# Study of ventilation performance and indoor air quality in eight sick houses

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## ABSTRACT
In this study, the houses where residents were suspected of having sick house syndrome located in Miyagi prefecture of Japan, had been investigated during the summer of 2001. The investigation included the measurements of the aldehydes and volatile organic compounds (VOCs) concentration, air tightness level, airflow volume at inlets/outlets and ventilation rate. This paper shows the results of indoor air quality and ventilation rate in eight houses. All these houses, which are air tight except one house, use mechanical ventilation system. It is found that the amount of outdoor air introduced was shortage in many residences and some ventilation systems are not operated properly. The formaldehyde concentration in the investigated houses exceeded the criterion from the guideline, set as 0.08ppm, of the Ministry of Health, Labor and Welfare of Japan. In some residences, shortage of the amount of air supplied is one of the factors causing high chemical substance concentration.

## INDEX TERMES
Sick house syndrome, Ventilation, Air tightness, Formaldehyde, VOCs

## INTRODUCTION
Indoor air pollution caused by chemical substances from building materials, furniture and various utensils has become a serious problem in Japan. Such polluted indoor air causes a serious health hazard to residents as "Sick House Syndrome." In order to take measures to prevent indoor air pollution, it is important to make clear the relationships of indoor air quality and ventilation performance. In this study, the houses located in Miyagi prefecture of Japan, where residents were suspected of having sick house syndrome, had been investigated during the summer of 2001. This investigation included the measurement of the aldehydes and volatile organic compounds (VOCs) concentration, air tightness level, airflow rate at inlets/outlets and ventilation airflow rate.

## METHODS
In this study, eight sample houses from the Miyagi prefecture, Japan, were investigated. Table 1 shows the description of these houses. Measured items are formaldehyde, VOCs concentration, air tightness level, airflow volume at inlets/outlets and ventilation airflow rate. Measurement was performed from June to October, 2001.

### Formaldehyde and VOCs concentration
The three typical rooms of each house were chosen for the measurement. Concentrations of formaldehyde and VOCs were measured at a height of 1.1m above the floor. Table 2 shows the methods for the measurement. The doors and windows of the room were closed as much as possible at the time of measurement and the measured data was recorded for 24 hours.

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**Air tightness levels**
The air tightness level of these houses was measured by the depressurization method, using the air tightness measurement device (Kona Sapporo Co.).

**Airflow rate at inlets/outlets**
Measurement of airflow rate was carried out at all air inlets and air outlets using the airflow meter (Kona Sapporo Co.).

**Ventilation airflow rate**
Ventilation airflow rate in this research means the outdoor airflow rate introduced to inside space. The outdoor airflow rate introduced to each room was monitored by the constant concentration method. The measurement equipment from Innova, Denmark was employed. Sulphur hexafluoride ($SF_6$) was used as the tracer gas. The 5ppm was the target concentration. To mix $SF_6$ gas, small fans were used during the measurement period. The doors and windows of the room were closed as much as possible at the time of measurement. Occupants were required to record the time of using fans and opening windows.

**Table 1.** Brief description of the investigated houses

| | Mecanical Ventilation System | Total Floor Area [$m^3$] | Building Age | Measurement Day |
|---|---|---|---|---|
| House A | Mecanical Suply and Exhaust | 183.0 | 2 month | 6/20-6/22 |
| House B | Mecanical Exhaust | 130.6 | 5 month | 7/2-7/4 |
| House C | Mecanical Exhaust | 173.8 | 1 year and 8 month | 7/7-7/9 |
| House D | Mecanical Exhaust | 134.2 | 3 year and 5 month | 8/6-8/8 |
| House E | Mecanical Exhaust | 114.3 | 1 year and 9 month | 8/17-8/19 |
| House F | Mecanical Exhaust | 150.9 | 2 year and 5 month | 8/27-8/29 |
| House G | Mecanical Suply and Exhaust | 182.4 | 8 year and 2 month | 9/17-9/20 |
| House H | Mecanical Suply and Exhaust | 121.7 | 3 year and 6 month | 10/6-10/8 |

**Table 2.** Concentrations of formaldehyde and VOCs measurement method

| Items | Formaldehyde | Volatile Organic Compounds |
|---|---|---|
| Sampler | DNPH-Sillica cartridge (Waters Sep-Pak XpoSure) | Charcoal absorpition tube (SIBATA Scientific Technology) |
| Sampling Method | Passive sampling (24 hours) | Active sampling (500ml/min×24 hours) |
| Measuring Point | 1.1m above the floor in 3 typical rooms | |
| Analyze Method | HPLC | GC(FID) |

## RESULTS AND DISCUSSION

### Result of measurements

Result of air tightness levels, airflow volume at outlets and ventilation airflow rate

Table 3 shows results of airflow rate and air tightness level. Table 4 shows measurement period. Measurement period of ventilation airflow rate is almost overlapped with concentration measurement of formaldehyde and VOCs in all house except for House G. The air tightness level of 7 houses meets standards of $5.0cm^2/m^2$, which is prescribed in the low of Energy Conservation Standard for Next Generation Residence in Japan (Institute for Building Environment and Energy Conservation., 1999). All mechanical exhaust fans were operated under occupants' normal operation mode. It is found that air change rates were around $0.5h^{-1}$ during the measurement period in 3 houses. However, this measurement is

possibly influenced by various kind of disturbing factors. Table 3 also shows nighttime (0:00~6:00) measurement results that are less influenced by disturbances. Although air change rates in Houses A and B are around $0.5h^{-1}$, the other results show a low air change rate. Especially Houses G and H indicate a very low air change rate, which is about $0.2h^{-1}$.

Result of ventilation airflow rate and airflow volume at outlets

Figure 1 shows the result of airflow volume at outlets and ventilation airflow rate during the nighttime period when the airflow rate is rather stable. Figure 2 shows the relationship between them. In House A, airflow volume is the measured value at air inlets, because the shape of outlets was not appropriate for measurement. House C has no data of ventilation airflow rate. Ventilation airflow rates are larger than airflow volume measured at outlets in 4 houses. It is estimated that a part of indoor air is exhausted through building air leakage. Especially, in case of House A, the ventilation airflow volume is 2.5 times the airflow volume measured at the inlets. It seems that the outdoor air of 150 $m^3$ enters rooms through air leakage. On the other hand, in Houses E and H, ventilation airflow rates are smaller than airflow volume at outlets. But the reason is not clarified.

Result of air tightness level and air change rate

Figure 3 shows air tightness level and air change rate during the nighttime period when the airflow rate is rather stable. It shows that there is no relationship between these two factors. Because all houses have mechanical ventilation system and air change rates are less influenced by air tightness level.

**Table 3.** Results of measurements

| | House A | House B | House C | House D | House E | House F | House G | House H |
|---|---|---|---|---|---|---|---|---|
| Air Change rate during the measurement periods [$h^{-1}$] | 0.97 | 0.72 | - | 0.35 | 0.37 | 0.45 | 0.78 | 0.32 |
| (Ventilation airflow rate [$m^3$/h]) | (445) | (225) | - | (120) | (100) | (173) | (341) | (87) |
| Air Change rate during the nighttime periods [$h^{-1}$] | 0.53 | 0.64 | - | 0.29 | 0.32 | 0.38 | 0.21 | 0.22 |
| (Ventilation airflow rate [$m^3$/h]) | (242) | (198) | - | (96) | (88) | (147) | (92) | (61) |
| Airflow volume at outlets [$m^3$/h] | 102 | 168 | 316 | 76 | 106 | 129 | 72 | 81 |
| Air tightness level [$cm^2/m^2$] | 3.11 | 0.40 | 5.16 | 2.83 | 1.10 | 0.85 | 1.33 | 0.86 |

**Table 4.** Measurement periods

| | Measured Item | Measurement Periods |
|---|---|---|
| House A | Indoor Air Quality | 6/20 14:20-6/21 14:20 |
| | Ventilation Airflow Rates | 6/20 20:00-6/21 6:00 |
| House B | Indoor Air Quality | 7/3 10:45-7/4 10:30 |
| | Ventilation Airflow Rates | |
| House C | Indoor Air Quality | 7/8 9:00-7/9 9:20 |
| | Ventilation Airflow Rates | missing data |
| House D | Indoor Air Quality | 8/7 13:15-8/8 12:50 |
| | Ventilation Airflow Rates | |
| House E | Indoor Air Quality | 8/18 10:35-8/19 10:15 |
| | Ventilation Airflow Rates | 8/18 11:00-8/19 10:15 |
| House F | Indoor Air Quality | 8/28 10:20-8/29 10:25 |
| | Ventilation Airflow Rates | |
| House G | Indoor Air Quality | 9/18 10:20- 9/19 10:35 |
| | Ventilation Airflow Rates | 9/19 14:00- 9/20 14:00 |
| House H | Indoor Air Quality | 10/7 10:10- 10/8 9:50 |
| | Ventilation Airflow Rates | |

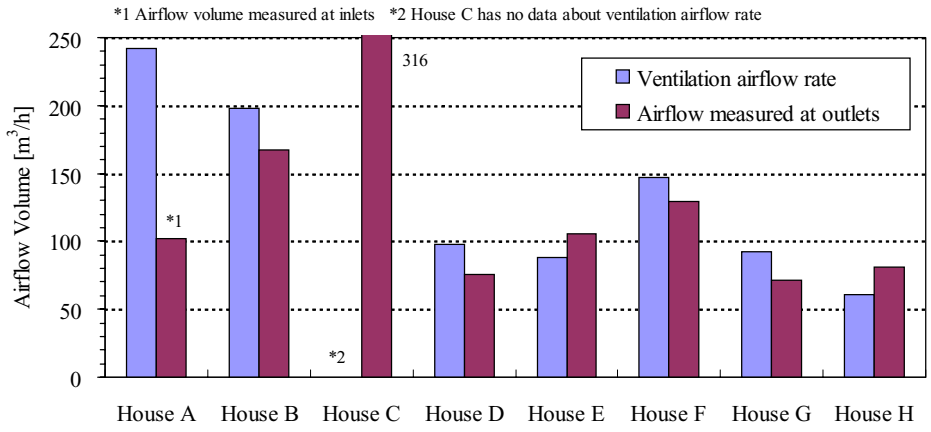


**Figure 1.** Results of ventilation airflow rate and airflow volume at outlets

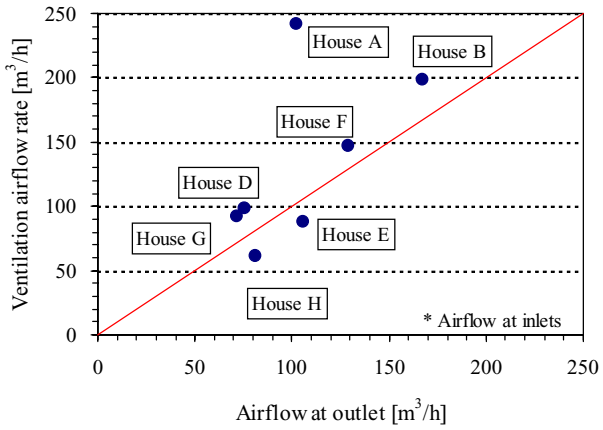


**Figure 2.** Relationships between airflow rates at outlets and ventilation airflow rate

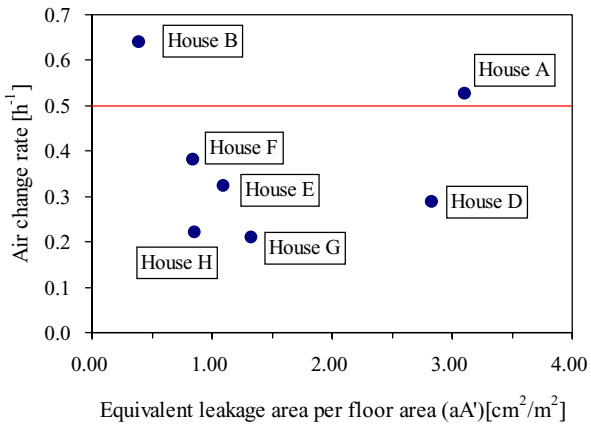


**Figure 3.** Relationships between air tightness levels and air change rate

**Relationship between air change rate and chemical substance concentration**

Relationship between air change rate and formaldehyde concentration

Figure 4 shows the relationship between formaldehyde concentration and air change rate during the concentration measurement periods. Formaldehyde concentration in almost all rooms exceeds the guideline (0.08 ppm) of the Ministry of Health, Labor and Welfare of Japan. Formaldehyde concentration is lower in other houses where air change rate exceeds $0.5h^{-1}$.

Relationship between air change rate and TVOC concentration

Figure 5 shows the relationship between TVOC concentration and air change rate during the concentration measurement periods. TVOC concentration in almost all rooms exceeds the criterion of the guideline ($400\mu g/m^3$). The concentration is high in some houses even if air change rate is large. In these houses with high concentration, the emission rate of VOCs from building materials, furniture and various materials seems to be very high.

**Relationship between chemical substance emission rate and building age**

Chemical substance emission rate calculation

Chemical substance emission rate $M$ [mg/h] is calculated by the following equation (1), where $C$ is the chemical substance concentration of the room [$mg/m^3$], $V$ is room volume [$m^3$], and $N_R$ is room air change rate during formaldehyde and TVOC concentration measurement periods [$h^{-1}$].

$$M = CVN_R \qquad (1)$$

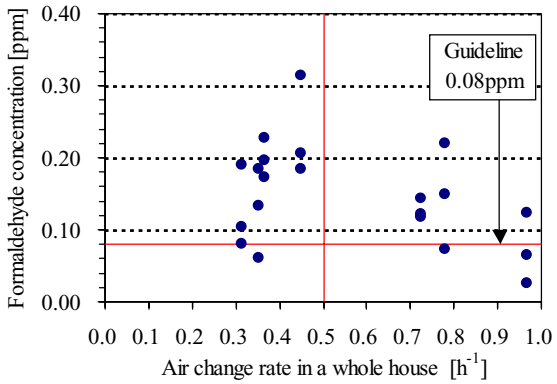


**Figure 4.** Relationships between air change rate in a whole houses and formaldehyde concentration

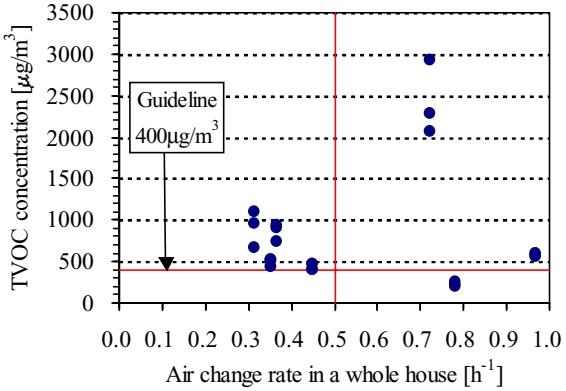


**Figure 5.** Relationships between air change rate in a whole houses and TVOC concentration

The air change rate $N_R$ is calculated from ventilation airflow rate for a room divided by the room volume. Ventilation airflow rate means the outdoor airflow rate directly entered the room. Figure 6 shows the relationship between air change rate of a whole house and air change rate of rooms where chemical substance concentration $N_R$ is measured. There are three measurement points in each house. Air change rate in concentration measurement rooms are smaller than those of a whole house. It is also indicated that air change rates in 1st floor are larger than those of 2nd floor, because the outdoor air easily enters the first floor due to buoyant effect.

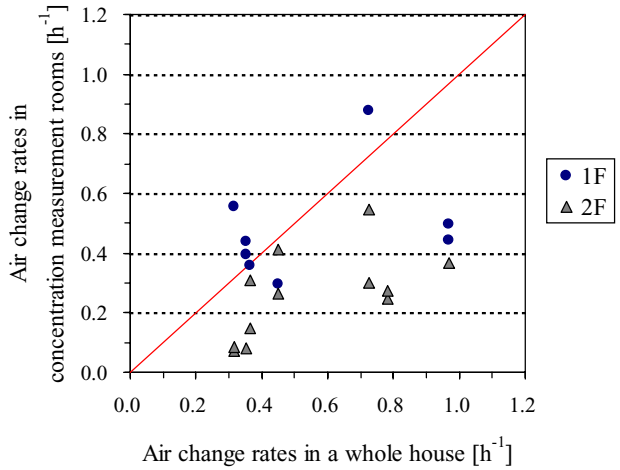


**Figure 6.** Relationship between air change rate in a whole house and measurement room

Relationship between formaldehyde emission rate and building age

Figures 7 and 8 show the relationship between formaldehyde concentration and building age and between formaldehyde emission rate and building age, respectively. Concentration does not decrease, even if building age increases. Emission rate decreases a little as building age increases. The highest emission rate appears in one of rooms in the house, which is over 6 years old. It is estimated that this is due to the influence of the emission from furniture.

Relationship between TVOC emission rate and building age

Figures 9 and 10 show the relationship between TVOC concentration and building age and between TVOC emission rate and building age, respectively. Concentration decreases a little as building age increases. Emission rate clearly decreases as building age increases. Decreasing rate of TVOC is greater than that of formaldehyde.

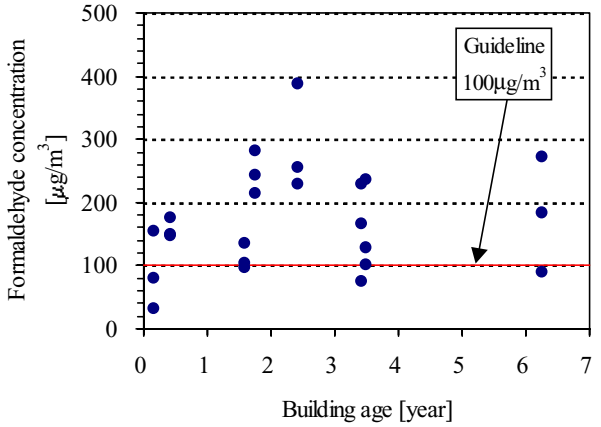


**Figure 7.** Relationships between building age and formaldehyde concentration

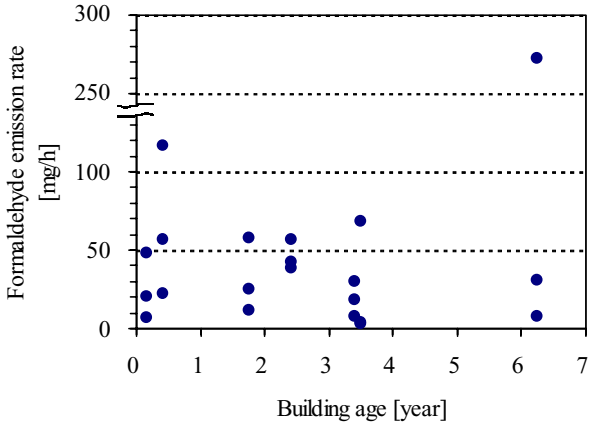


**Figure 8.** Relationships between building age and formaldehyde emission rate

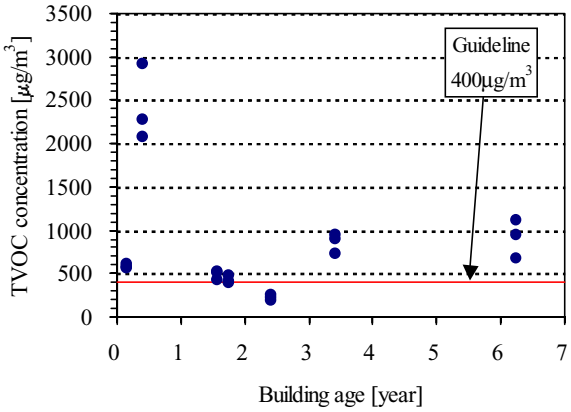


**Figure 9.** Relationships between building age and TVOC concentration

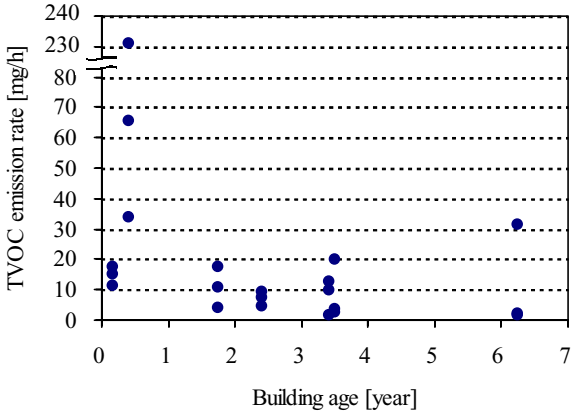


**Figure 10.** Relationships between building age and TVOC emission rate

## CONCLUSION

Air change rate is insufficient in 5 houses within 7 houses. It was found by comparing measurement results between ventilation airflow rate and airflow volume at outlets that a part of the indoor air was exhausted through building air leakage. Formaldehyde concentration is lower in houses where the amount of ventilation airflow rate is large. Formaldehyde emission rate decreases a little as building age increases. TVOC emission rate clearly decreases as building age increases.

## ACKNOWLEGEMENTS

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