ESTIMATION OF THE EFFECTIVE FRESH AIR SUPPLY RATE ON TWO STOREY DWELLINGS EMPLOYING STACK EFFECT VENTILATION

M. Tajima[1], T. Sawachi[2] and M. Okabe[3]

[1] *Housing Department, National Institute for Land and Infrastructure Management*
1 Tachihara, Tsukuba, 305-0802 JAPAN
[2] *Building Department, National Institute for Land and Infrastructure Management*
1 Tachihara, Tsukuba, 305-0802 JAPAN
[3] *Tsukuba Building Test Laboratory of Center for Better Living*
2 Tachihara, Tsukuba, 305-0802, JAPAN

ABSTRACT

This study deals with the ventilation performance of two storey dwellings employing stack effect ventilation to satisfy the overall ventilation requirement. The SRF (Supply Rate Fulfillment) index was used as a ventilation performance index. The experiments were implemented to measure effective fresh air rate by using tracer gas in a test house. Following are the results of the experiments and the theoretical calculations.

- The measured air change rate and the SRF value were fairly close to the theoretical calculation.
- The ventilation factors such as the ventilation rate, the effective fresh air supply rate and the SRF value were measured by using two tracer gases in transient conditions.
- The relationships among the equivalent leakage area of dwellings, the total ventilation rate and the overall SRF value are quantified on the basis of the measurements and theoretical calculations.

KEYWORDS

Ventilation performance, Measurement, Network air flow model, Tracer gas, Stack effect

INTRODUCTION

It is not easy to estimate ventilation performance of multi zoned building, because of the existence of the transferred air among the zones. The transferred air from other rooms contains effective fresh air when it has a potential to dilute contaminants. On the other hand, the transferred air is categorised as a contaminant source when it has higher pollutant level compared with acceptable concentration. From the viewpoint of the effective fresh potential of the transferred air, the authors defined the Supply Rate Fulfillment (hereinafter referred to as SRF (Sawachi et al. 1998)) index. The index has been used for the evaluation of ventilation performance of multi zoned dwellings employing mechanical ventilation systems as well as natural ventilation systems. This study, focused on whole house ventilation performance on two storey dwellings employing a stack effect ventilation system, has the following objectives.

- Measurement of the SRF value and the direct fresh air supply rate by using tracer gas methods in transient condition.
- Verification of the accuracy of the calculated rate by using a network air flow model, which is used as a tool for ventilation design, based on the measurement.
- Clarification of the relationships among the temperature difference, total fresh air supply

rate and the SRF value by the field measurement.

METHODS

Ventilation Performance Index SRF

The SRF index is used to evaluate the ventilation performance. This terminology is based on the theory of conservation law of fresh air rate. The index is given by Eqn.1 and defined as the ratio of the effective supply rate S_i (Eqn.3) to the substantial required fresh air supply rate P_i'. The SRF value ranges from 0 to 1 and SRF=1 means the referenced room has sufficient effective fresh supply air rate comparing to the P_i'. The S_i and the P_i' are calculated by using the α_i (surplus fresh air supply rate of the zone i, which is obtained by solving Eqn.2). The α_i can be calculated when all airflow rates among zones in a building are known. The maximum value of α_i, 1.0 represents purely fresh air like outside air, and the negative means no fresh air quantity included in the air. The OSRF (Overall Supply Rate Fulfillment） is defined as the geometric mean of SRF values of rooms as shown in Eqn.4. The OSRF value is used to evaluate the whole house ventilation performance. As mentioned above, the SRF value can be derived by theoretical calculations like as network air flow model. Furthermore, the value can be measured by using two tracer gas techniques which are the constant injection method and the constant concentration method (Tajima et al. 2003).

$$SRF_i = \frac{S_i}{P_i - \sum_{j=1}^{n} \min(0, \alpha_j \cdot Q_{ij})} = \frac{S_i}{P_i'} \quad (1)$$

$$A_i + \sum_{j=1}^{n} \alpha_j \cdot Q_{ij} - \alpha_i \cdot (\sum_{j=1}^{n} Q_{ji} + B_i) - P_i = 0 \quad (2)$$

$$S_i = A_i + \sum_{j=1}^{n} \max(0, \alpha_j \cdot Q_{ij}) - \sum_{j=1}^{n} \max(0, \alpha_i \cdot Q_{ji}) - \max(0, \alpha_i \cdot B_i) \quad (3)$$

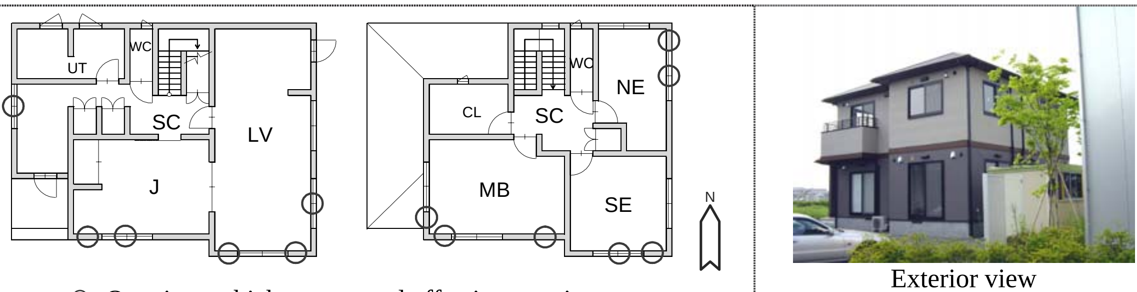
$$OSRF \equiv (SRF_1 \times SRF_2 \times \cdots \times SRF_M)^{1/M} \quad (4)$$

where

A_i	direct fresh air supply rate, the rate of air that is supplied directly from outside to room i [m^3/h]
B_i	rate of air exhausted directly to the outside from room i [m^3/h]
M	numbers of rooms for which the required fresh air supply rate is specified
P_i	required fresh air supply rate for room i [m^3/h]
P_i'	substantial required fresh air supply rate of room i [m^3/h]
Q_{ij}	transferred airflow rate, rate of air flowing from room j to room i [m^3/h]
S_i	effective fresh air supply rate of room i [m^3/h]
n	number of rooms
α_i	surplus fresh air supply rate contained in the air exhausted from room i

Experimental Conditions

To verify theoretical total ventilation rate and the SRF value, the experiments were implemented by using two tracer gases in a two storey test house employing a stack effect whole house ventilation system and heating equipment (Figure1). The dwelling can vary its air tightness by openings on the external wall. By using the constant injection and constant concentration methods with tracer gas, the ventilation aspects were measured and estimated. At the same time the wind direction, wind velocity, pressure differences between internal and external walls and temperatures of each zone were measured. Table1 and Table2 show the experimental conditions and Table3 shows the setting values of P_i (required fresh air supply rate) to measure the SRF value. One was based on the required fresh air supply rate of the Japanese Energy Conservation Standard of 1999 (hereinafter referred to as ECS99) and the other is based on formaldehyde concentration at a hypothetical room temperature of 20^{o}C and relative humidity of 50%RH as winter condition.



○: Openings which can control effective opening area

Location: TSUKUBA(warm region in Japan) Structure: Timber(ZAIRAI)
Floor area:131m^2 Air volume:315m^3 Air tightness: 1.6cm^2/m^2 at 9.8Pa

Figure1Configurations of the two storey test house

Table1 Experiment conditions

Temperature of outside	-5.4 to 23.3 ^{o}C (wintertime)
Temperature of internal zone	20^{o}C (controlled by heat pump heater)
Equivalent leakage area ($ELA_{9.8}$)	5 or 8 cm^2/m^2 at 9.8 Pa (controlled by additional openings)

$ELA_{9.8}$ is defined as Total leakage area of envelope / Floor area at 9.8Pa [cm^2/m^2]
$ELA_{9.8}$=5 equals n_{50}= 8.4, $ELA_{9.8}$=8 equals n_{50}=13.4

Table2 Experiment settings

CASE	$ELA_{9.8}$	Setting value of P_i
EX-08-E	8	ECS99
EX-08-H	8	HCHO(20^{o}C 50%RH)
EX-05-E	5	ECS99
EX-05-H	5	HCHO(20^{o}C 50%RH)

ECS99: fresh air requirement of Japanese Energy Conservation Standards of 1999

HCHO (20^{o}C 50%RH): Fresh air requirement derived from the area and Formaldehyde emission rate of plywood in prevailing condition.

The P_i values are shown in Table3.

Table3 Conditions to measure SRF values

	ECS99			HCHO(20^{o}C 50%RH)		
	P_i m^3/h	q_i ccm	σ_c ppm	P_i m^3/h	q_i ccm	σ_c ppm
J	20	20	60	9.6	12	76
LV	50	50		17.9	23	
MB	40	40		9.5	12	
SE	20	20		7.9	10	
NE	20	20		7.0	9	
SC	0	0		27.1	34	
ΣP_i	150m^3/h (0.48ACH)			79m^3/h (0.25ACH)		

P_i: Required fresh air supply rate (designing rate) q_i: Tracer gas injection rate (constant Injection)
σ_c: concessionary tracer gas concentration (for constant injection method)

RESULTS AND DISCUSSION

The condition of air leakage openings of envelope for theoretical calculation is different from the real situation (Table4). The measured values averaged 30 minutes data even though they include affection of transient condition. Beside, the effective temperature differences between indoor and outside are defined as Eqn.6 for the purpose of considering the wind pressure and temperature differences simultaneously.

Table4. The conditions of air leakage openings distribution on envelope

Real situation	Theoretical calculation
Existing on roof, external walls, floor, Window and so on	Existing on only external walls hypothetically

$$\Delta T_E \equiv \Delta T + \frac{T_r \Delta Cp_E \mathbf{V}^2}{2gh} \qquad (5)$$

where

T_r	indoor temperature [K]
g	gravity [m/s^2]
h	height of storey [m]
v	wind velocity [m/s]
ΔCp_E	effective wind pressure coefficient
ΔT	temperature difference between indoor and outside [K]
ΔT_E	effective temperature difference between indoor and outside [K]

Figure2, 3, 4, 5 show the results of the experiments and theoretical calculations. Over 0.6ACH air change rate is required to comply with the Japanese energy conservation standard of 1999 perfectly, judging from the results of theoretical calculations (Figure2). On the other hand, only 0.3ACH is required to satisfy HCHO (20^{o}C 50%RH) condition. In addition, the required air change rate is less than 0.2ACH where the absorption rate (0.1m/h) of plywood was considered. The measured total fresh air supply rates are distributed closely along the calculated rate. Its mean rates are a little lager than theoretical values which means the hypothesis of the distribution of openings on external walls contributes to less fresh air supply rate than real situation (Figure3). The calculated air change rate indicates sufficient value from the viewpoint of ventilation designing. The measured OSRF values close to the calculated rate, and mean values are a little larger than the calculated rate (Figure4 and Figure5).

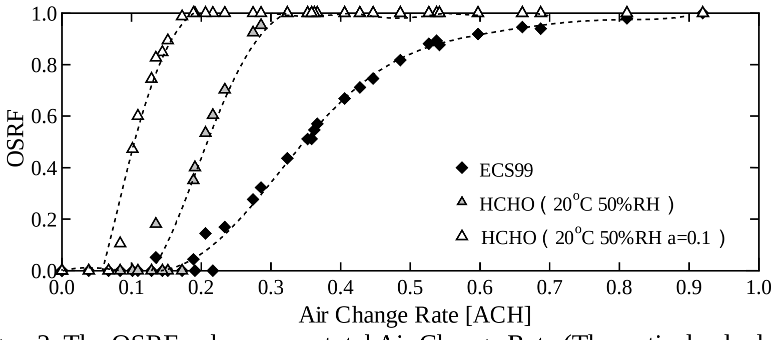


Figure2. The OSRF value versus total Air Change Rate (Theoretical calculation)

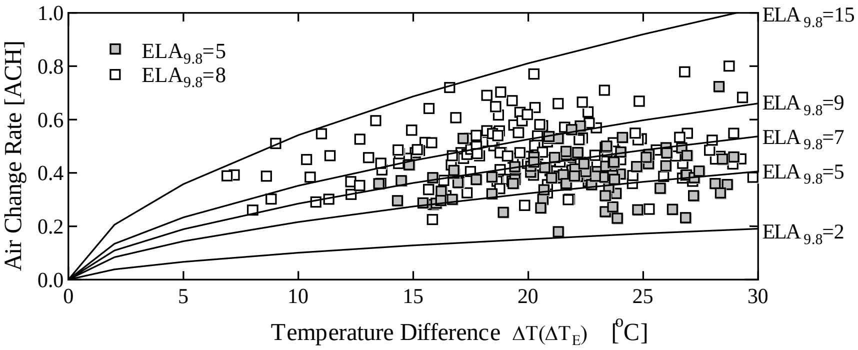


Figure3. Relations between ΔT and Air Change Rate
(Solid lines: theoretical value, Dots: measured value)

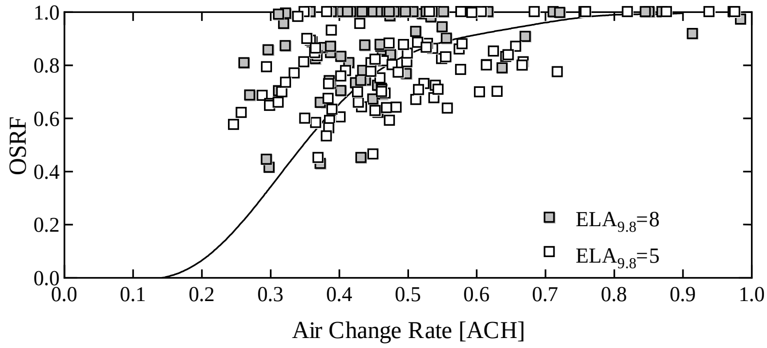


Figure4. The OSRF value for ECS99 versus Air Change Rate
(Solid line: theoretical value, Dots: measured value)

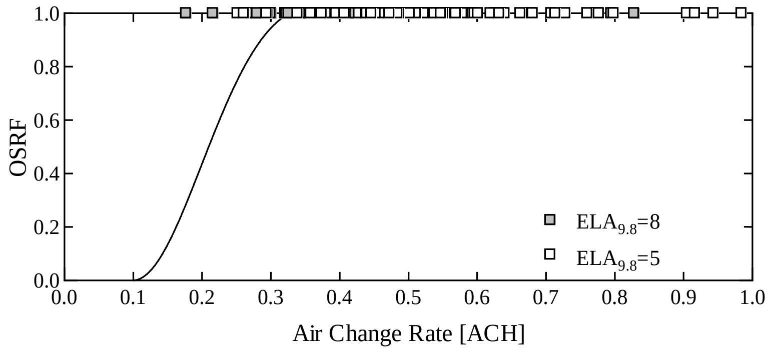


Figure5. The OSRF value for HCHO conc. versus Air Change Rate
(Solid line: theoretical value, Dots: measured value)

CONCLUSIONS

The ventilation aspects such as the whole house ventilation rate and the SRF values were measured by using two tracer gas techniques in transient conditions. The relationships among equivalent leakage area of the envelope, the total ventilation rate and the OSRF value are shown on the basis of the measurements and the theoretical calculations. This method allows the required effective leakage area of openings for sufficient fresh supply and the SRF values in two storey dwellings employing stack effect systems to be easily determined. These results can make it easy for designers to build structures by giving them a way to know the necessary effective leakage area of envelope to comply with required fresh air rate.

REFERENCES

Claude - Alain Roulet, Luk Vandaele. (1991). *Technical Note AIVC34 Air Flow Patterns within Buildings Measurement Techniques*, Air Infiltration and Ventilation Centre.

Takao Sawachi, Yoshinori Taniguchi, Shigeki Ohnishi, Haruki Ohsawa and Hironao Seto. (1998) A new experimental approach for the evaluation of domestic ventilation systems, *ASHRAE Transactions: Research*, pp.570-611.

Masaki Tajima, Takao Sawachi, Hironao Seto and Hitoshi Takeda. (2003). Presumption experiment of supply rate fulfillment sing tracer gas, *Healthy building 2003* **volume2**, pp.422 426.