FIELD SURVEY OF INDOOR AIR QUALITY IN DETACHED HOUSES IN NIIGATA PREFECTURE

Jun SAKAGUCHI [1], Shin-ichi AKABAYASHI [2]

[1] Department of Human Life and Environmental Science, Niigata Women's College
471 Ebigase, Niigata, JAPAN
[2] Graduate School of Science and Technology, Niigata University
8050 2nocho, Igarashi, Niigata, JAPAN

ABSTRACT

In this study, measurements of the IAQ and the ventilation rate of detached wooden houses in Niigata Prefecture are carried out. The air quality (the concentration of formaldehyde and Volatile Organic Compounds (VOCs)), air-tightness of the houses and the life style of the occupants were investigated.

The temperature and humidity were logged for one week at 10-minute intervals using stand-alone data loggers. The measuring points were at 110cm and 5cm above the floor and 10cm below the ceiling. A 2,4-dinitrophenylhydrazine-coated silica (DNPH) cartridge (Waters Sep-Pak XpoSure) was used to measure the concentration of formaldehyde and a passive air sampler (3M Organic Vapor Monitor) was used to measure the concentration of VOCs in the living room for one week. High Performance Liquid Chromatography (HPLC) and Gas Chromatography with Mass-Spectrometry (GC/MS) were used to analyze the average weekly concentration of VOCs. The weekly averaged ventilation rate of the house was measured by perfluorocarbon tracer gas technique (PFT).

The main results can be summarized as follows.

(1) 38.2% of the occupants felt that the indoor air quality was bad when cooking or smoking in the house took place.
(2) The HCHO concentration in the houses is inversely proportional to the air leakage from the house, i.e. it was high for airtight houses.
(3) The HCHO concentration in older houses is lower than in new houses of similar air-tightness.
(4) When building age increases, HCHO concentration in indoor air decreases.
(5) Generally the concentration of Benzene, Toluene, p-Dichlorobenzene, o-, m-, p-Xylene is high, especially it is remarkable in a newly constructed house.

KEYWORDS

Indoor Air Chemical Pollution, formaldehyde, VOCs Concentration, PFT method

INTRODUCTION

Recently, the chemical indoor air pollution (sick building syndrome) is a problem in newly constructed housing due to the use of new building materials, wallpaper and insecticides, etc. This problem partially results from inadequate ventilation of airtight houses. It is important to break the connection between indoor air quality in houses and multiple chemical compounds emitted by new building materials.

The Ullrich et al. study... on indoor air concentration of VOC was conducted in 86 houses of children with asthma and 94 houses of symptom-free children in Germany [1]. Ullrich et al. describe that the VOC concentration in homes of children with asthma is higher. Bouhamra et al. reported on VOC concentration in 99 houses in Kuwait [2]. This report shows that indoor concentration is higher when ventilation rate decreases, and high outdoor concentrations of VOC contribute to high indoor air concentration. The Brown et al. study on formaldehyde and VOC concentration level in approximately 1000 homes in England [3] shows that the mean formaldehyde concentration is 25μg/m^3 and the mean concentration of TVOC is 319μg/m^3 in houses in England.

In this study, measurements of the IAQ and the ventilation rate of detached wooden houses in Niigata Prefecture are carried out. The air quality (the concentration of formaldehyde and VOCs), indoor thermal environment, air-tightness, thermal insulation of the houses, and the life style of the occupants were investigated.

INVESTIGATION OUTLINE

(1) Where is Niigata

Niigata Prefecture is located in northeastern area of JAPAN and approximately 300km northwest of Tokyo (Fig.1). Niigata is known as a heavy snow area. Average outdoor temperature in winter is 2.1°c and relative humidity is 75%, summer is 26.2°c and relative humidity is 75%.

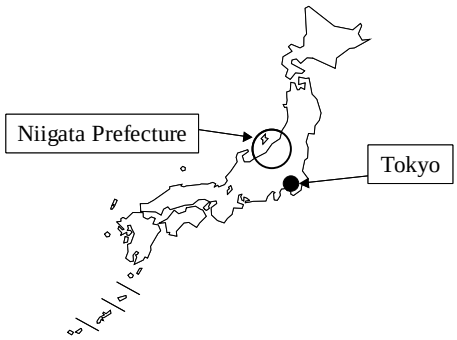

Figure 1 Location of Niigata

(2) Description of the houses

For this study, all 104 wooden detached houses sampled were located in Niigata Prefecture. All investigated houses were measured for indoor thermal environment, formaldehyde concentration, by questionnaire of IAQ and air-tightness. In addition 5 out of the 104 houses had the VOCs concentration and the ventilation rate measured by the PFT method.

(3) The measurement of the indoor air quality

The IAQ(the concentration of formaldehyde and VOCs) was measured at 110cm above the floor by a passive sampler. The DNPH cartridge (Waters Sep-Pak XpoSure) was used to measure the concentration of formaldehyde, and a passive air sampler (3M Organic Vapor Monitor) was used to measure the concentration of VOCs in the living room for one week. High Performance Liquid Chromatography (HPLC) and Gas Chromatography with Mass-Spectrometry(GC/MS) were used to analyze the weekly averaged concentration of

Table 1 Analytical Method of HPLC

Instrument : Shimazu LC-10AT
Column : LUNA 5u C18(2)
Flow rate : 1.3mL
Temperature : 40°C
Mobile Phase : A=Acetonitrile, B= Water,(60:40)
Injection : 20mL
UV Detector : SPD-10A (360nm)

Table 2 Analytical Method of GC/MS

Instrument : Hewlett-Packard HP6890GC/5973
Carrier : Helium 1.0mL/min constant
Column : HP-5(Cross-Linked 5% Phenyl Methyl Silicone) 60m X 0.25mm X 1.00μm
Injection : Split(20:1), 1.0μL, 250°C
Oven : Initial temp. 40°C(2min) to 230°C at 10° C/min, Final time 7min

VOCs.

For the concentration of formaldehyde, the DNPH cartridge was desorbed by adding 5ml of acetonitrile. The desorbate was analyzed by high-speed liquid chromatography (HPLC). Table 1 shows analytical method of HPLC. The accuracy of formaldehyde concentration is about 10% by a coefficient of variation. To obtain the concentration of VOCs, a passive air sampler was desorbed by adding 1.5ml of carbon disulfide. The desorbate was analyzed by gas chromatography with a mass spectrometry detector using a high sensitivity analysis (SIM method). Table 2 shows analytical methods of GC/MS. The accuracy of the measurement of VOCs concentration is about 17% by a coefficient of variation. The analysis shows the VOCs concentration of 12 compounds. Formaldehyde and VOCs concentrations were measured from winter to spring (from January 23, 1999, to April 25,1999). Opening and heating conditions in the house were according to the occupants' usual life style. Occupants were asked to live as usual during the study. The temperature and humidity were logged for one week at 10-minute intervals using stand-alone data loggers. The measuring points were at 110cm and 5cm above the floor and 10cm below the ceiling. The air-tightness of the houses was measured by the fan depressurization method.

(4) The measurement of the ventilation rate

The weekly averaged ventilation rate of the house was measured by perfluorocarbon tracer gas technique (PFT) [4-5].

(5) The contents of questionnaire

An investigation questionnaire was distributed to each house to collect information about relations between lifestyle and indoor chemical pollution. Table 3 shows the contents of the questionnaire. The questionnaire is concerned with consciousness toward indoor air quality, the amount of indoor dust, the frequency of cleaning, smoking, the use of insecticides, awareness of sick-house syndrome, consideration of the indoor air pollution, and so on.

Table 3 Details of questionnaire survey

Consciousness toward the IAQ	Perceptible IAQ
	The amount of indoor dust
Indoor environment	The frequency of cleaning
	Items used for cleaning
	The frequency of smoking
	The use frequency of perfume
	The use frequency of hair tonic
	The use frequency of cosmetics
	The use frequency of wax
	The use frequency of insecticide
	The kind of insecticides used
	Agricultural chemicals
	Aromatics
	The existence of pets
	The existence of indoor plants
	The kinds of electrical appliances
Health	The present condition of health
	Change in the condition of health
	Allergies
Sick house syndrome	Awareness of sick house syndrome
	Consideration of the indoor air pollution

RESULTS OF THE QUESTIONNAIRE SURVEY OF IAQ

(1) The perceived indoor air quality

Figure 2 shows the perceived indoor air quality. The question is "Do you feel that indoor air is bad in your house?" As for the answer to this question, "yes" answers are 38.2% of all houses, and "no" answers are 61.8%. The worst smell is the smell of cigarette smoke. Other bad smells are from heaters, cooking, pets, newly built house and so on.

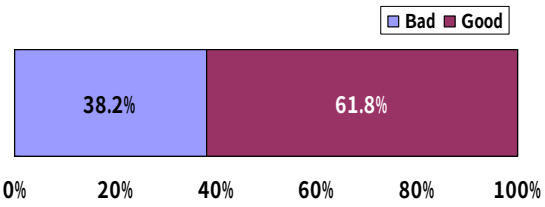

Figure 2 The questionnaire results about IAQ.

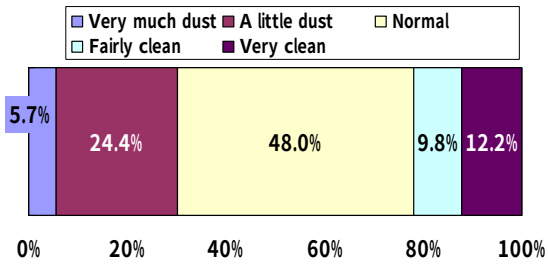

Figure 3 The questionnaire results about dust in the house.

(2) The existence of indoor dust

Figure 3 shows the perception of indoor dust. “There is very much dust.” was 5.7%. “There is a little dust.” was 24.4%. “Normal” was 48.0%. “It is fairly clean.” was 9.8%. “It is very clean.” was 12.2%.

(3) The frequency of cleaning

Figure 4 shows the frequency of house cleaning. “Clean every day.” was 43.1%. “Clean every 2 ~ 3 days.” was 43.9%. “Clean every week.” was 12.2%.

(4) The frequency of use of insecticide

Figure 5 shows the frequency of use of insecticide. “Often” was 13.8%. “Sometimes” was 13.0%. “Rarely” was 13.8%. “Very rarely” was 43.9%. It shows about 86% of the houses use insecticide rarely.

(5) Smoking

Figure 6 shows smoker's presence. Smokers are present in 56.1% of all houses. Figure 7 shows the number of cigarettes smoked per day in the households studied. No cigarettes was 43.9%, 1~5 cigarettes was 12.2%, 6~10 cigarettes was 14.6%, 11~20 cigarettes was 16.3%, 21~40 cigarettes was 11.4%, 40 over was 1.6%.

(6) The awareness of the sick building syndrome

Figure 8 shows the knowledge or the awareness of the sick building syndrome. The question “Do you know the words ‘sick building syndrome’ and ‘sick house syndrome’?” is answered affirmatively by 57.7%. Figure 9 shows the existence of awareness of “chemical sensitivity”. 67.5% of those responding were aware of “chemical sensitivity”.

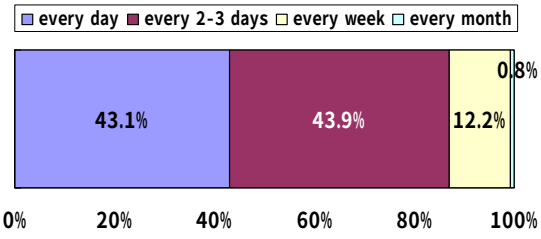

Figure 4 The questionnaire results about frequency of cleaning.

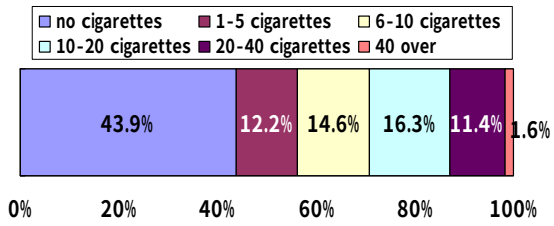

Figure 7 The questionnaire results about the number of a cigarettes smoked in a day in the house.

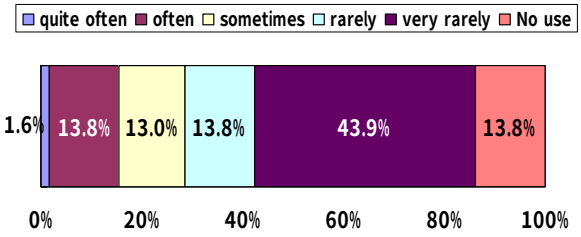

Figure 5 The questionnaire results about the use frequency of insecticide.

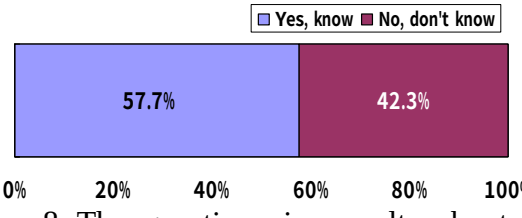

Figure 8 The questionnaire results about the awareness of sick building syndrome.

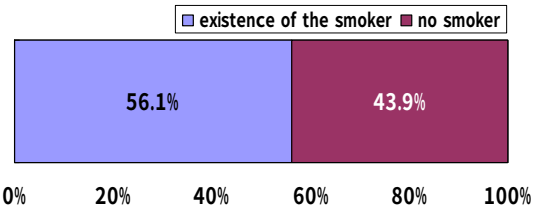

Figure 6 The questionnaire results about smokers in the house.

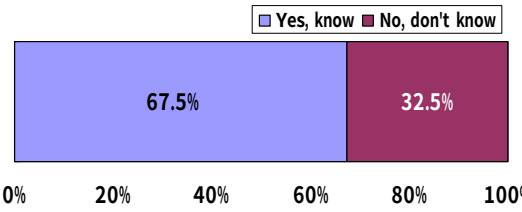

Figure 9 The questionnaire results about the awareness of chemical sensitivity.

(7) Relation between the self-reported IAQ Level and questionnaire survey results

Figure 10 shows relation between average number of cigarettes smoked in household and self-reported IAQ Level. Bad answer smoked about 6.5 cigarettes per day and Good answer smoked about 7.9 cigarettes per day is no significant difference the relation between the number of cigarettes smoked and IAQ Level. Figure 11 shows relation between the frequency of cleaning and IAQ level and Figure 12 shows the relation between the frequency of insecticide and IAQ level. There are no significant differences, either.

Figure 13 shows the relation between indoor temperature and IAQ level and Figure 14 shows that between indoor relative humidity and IAQ level. Both show significant differences. The indoor temperature of Good IAQ level is lower than that of Bad IAQ level, and the relative humidity of Good IAQ level is higher than that of Bad IAQ level. Fanger et al. shows similar results [6].

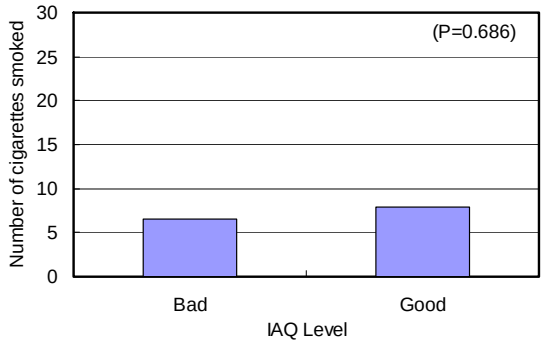

Figure 10 Relation between the number of a cigarettes smoked and IAQ level

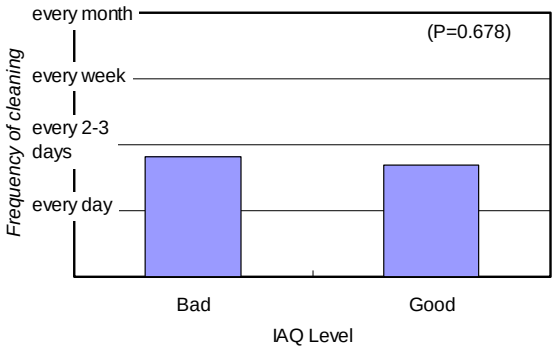

Figure 11 Relation between the frequency of cleaning and IAQ level

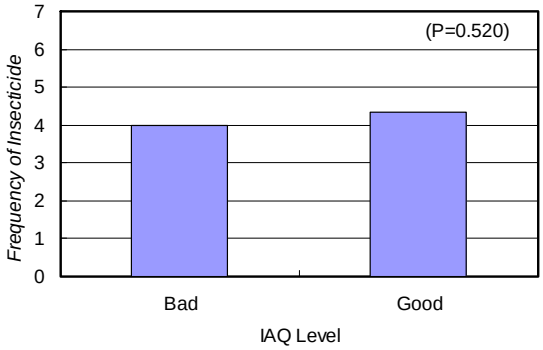

Figure 12 Relation between the frequency of insecticide use and IAQ level

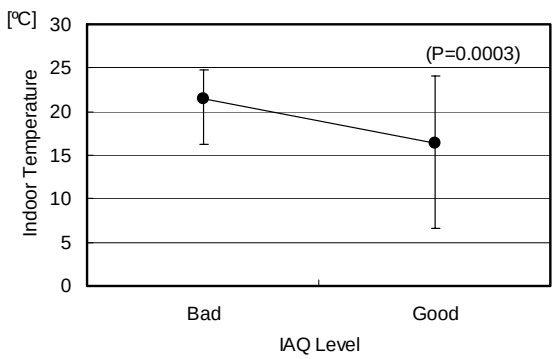

Figure 13 Relation between the indoor temperature and IAQ level

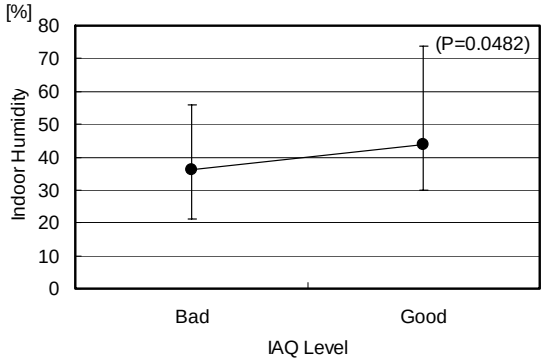

Figure 14 Relation between the indoor humidity and IAQ level

RESULTS OF THE MEASUREMENT OF FORMALDEHYDE CONCENTRATION

(1) The accumulation frequency of formaldehyde concentration

Figure 15 shows the accumulation frequency of formaldehyde concentration using DNPH cartridges that were exposed 1 week in the living room. The concentration in about 29% of all houses exceeds 100μg/m^3 (0.08ppm) the guideline for safe levels of formaldehyde concentrations as set by the Ministry of Health, Labour and Welfare of Japan. This result shows higher concentration than the results in homes in England [3].

(2) Relation between formaldehyde concentration and equivalent leakage area

Figure 16 shows the relation between equivalent leakage area per floor area (αA') and formaldehyde concentration using DNPH cartridges exposed 1 week in the living room. The relation between airtightness and formaldehyde concentration isn't so clear, because the ventilation rate varies in the houses. However, the concentration rises in the houses which are partly ventilated when airtightness improves.

(3) Relation between the formaldehyde concentration and age of building

Figure 17 shows relation between the formaldehyde concentration and the age of the building. As building age increases, formaldehyde concentrations decrease.

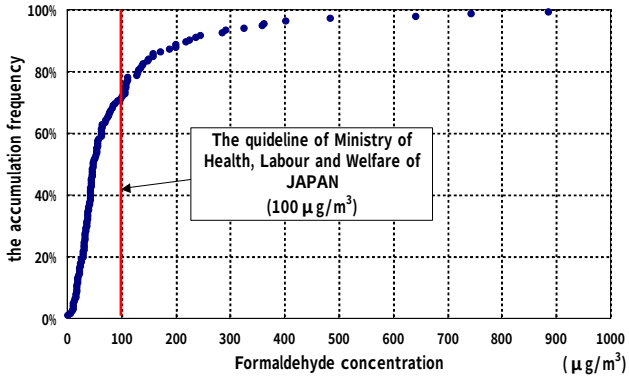

Figure 15 The study results about the accumulation frequency of formaldehyde concentration

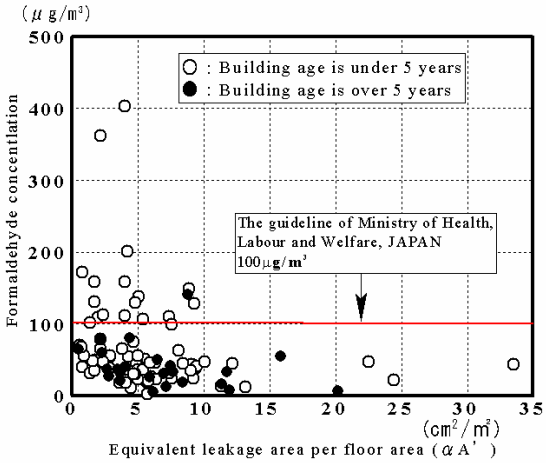

Figure 17 Relation between formaldehyde concentration and building age

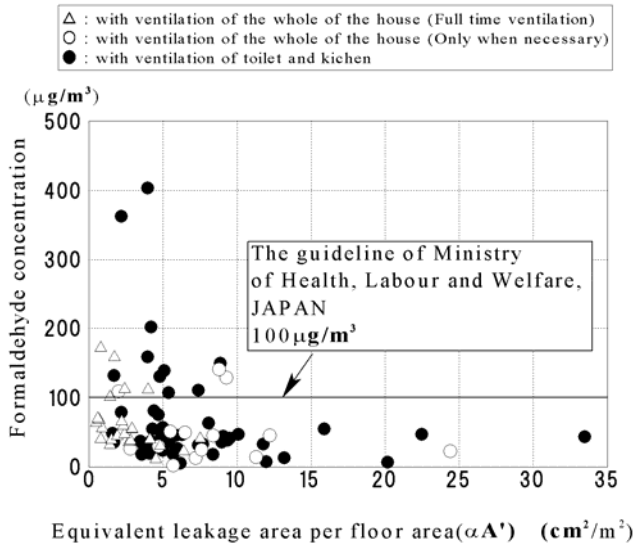

Figure 16 Relation between formaldehyde concentration, equivalent leakage area and ventilation system

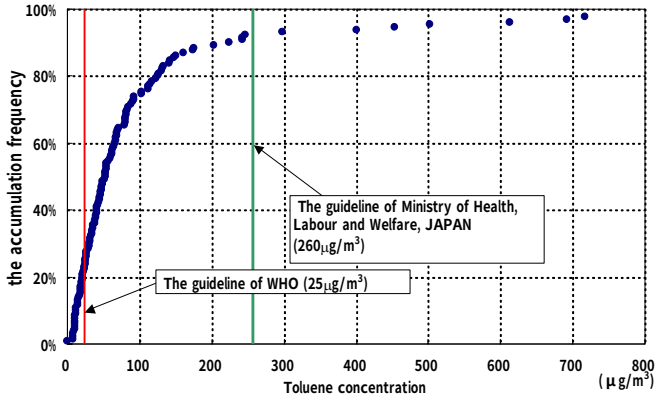

Figure 18 The study results about the accumulation frequency of toluene concentration

(3) The accumulation frequency of the toluene concentration

Figure 18 shows the accumulation frequency of toluene concentration using Passive gas monitors that were exposed 1 week in the living room. The concentration in about 7% of all houses exceeds 260μg/m^3 (0.07ppm) the guideline of safe toluene concentration as set by the Ministry of Health, Labour and Welfare of Japan.

RESULTS OF VOCS CONCENTRATION AND THE MEASURED VENTILATION RATE

The indoor concentration was decided by the ventilation rate and the emission rate of pollutants in the house. When measurement of concentration is high in the house, it is difficult to distinguish whether the ventilation rate is small or the emission rate of pollutant is large. Therefore, The measurement of ventilation rate and indoor concentration are investigated at the same time in 5 houses selected from all of the detached houses sampled. The self-reported IAQ level of the all the measured houses is Normal. The smoking conditions of House A is 20-40 cigarettes, Houses C,D,E are 6-20 cigarettes, House B has no cigarettes.

Table 4 The overview of the houses where VOCs concentration was measured

	Total Floorage (m^2)	Equivalent leakage area $\alpha A'(cm^2/m^2)$	Building age (year)
House A	213.0	6.4	1
House B	222.6	2.2	8
House C	132.5	2.4	3
House D	156.4	3.7	4
House E	150.0	0.8	4

Table 5 Ventilation rate of houses

	House A			House B			House C			House D			House E		
	Room Living	Room Bed	Room Guest	Room Living	Room Bed	Room Guest	Room Living	Room Bed	Room Guest	Room Living	Room Bed	Room Guest	Room Living	Room Bed	Room Guest
Room Volume (m^3)	23.3	31.8	63.8	23.1	42.9	55.8	47.3	41.2	41.2	25.1	60.1	33.4	100.2	38.2	35.9
Ventilation rate (1/h)	0.49	0.42	0.03	0.11	0.09	0.09	0.13	0.35	0.36	0.23	0.15	0.15	0.29	0.08	0.08
Ventilation flow (m^3/h)	11.5	13.3	38.3	14.1	30.1	12.7	25.2	13.3	18.5	30.1	18.4	20.1	43.3	30.8	11.5

Table 6 Results of the VOCs concentration measurement

	House A			House B			House C			House D			House E		
	Living Room	Bed Room	Guest Room	Living Room	Bed Room	Guest Room	Living Room	Bed Room	Guest Room	Living Room	Bed Room	Guest Room	Living Room	Bed Room	Guest Room
1,1,1-Trichloroethane	2	3	2	1	1	1	1	2	1	1	2	2	2	3	2
Benzene	98	N.D.	117	42	39	25	32	N.D.	23	N.D.	N.D.	15	N.D.	6	21
Tetrachloromethane	3	4	3	3	3	2	2	3	2	3	3	5	2	3	3
Trichloroethylene	1	2	2	1	1	1	3	4	2	1	1	1	2	2	2
Toluene	231	315	274	43	39	24	91	126	64	24	48	34	36	53	56
Tetrachloroethylene	2	11	2	0	0	0	1	2	1	1	1	1	0	1	0
m.p-Xylene	25	38	30	16	15	9	23	32	16	18	28	33	5	6	8
Styrene	2	3	2	1	1	0	0	2	1	1	1	1	1	1	4
o-Xylene	17	25	20	12	11	7	16	22	11	10	15	15	3	4	5
1,3,5-Trimethylbenzene	9	14	11	7	7	5	6	7	3	6	9	7	1	1	1
1,2,4-Trimethylbenzen	22	33	25	15	14	9	12	14	7	13	19	16	1	2	2
p-dichlorobenzene	935	2695	1079	11	13	6	46	160	45	4	26	6	8	13	20
Total VOCs	1347	3142	1566	152	143	89	235	374	176	82	154	137	62	96	125

unit: μg/m^3 N.D. :Not Detected

Table 7 Results of the VOCs emission rate

	House A			House B			House C			House D			House E		
	Living Room	Bed Room	Guest Room	Living Room	Bed Room	Guest Room	Living Room	Bed Room	Guest Room	Living Room	Bed Room	Guest Room	Living Room	Bed Room	Guest Room
1,1,1-Trichloroethane	0.04	0.04	0.08	0.04	0.02	0.01	0.03	0.03	0.01	0.03	0.03	0.03	0.11	0.08	0.04
Benzene	2.56	N.D.	4.49	1.75	1.18	0.39	0.89	N.D.	0.37	N.D.	N.D.	0.32	N.D.	0.20	0.55
Tetrachloromethane	0.07	0.05	0.13	0.13	0.08	0.03	0.07	0.04	0.03	0.08	0.05	0.10	0.15	0.10	0.07
Trichloroethylene	0.03	0.03	0.06	0.04	0.02	0.01	0.08	0.05	0.04	0.03	0.02	0.03	0.11	0.07	0.05
Toluene	6.04	4.50	10.48	1.76	1.16	0.38	2.51	1.67	1.04	0.74	0.79	0.71	2.30	1.62	1.47
Tetrachloroethylene	0.04	0.15	0.08	0.01	0.01	0.00	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.04	0.01
m.p-Xylene	0.66	0.54	1.14	0.65	0.44	0.14	0.64	0.42	0.25	0.57	0.46	0.69	0.31	0.19	0.21
Styrene	0.05	0.05	0.09	0.03	0.02	0.01	0.01	0.03	0.02	0.03	0.02	0.01	0.09	0.04	0.11
o-Xylene	0.45	0.36	0.77	0.48	0.33	0.11	0.44	0.29	0.18	0.29	0.25	0.32	0.21	0.13	0.12
1,3,5-Trimethylbenzene	0.24	0.20	0.40	0.31	0.21	0.07	0.17	0.09	0.06	0.19	0.16	0.15	0.05	0.03	0.04
1,2,4-Trimethylbenzen	0.56	0.47	0.97	0.63	0.44	0.14	0.34	0.19	0.12	0.41	0.32	0.33	0.09	0.06	0.05
p-dichlorobenzene	24.42	38.57	41.29	0.45	0.40	0.10	1.28	2.13	0.72	0.13	0.42	0.12	0.51	0.39	0.53
Total VOCs	35.17	44.96	59.96	6.27	4.31	1.41	6.47	4.97	2.84	2.50	2.52	2.84	3.97	2.96	3.25

Unit: mg/h N.D. :Not Detected

(1) Description of the houses and results of ventilation rate

Table 4 shows the description of the houses. All the measured houses have mechanical ventilation systems, and the mechanical ventilation systems are always operating. Table 5 shows the ventilation rate of the houses using the PFT method. The air exchange rate for all the houses is within the range of 0.3~0.8 h^{-1}.

(2) Results of the VOCs concentration

Table 6 shows the results of VOC concentration in the houses. The definition of Seifert is known as a definition of Total VOC (TVOC). In this paper, the total of the substance which determined a fixed quantity with GC-MS by the reference is shown. The concentration of VOCs in House A is comparatively high because House A was built last year. The concentrations of Benzene, Toluene, p-Dichlorobenzene, Xylene are especially high. The concentration of VOCs in House B is comparatively low because the house was built eight years ago. The VOC concentration in House C is highest after House A. Though αA' of House E is the smallest of the measured houses, the VOCs concentration is comparatively low. This is because there is relatively high ventilation rate in House E. The emission rate of VOCs of each room can be obtained by:

$$M = CVN$$

Where

M: emission rate (μg/h) C : VOC indoor concentration (μg/m^3)
V: room volume (m^3) N: ventilation rate (1/h)

Table 7 shows the calculated emission rate of VOCs of each room. The emission rate of VOCs of House A, which is newest, is highest. The emission rate of Total VOCs in this house is 35.2mg/h in the living room. And there is no remarkable difference among 3~4-year-old Houses C,D and E and 8-year-old House B in comparison to House A.

CONCLUSION

As a result of the investigation about the IAQ in the residences, some knowledge is clear. The words of "sick house syndrome" and "chemical sensitivity" are known to about 60% of occupants of the surveyed houses, and concern about the IAQ is high. 38.2% of the measured households answered "Sometimes feels that the air is bad in the house." The self-reported IAQ level rises when the indoor temperature becomes low. And, there is no relation between the self-reported IAQ level and the smoking conditions, the frequency of the insecticide use and cleaning. According to the investigation, the formaldehyde concentration in houses which are newer and which have partial ventilation is high. Therefore, the building materials have a low emission rate of pollutants and it must be considered that planning ventilation in airtight houses is important.

ACKNOWLEDGMENTS

This study was supported by the Special Coordination Funds for Promoting Science and Technology of Science and Technology Agency, Japan.

REFERENCES

1 D Ullrich, S K Weiland, B Seifert, (1999), VOC in homes of children with asthma a case-control study of

indoor air quality, Indoor Air 99 Proceedings, The 8th international conference on indoor air quality and climate.
2 W S Bouhamra, A S Elkilani, (1999), Evaluating indoor TVOC in Kuwait residences, Indoor Air 99 Proceedings, The 8th international conference on indoor air quality and climate.
3 V M Brown, H S Mann, DR Crump, (1999), Formaldehyde and VOC levels in houses in England, Indoor Air 99 Proceedings, The 8th international conference on indoor air quality and climate.
4 Stymne H., Boman C.A., (1994), Measurement of ventilation and air distribution using the homogeneous emission technique, a validation, Healthy Buildings '94, Proceedings of the 3rd International Conference.
5 Russell N. Dietz and Edgar A. Cote, (1982), Air infiltration measurements in a home using a convenient perfluorocarbon tracer technique, Environmental International. Vol. 8, pp.419-433.
6 Fanger P.O., (1997), Global issues related to offices and public assembly halls from a building perspective, Healthy Buildings 97, pp19-24
7 Seifert B., (1990),Regulating Indoor Air?, Proceedings for Fifth International Conference of Indoor Air Quality and Climate, Vol. 5, pp35-49
8 Martin A. Cohen, P. Barry Ryan, Yukio Yanagisawa, John D. Spengler, (1989), Indoor/Outdoor Measurements of Volatile Organic Compounds in the Kanawha Valley of West Virginia, JAPCA Journal.
9 Husao Hasegawa et.al., (1983), Field survey of thermal environment in winter for wooden detached houses in the Tohoku District, Journal of Architecture, Planning and Environmental engineering, (Transactions of AIJ). (in Japanese)
10 Matsumura Toshiro, et. al., (1999), Field Survey on Indoor Air Chemical Pollution in the Residential Houses, Part 4 Study on Passive Typed Formaldehyde Sampler, Summaries of technical papers annual meeting architectural institute of Japan, AIJ, (in Japanese)