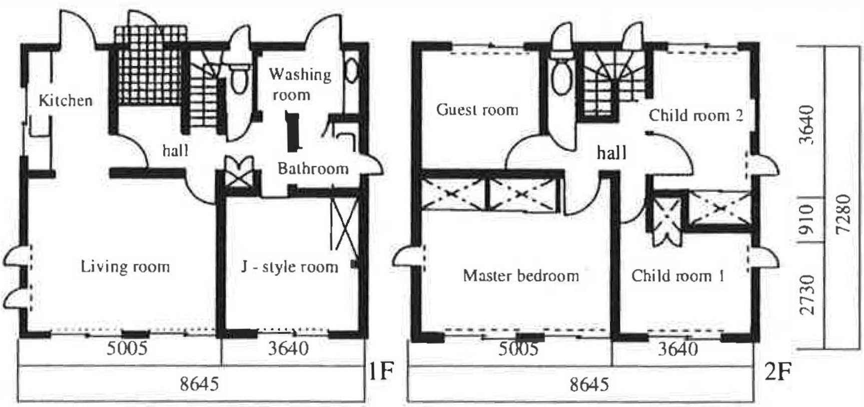

Figure 1 Floor plan of model house

Table 1 Climate conditions of three regions during heating season

Climate	Cold (Sapporo)	Moderate (Tokyo)	Mild (Kagoshima)
Heating season	30 Sep-14 Apr	24 Oct-26 Mar	15 Nov-10 Jan
Average temperature [℃]	1.09	8.21	9.13
Average humidity [g/kg']	3.19	3.79	5.44
Average wind speed [m/s]	2.64	3.09	3.15
Prevailing wind direction [°]	182.4 (S)	148.2 (SE)	269.0 (SW)

walls. The leakage for each wall was assumed to be concentrated at two heights; half of the leakage occurs at 0.6m above the floor and the other half at 1.8m above the floor. The interior doors and the windows were closed all the time. The exterior door was not taken into account. The cracks of all the interior doors were concentrated at the bottom of each door and the equivalent areas were assumed as 200cm^2 except the door between hall and guest room (100cm^2), the door between washing room and bathroom (800cm^2). Indoor air temperature was assumed uniformly as 20℃ .The occupancy was assumed to be two adults and two children. The residents' behaviour was based on NHK statistics.[2]

Three regions were selected to represent the different climate conditions. Standard Weather Data developed by SHASE (The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan) was used. Table 1 illustrates their main meteorological parameters during heating season.

2.2 *Ventilation System*

Four kinds of ventilation systems, i.e., natural, passive stack, mechanical exhaust and mechanical supply and exhaust ventilation system were taken into account (expressed as system 1 to 4, respectively, in this paper). The mechanical airflow rate of system 3 and 4 was 150m^3/h which could assure 0.5[ach] for the whole building. The airflow rate to each room depends on the ratio of each room's volume to the total.

All opening for natural ventilation were assigned an equivalent leakage area of 20cm^2 and a flow exponent of 0.5. They are located at 2.0m above the floor level. The total area of natural supply openings for system 1, 2 and 3 was 320, 140 and 140 cm^2, respectively.

Exhaust airflow rates of kitchen hood and bathroom fan were assumed as 300 and 100m^3/h, respectively. The bathroom fan was operated at 22:00 - 23:00 every day[2]. The operation time and duration of kitchen hood were different from cooking time: 6:30 - 6:45 for breakfast, 12:00 - 12:15 for lunch and 17:30 - 18:00 for dinner.

The reference data of wind pressure coefficient Cp were obtained from the AIVC Techniques guide for the following conditions: length to width ratio is 1:1, ratio of reference building height to the height of the surrounding buildings is 1:2[3]. Because the wind speed of Standard Weather Data is at the meteo site of 10m, while the data from AIVC is for sheltered conditions with a reference wind speed taken at roof height (5.4m), a vertical correction factor of 0.87 has been used in this paper.

Indoor Air Pollutant

As mentioned by Dumont (1994) and Figley et al. (1995), the emission rate of TVOC may change relatively with time and the kind of emitting sources[4][5]. However, in this paper, the source strength was assumed to have a constant value of $10^3 \mu g/(m^2 \cdot h)$. This value has been typically observed in the field[6].The outdoor level of TVOC was assumed as $0 \mu g/h$.

Because VOCs are always at low concentrations but have large toxicological effect during a long term exposure, a special index in terms of CV was introduced to show the cumulative effect of VOCs on residents during heating season. This description has been used in the research work of ANNEX27, one project of IEA - ECB&CS [7]. CV is the highest cumulated value among family members on the basis of the number of exposed hours Nh above a certain concentration Ci:

$Nh(C_i)$. $$CV = \int Nh(C_i)dC_i \quad (1)$$

Energy Consumption

The cumulative value of energy consumption was adopted here during the heating season if outdoor temperature is below 17℃.

Cases for Simulation

Twenty four cases were simulated including combination of three regions, two airtightness performances and four kinds of ventilation systems as previously mentioned.

RESULTS AND DISCUSSION

Variation of TVOC Concentration

Fig 2 shows the results of variations for TVOC concentrations of 4 kinds of ventilation systems at two levels of airtightness. The calculation was based on the weather data of Jan 31 within the heating season of Tokyo.

As one important feature, for the case of system 1, 2 and 3, the TVOC concentration in rooms at the second floor are much higher than the rooms at the first floor. From this point, system 1, 2 and 3 are not good enough to achieve both appropriate air exchange and movement of fresh air to all the rooms.

The trend of concentration variations display low peaks corresponding to the operation of kitchen hood and bathroom fan. As shown in Fig 2 for system 3, TVOC concentration decreases from 2157 $\mu g/m^3$ at 17:00 to 1434 $\mu g/m^3$ at 18:00 due to the operation of kitchen fan preparing for supper.

With regard to system 3, the TVOC concentration varies widely: in a range from 375 to 2157 $\mu g/m^3$, and the average level is much higher than the other ventilation systems. The reason of difference between system 3 and 1 can be indicated as the following: the operation of mechanical exhaust system affects airflow across the building sighificantly. Because mechanical equipment was assumed to be installed in the rooms at the first floor, it decreases the inside pressure and raises the neutral pressure level as a consequence. This superpositon causes the airflow rates at the second floor being decreased and even changes from outflow to inflow at times. Therefore, the TVOC concentration at the second floor (bedroom mainly) is much higher than the other cases. In addition, checking the airflow rates through the building, we found that the average airflow rate in the case of system 2 is always higher than that of system 3.

The variation of TVOC concentration in the case of system 4 is very slight and the level remains low all the time. It indicates that system 4 can be considered to be immune from the influence of the factor of weather.

CV Value and Energy Consumption

Figure 3 shows the cumulative curves for the housewife (she can be considered to have the worst level of exposure to indoor air pollutants in the family). In addition, because the energy consumption and IAQ can be taken into account as the most important evaluated indexes concerned with indoor environment, the combination of them may be an effective and simple method to evaluate the effect of

Table 2. CV value versus energy consumption

Region	Airtightness	System	CV	Energy
Sapporo	2	1	3366	4666
		2	2397	8821
		3	3882	6040
		4	2079	6939
	5	1	2225	7004
		2	1974	12397
		3	2343	8640
		4	1577	9756
Tokyo	2	1	3300	1966
		2	2590	3551
		3	3618	2756
		4	1767	3218
	5	1	2172	3046
		2	2234	5063
		3	2310	3801
		4	1421	4438
Kagoshima	2	1	1213	656
		2	1010	1145
		3	1174	922
		4	649	1090
	5	1	421	1019
		2	504	1656
		3	518	1272
		4	356	1497

(unit: CV value - $10^3\ \mu g/m^3 \times h$, Energy - kWh)

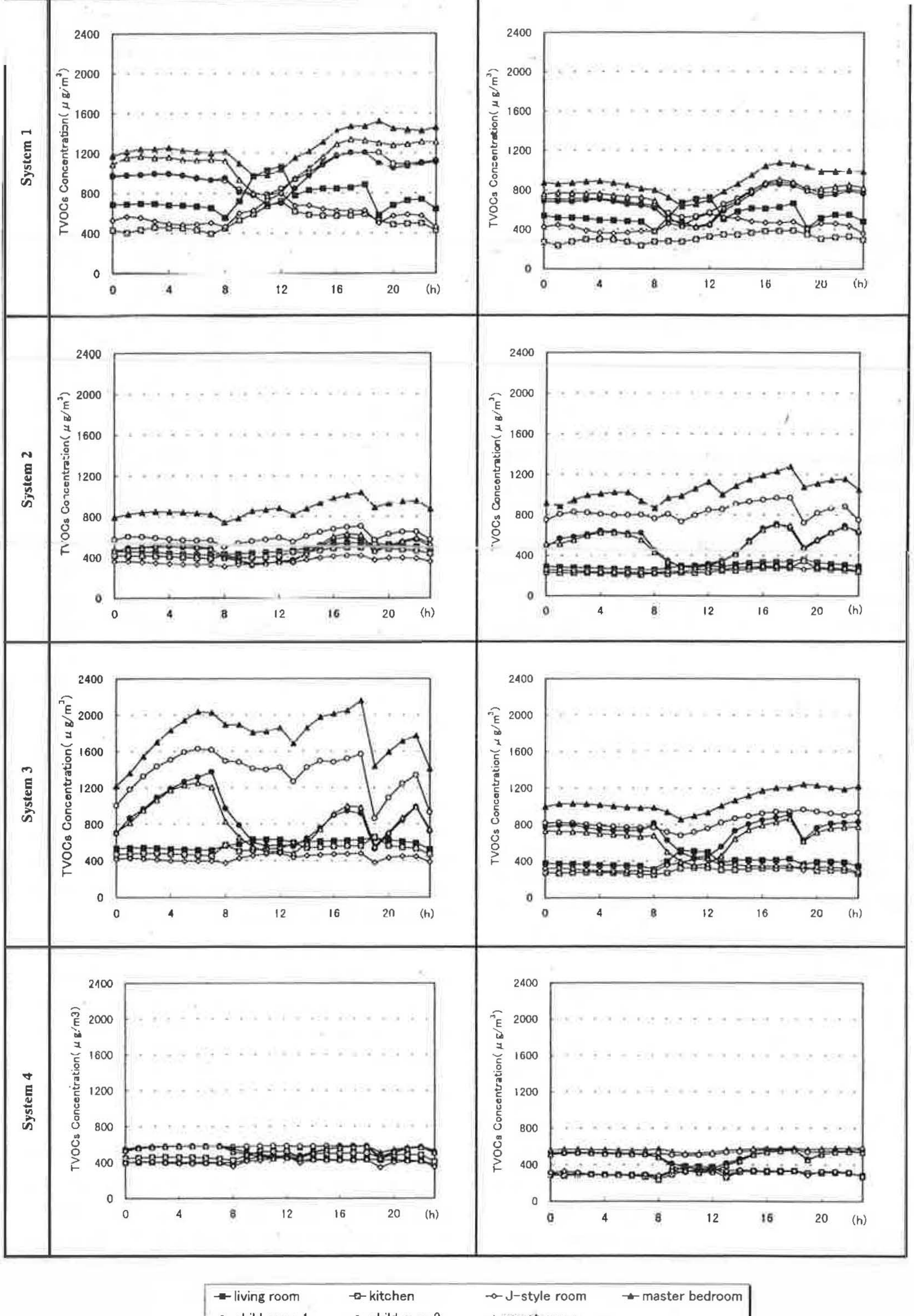

Figure 2. TVOC concentration four ventilation systems

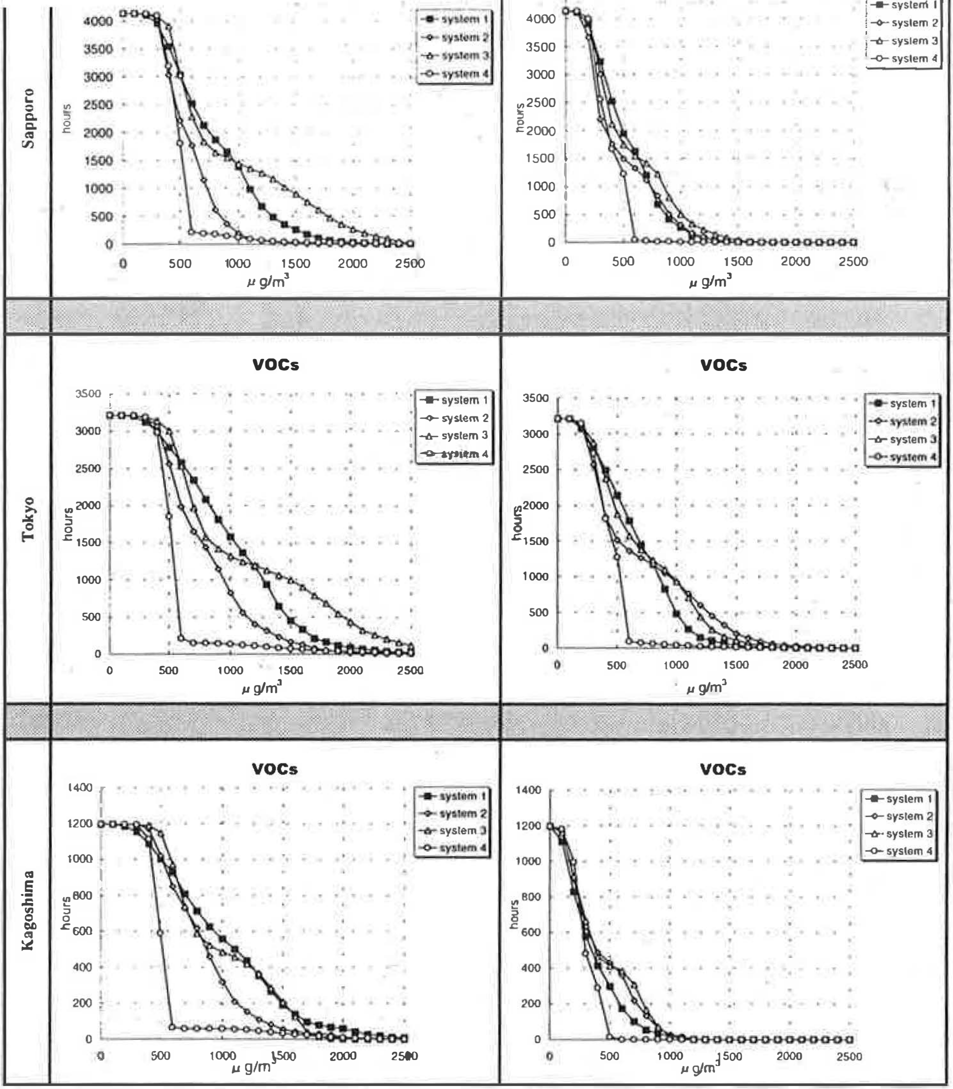

Figure 3. CV Cumulative curves of house wife

ventilation systems and other influential parameters such as region and airtightness. The results were summarized in Fig 4 while CV values and energy consumption were presented as condensed results in Table 2. The following comments can be noted regarding the figures and table:

From system 3, 1, 2 to 4, CV value decreases gradually. System 3 shows the highest CV value among all the systems, especially in the case of low airtightness. It can be concluded that the efficiency of this kind of system to remove TVOC is not good as expected. The reason is simular as what have been mentioned before. On the contrary, the inverse situation can be observed for system 4. As indicated in Fig 3, although from 0 to 300 $\mu g/m^3$, there is no difference among the cumulative curves of the four kinds of ventilation systems, but the cumulative curve of system 4 begins to fall abruptly from 300 $\mu g/m^3$. In practice, the frequency of occurring a concentration above 500 $\mu g/m^3$ for system 4 can be neglected. It can be attributed to the fact that both indoor air quality and air distribution are good due to the central mechanical force.

influence on the CV value and energy consumption. For the case of Kagoshima, Tokyo and Sapporo, the ratio of CV value for low airtightness (5.0 cm²/m²) to for high airtightness (2.0 cm²/m²) is 2.25, 1.39 and 1.44, respectively. From Fig 4, it is evident to observe the influence of region on CV value and energy consumption. The reason is that the heating seasons of three selected regions vary from each other too greatly. For example, the heating season duration of Sapporo is about 3.5 times of Kagoshima.

CONCLUSIONS

The results of this simulation can be summarized as the followings:

In the case of mechanical exhaust ventilation system, the TVOC level is the highest among all the systems. It can be concluded that the efficiency of this kind of system to remove TVOC is not as good as expected. The mechanical central supply and exhaust ventilaton system shows its advantages for minimizing energy consumption and maintaining a comfortable indoor environment. In addition, airtightness and region show great influence on the CV value and energy consumption.

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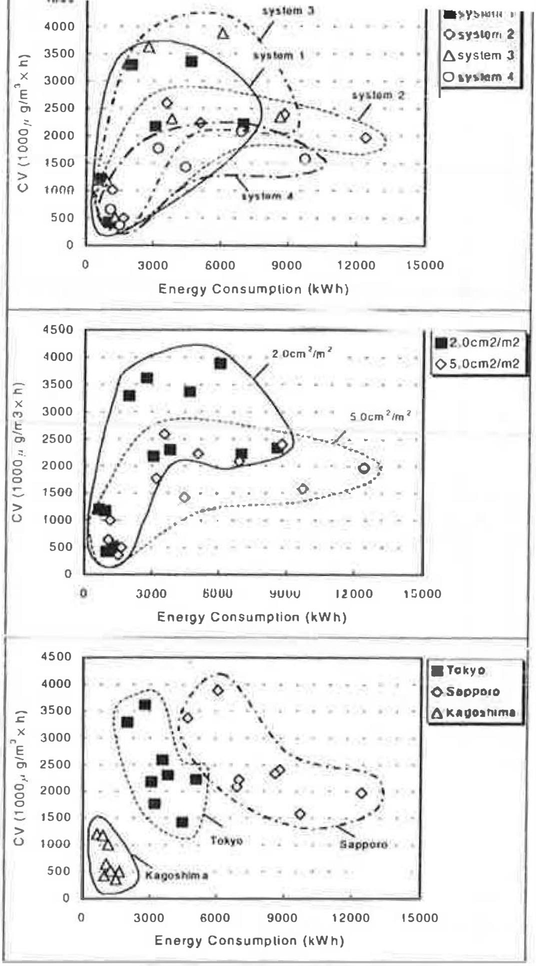

Figure 4 Energy consumption versus CV value

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