EVALUATION OF DOMESTIC VENTILATION SYSTEM PERFORMANCE BY COMIS MODEL FOR JAPANESE CONDITIONS

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ABSTRACT

The purpose of this paper is to evaluate the performance of four kinds of ventilation systems from the point of view of air exchange, indoor air pollution, and space heating load under Japanese conditions by numerical simulation. TVOC and CO_2 are selected to characterize the indoor air quality impact to residents. The results show that the equivalent leakage area has great influence on air movement. In addition, compared with other kinds of ventilation systems, mechanical central supply and exhaust ventilation system shows its advantages for minimizing energy consumption and maintaining an acceptable indoor air quality.

INTRODUCTION

Lack of natural air exchange and poor indoor air quality due to high airtightness has proved to be one of the biggest technical problems confronting the residential building professions since the 1980s. Therefore, there is a growing awareness of the importance of the domestic ventilation system performance for a high quality indoor environment.

Simulation under various conditions by the means of COMIS model was carried out in order to evaluate the performance of various ventilation systems for the sake of optimum indoor environment with sufficient energy conservation (Some other results have been reported in another paper [1]). COMIS is a multizone infiltration and pollution transport model which was developed in 1989 during a one-year international workshop. Further development took place between 1990 and 1996 within the framework of IEA' Annex23, Multi-Zone Airflow Modeling, one project of IEA - ECB&CS [2].

SIMULATION METHODS

House model and climate condition

The standard house model employed for this simulation is a Japanese two storied single-family house proposed by AIJ (Architectural Institute of Japan) [3], having a volume of 297m^3. The floor plan is shown in Figure 1. The leakage is uniformly distributed on each exterior wall and concentrated to two points: one half located at 0.6m and the other half at 1.8m from the floor. The status of interior doors and windows are all closed continuously. The cracks of all the interior doors are concentrated at the bottom of each door and the equivalent areas are assumed as 200cm^2 except the door between hall and guestroom (100cm^2), the door between washing room and bathroom (800cm^2). Indoor air temperature is assumed uniformly as 20• . The number of occupants is four (parents and two children) in this simulation.

Tokyo is selected as the representative climate condition in this simulation. The heating season for calculation is determined from Oct. 25th to Mar. 26th according to outdoor temperature and wind speed.

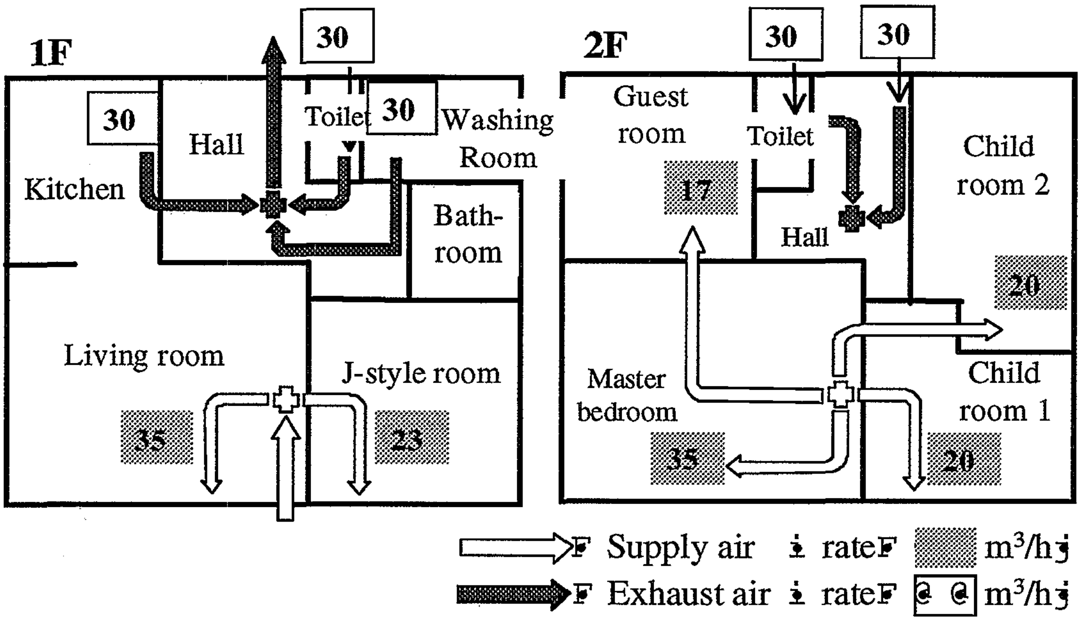


Figure 1. Ventilation plan of a standard house model for calculation

Ventilation system

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

Natural supply openings are set up at a height of 2.0m. Each equivalent leakage area is 20cm^2 and flow exponent is 2.0. The total area of natural supply openings for systems 1, 2 and 3 is 320, 140 and 140 cm^2, respectively.

Exhaust airflow rates of kitchen and bathroom fans are assumed as 300 and 100m^3/h, respectively. The bathroom fan is operated at 22:00 - 23:00 every day. The kitchen fan is operated at 6:30 - 6:45 for breakfast, 12:00 - 12:15 for lunch and 17:30 - 18:00 for supper.

The reference data of wind pressure coefficient Cp comes from a literature by AIVC [4], which are based on 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. 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 is used in this paper. This factor is the ratio of the factual wind speed at 5.4m to the value from Standard Weather Data.

Indoor air pollutant

Except for the traditional indoor air pollutant such as CO_2, CO, etc., the potential adverse health effect of exposure to total volatile organic compounds (TVOC) is becoming an increasingly important issue in recent days. Therefore, in this paper, CO_2 and TVOC was selected to characterize the indoor air quality impact to residents. As mentioned by Dumont and Figley et al., the emission rate of TVOC may change relatively with time and the kind of emitting sources [5][6]. However, in this paper, the source strength is assumed to have a constant value of 10^3• g/m^2/h. This value has been typically observed in the field measurement [7]. The outdoor level of TVOC is assumed as 0• g/m^3.

Because volatile organic compounds are always at low concentrations but have large toxicological effect during a long term, so in this paper, a special index in terms of CV was introduced to show the cumulative effect of TVOC on occupants during heating season. This index has been used in the research work of ANNEX27, one project of IEA - ECB&CS [8]. CV is calculated on the basis of the number of exposed hours Nh above a certain concentration Ci: Nh(Ci). For TVOC and CO_2, the threshold concentration Ci is defined as 300• g/m^3 and 1000ppm, respectively.

$$CV = \int Nh(C_i)dC_i \qquad \ldots(1)$$

The occupants' behavior that is related with the metabolic CO_2 and water vapor (including showering and cooking) production is based on NHK (Japan Broadcasting Corporation) statistics in order to represent Japanese life style [9]. According to the statistics, housewife spends the longest time at home, the next is child1 (middle school student), child2 (primary school student) and the master.

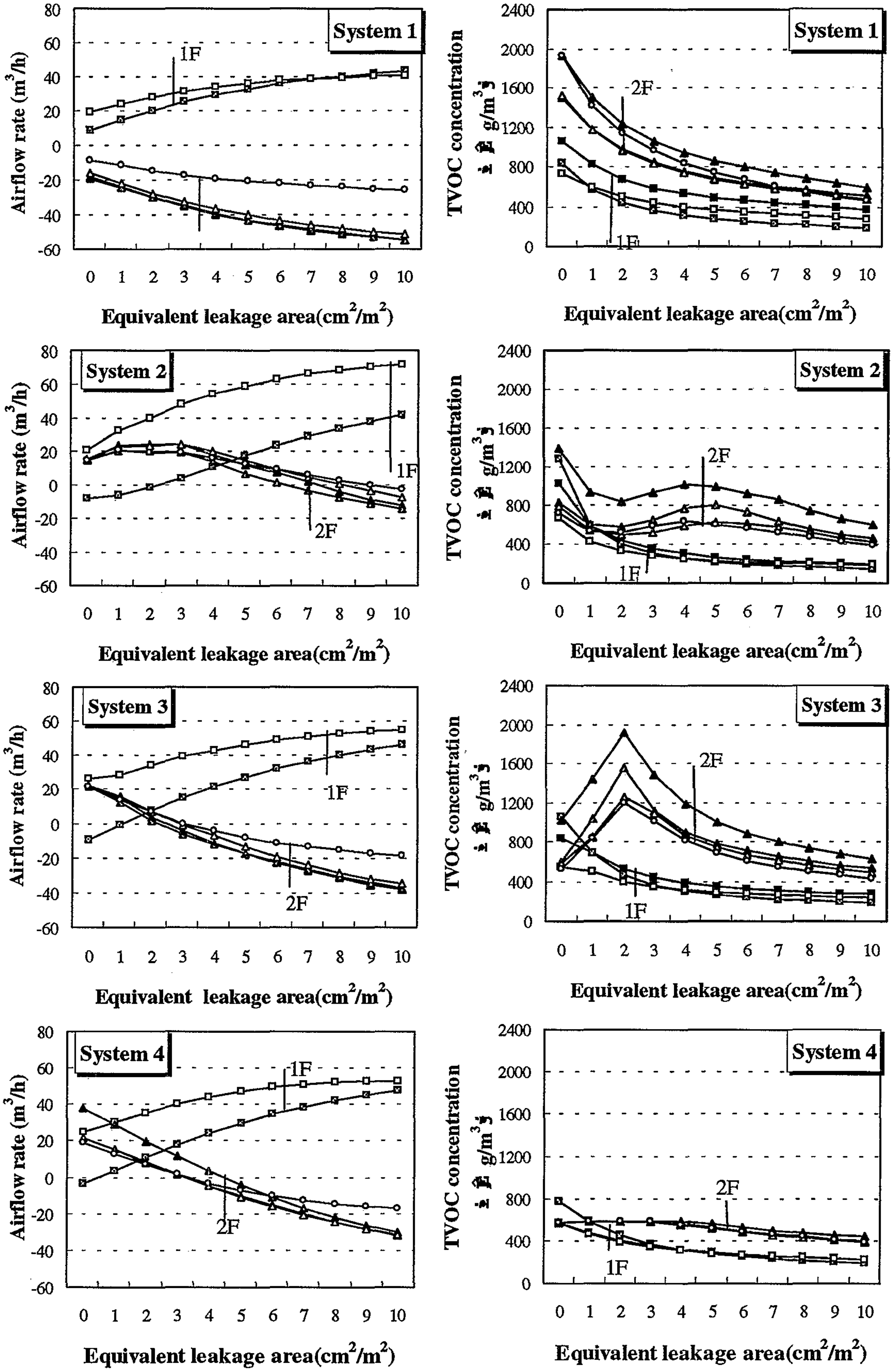
Space heating load

The cumulative value of space heating load during the heating season is calculated. Only for system 4, the heat recovery coefficient was assumed as 0.5.

RESULTS AND DISCUSSION

Airflow rate and TVOC concentration with different equivalent leakage areas

Figure 2 shows the variation of airflow rate from each room to the hall and TVOC concentration per room under different air leakage conditions. The airflow direction is taken into account. Negative value is expressed at opposite direction. The values are average ones of five hours from 3:00 to 7:00 on Jan. 30th (average wind speed: 1.30m/s, outdoor



(1) Airflow rate **(2) TVOC concentration**

Figure 2. Variation of airflow and TVOC concentration at different equivalent leakage area with various ventilation systems

temperature: -0.92•)

Regardless of the kind of ventilation system, with increasing the equivalent leakage area, the TVOC concentration in each room on the first floor decreases due to the increase of airflow rates. The airflow pattern in the rooms on the second floor changes with the increase of equivalent leakage area except system 1. For the case of systems 2 and 3, the TVOC concentrations in the rooms on the second floor reach the peak values when the equivalent leakage area is increased to 4~5 and $2cm^2/m^2$, respectively. On the other hand, airflow rates between hall and each room decrease to zero at 8~9 and $2cm^2/m^2$. By additional calculation, with system 2, the factual airflow rates from outside show a minimum at 4~5 cm^2/m^2, which is the same as the equivalent leakage area when peak value of TVOC concentration occurs. That is, for the rooms on the second floor, bi-directional airflow occurs and the airflow rate presented in Figure 2 is only the superposed result of the bi-directional airflow. With system 4, TVOC concentrations are almost independent of the effective league area in all the rooms, within a range of 200~780• g/m^3.

Relationship between CV_{TVOC} and space heating load

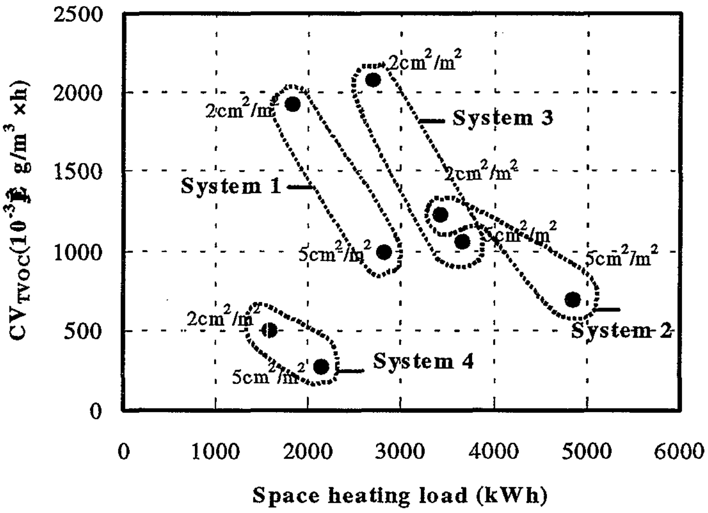


Figure 3. CV value versus space heating load at different equivalent leakage with various ventilation systems

Because the indoor air quality (expressed by the highest CV_{TVOC} among occupants here.) and space heating load can be taken into account as the most important indexes concerned with indoor environment, the combination of them may be a simple method to evaluate the effect of various ventilation systems. The results of the cases studied are shown in Figure 3. It is obvious that with a smaller equivalent leakage area, the values of CV_{TVOC} increase and that of space heating load decrease. The highest space heating load is about 4858 kWh, with system 2 at the equivalent leakage area of $5cm^2/m^2$. The CV_{TVOC} exceeds $2000(10^{-3}$• $g/m^3xh)$ with system 3 at the equivalent leakage area of $2cm^2/m^2$. Both CV_{TVOC} and space heating load are small with system 4. The reason can be attributed to the force of the central mechanism, and space heating load is less than that in other systems because of heat recovery. Conversely, both CV_{TVOC} and space heating load are much great with system 3 because the mechanical exhaust equipment is installed in the rooms on the first floor and it decreases the inside pressure and raises the neutral pressure level as a consequence. This causes the airflow rate on the second floor being decreased. Therefore, despite the fact that the space heating load with system 3 is somewhat higher than that with system 1, CV_{TVOC}, which is strongly influenced by the pollutant concentration on the second floor, is about the same as systems 1.

Comparison between CV_{co2} and CV_{TVOC}

Figure 4 presents the correlation between CV_{CO2} and CV_{TVOC} of all the residents for the cases shown in Figure 3. A high correspondence is shown. The correlation coefficient is about 0.83.

CONCLUSIONS

The equivalent leakage area has great influence on both airflow pattern and pollutant concentration. Mechanical central supply and exhaust ventilation system shows its advantages for minimizing energy consumption and maintaining a comfortable indoor environment. Other kinds of systems are not good as expected to gain a good indoor environment. For example, the CV_{TVOC} and space heating load is too high with natural and passive stack ventilation system, respectively, and mechanical exhaust system is not very efficient in satisfying the requirement for the two points.

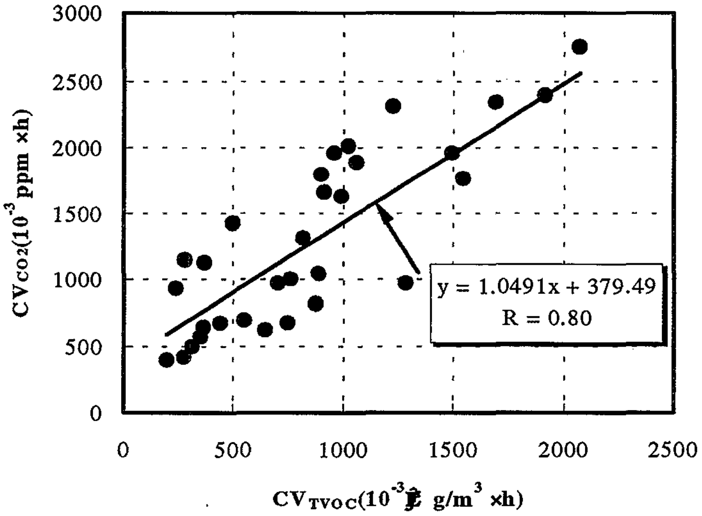


Figure 4. Comparison between CV_{CO2} and CV_{TVOC}

ACKNOWLEDGEMENTS

The authors acknowledge the members of ANNEX27, especially Robert Millet, Helmut E. Feustel, for valuable suggestions and data presentation.

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