Long-Termed Field Survey of Indoor Air Quality and Health Hazards in Sick House

Hiroshi Yoshino*1, Kentaro Amano2, Mari Matsumoto2, Koji Netsu2, Koichi Ikeda3, Atsuo Nozaki4, Kazuhiko Kakuta5, Sachiko Hojo6 and Satoshi Ishikawa7

1 Professor, Graduate School of Engineering, Tohoku University, Japan
2 Student, Graduate School of Engineering, Tohoku University, Japan
3 Professor, The National Institute of Public Health, Japan
4 Professor, Tohoku Bunkagakuen University, Japan
5 Doctor, Saka General Hospital, Japan
6 Professor, Shoukei Gakuin College, Japan
7 Professor, Kitasato Institute Hospital, Japan

Abstract

In order to determine the factors of origin of Sick House Syndrome (SHS), data of indoor air quality in the sick houses and field survey were collected and carried out respectively, over three summer seasons from 2000 to 2002, from 35 houses where occupants are suspected of suffering from the so-called Multiple Chemical Sensitivity (MCS) and SHS, in the Miyagi prefecture of Japan. This survey consisted of the measurements of indoor air pollutants (the concentration of formaldehyde and volatile organic compounds (VOC)), air tightness and ventilation rate, together with questionnaire regarding environmental conditions, subjective symptoms and lifestyle. Medical examination was also conducted to residents having heavy symptoms. In addition, 15 houses out of 35 houses were investigated continuously for another two or three years.

As the results, the average values of formaldehyde concentration and TVOC of the investigated rooms from this study are 0.12 ppm and 1557 µg/m³, respectively.

The formaldehyde concentration in over 71% of rooms exceeds the guideline from the Ministry of Health, Labour and Welfare of Japan. While the VOC concentrations have been reducing, the formaldehyde concentration has hardly changed. The most frequently described symptoms are mucosal and respiratory symptoms (such as eye irritation, sore throat, cough). In addition, it is revealed that many patients are found having allergic diseases. The relationships between the measurement results of indoor chemical substance concentrations and the symptoms obtained from questionnaire, suggest that the symptoms become serious not only in the houses with higher concentration of TVOC, but also in the houses with lower concentration.

Keywords: sick house; sick building syndrome; volatile organic compounds

Introduction

Polluted indoor air quality from chemical substances, which may cause a hazardous influence on human being such as Sick Building/Sick House Syndrome (SBS/SHS), has become a serious problem in our daily life. In Japan, this problem has been looked into for several years, but a lot of uncertainties are not yet resolved. Especially, data about the actual living conditions in houses, where the occupants have SHS, is inadequate. This survey was conducted to understand the state of indoor air pollution and residents’ health conditions in dwelling, which was suspected to be a Sick House.

Methods

In this study, the air quality of houses in Miyagi prefecture of Japan, where residents worry about indoor air pollution had been investigated during the summers of 2000 to 2002.

This paper provides a summary of the measurement results of 35 houses selected by the aspect of sick house problems. The residents in these houses are suspected to suffer from health hazard due to indoor air chemical pollutants. These 15 houses out of 35 houses were investigated more than twice during the above span of time.

The measurements of chemical concentrations (carbonyl compounds and VOCs), ventilation rate, airtight performance and questionnaire survey about indoor air quality were carried out in 35 selected houses. In addition, survey of health conditions, based on the Quick Environmental Exposure and Sensitivity Inventory (QEESI) (Miller and Prihoda, 1999), was also

*Contact Author: Hiroshi Yoshino, Professor, Graduate School of Engineering, Tohoku University, Aoba 06, Aramaki, Aoba-ku, Sendai. 980-8579, Japan
Tel: +81-22-217-7883 Fax: +81-22-217-7886
e-mail: yoshino@sabine.pln.archi.tohoku.ac.jp

(Received May 10, 2004 ; accepted September 13, 2004 )
conducted to the residents. The measurement of chemical substance concentrations
A few typical rooms of each house were chosen for the measurements. The chemical substance concentrations (carbonyl compounds and VOCs) were measured at a height of 1.2 m above the floor. Table 2 shows the methods of measurement. The openings of the rooms were closed as much as possible at the time of measurement. Indoor air was sampled for the period of 24 hours.

### Contents of questionnaire survey

Two types of questionnaire regarding dwelling and occupant’s health conditions, were distributed. The former contained building attribution (building age, structure, building materials, etc.), indoor environment (use of pesticides, use of cleaners, frequency of ventilation, etc.) and consciousness of life (awareness of Sick House, provision of indoor pollution, etc.). The other was QEESI, contents of which are shown in Table 3.

### Table 1. Outline of analysis methods of chemical substance concentrations

| Items                  | Calbonil Compounds                          | Volatile Organic Compounds                |
|------------------------|---------------------------------------------|-------------------------------------------|
| Sampler                | DNPH-Silica cartridge (Waters Sep-Pak XpoSure) | Charcoal absorption tube (SIBATA Scientific Technology) |
| Sampling Method        | Passive sampling (24 hours)                 | Active sampling (500ml/min, 24 hours)     |
| Measuring Point        | 1.2m above the floor in 2 or 3 typical rooms|                                           |
| Analysis Method        | HPLC                                        | GC/FID                                    |

DNPH: 2,4-di-nitrophenyl-hydrazin  HPLC: High Performance Liquid Chromatography  GC/FID: Gas Chromatography/Flame Ionization Detector

### Table 2. Contents of questionnaire about house, occupants and environment

| Items                           | Contents                                                                 |
|---------------------------------|--------------------------------------------------------------------------|
| 1. Information about residents  | A family type (The number of person, age, etc.)                          |
|                                 | The existence of smokers, etc.                                           |
| 2. Information about house      | Institutions around building, use of pesticides, etc.                   |
|                                 | Structure, scale, materials, ventilation system, etc.                   |
| 3. Information about awareness of life | Knowledge of sick house, provision, etc.                             |
|                                 |                                                                          |

### Table 3. Contents and risk criteria of QEESI

| Items                           | Contents                                                                 | Degree to which MCI is suggested |
|---------------------------------|--------------------------------------------------------------------------|---------------------------------|
|                                 |                                                                         | Very suggestive | Somewhat suggestive | Problematic |
| 1. Chemical Intolerance         | Intolerance of chemical substances like insecticides, paints etc. (0-100) | ≥40              | ≥40                | <40         |
| 2. Other Intolerance            | Intolerance of substances like pollen, foods, house-dust etc. (0-100)   | -                 | -                  | -           |
| 3. Symptom Severity             | Degree of symptoms on residents’ bodies like headache, cough, eczema etc. (0-100) | ≥40              | <40                | ≥40         |
| 4. Life Impact                  | Relation with daily lives of residents (0-100)                           | -                 | -                  | -           |
| 5. Masking                      | Being camouflaged of residents’ symptoms by chemical substances (0-10)    | ≥4 or <4          | ≥4                 | ≥4 or <4    |

MCI: Multiple Chemical Intolerance  (Item 1-4; 0:Not in particular, 50:Middle level, 100:Serious case)
Results
The questionnaire survey of residential environment

Figure 1 shows the building type and the age of houses under investigation. There were 30 detached houses and 5 multi-family houses. Six houses were retrofitted. The mean building age was 4.36 years, and more than half were less than 3 years. The mean age after retrofitting was 2.79 years.

Figure 2 shows the ventilation system and the frequency of opening window. Nearly half of houses had mechanical ventilation. The percentage of the houses where residents often open windows to ventilate the room was 60%.

Figure 3 shows the results of the resident’s understanding of Sick House. It was found that 66% of the families showed positive to the understanding. 40% houses (14 houses) took measures on building materials against Sick House problem.

The questionnaire survey of health hazard

As a result from the oral investigation, 80 (male; 31 female; 49) out of 149 residents were suspected of having SHS (the symptoms began or became worse after moving in the house). QEESI was distributed to 80 SHS patients and 69 of them responded. The most frequently symptom was respiratory disorder (air way / mucous membrane) following with skin irritation (skin /mucous membrane) and gastrointestinal disorder. 39 patients (56%) had a history of allergic disease. Chemical intolerance was suggested to 33 patients (48%) according to the risk criteria of QEESI.

The measurements

Table 4 gives the results of typical indoor chemical substances concentrations. Figure 5 shows the cumulative frequency distribution of the formaldehyde, toluene and TVOC concentrations. These values were obtained from the initial measurement (35 houses). These
Table 4. Results of measurement of indoor concentration about chemical substances compared with the guidelines from the Ministry of Health, Labour and Welfare of Japan

| Substance         | Unit  | Indoor concentration | Guideline from MHLW | The number of detected data | The number of detected data (over guideline) |
|-------------------|-------|----------------------|----------------------|-----------------------------|---------------------------------------------|
|                   |       | Average | Median | Max  |                 |                                             |
| Formaldehyde      | ppm   | 0.124   | 0.111  | 0.315| 0.06           | 87/91                                       |
| Acetaldehyde      | ppm   | 0.079   | 0.069  | 0.265| 0.03           | 80/83                                       |
| Toluene           | μg/m³ | 138.4   | 43.2   | 2530.0| 260            | 93/93                                       |
| Ethylbenzene      | μg/m³ | 15.9    | 10.1   | 140.0| 3800           | 68/93                                       |
| Xylene            | μg/m³ | 28.0    | 17.0   | 196.1| 780            | 78/93                                       |
| p-Dichlorobenzene | μg/m³ | 452.9   | 38.5   | 16055.5| 240           | 68/93                                       |
| α-Pinene          | μg/m³ | 178.0   | 12.5   | 3350.0| 950            | 67/93                                       |
| TVOC              | μg/m³ | 1556.5  | 701.7  | 16815.8| 400           | 61/93                                       |

Fig. 5. The measurement results about cumulative frequency of chemical substances concentration
substances were detected in over 70% rooms. The formaldehyde concentrations in 65 rooms within the 91 rooms (71%) exceed the criterion of the guideline (0.08 ppm) from the Ministry of Health, Labor and Welfare of Japan. These formaldehyde concentrations are found higher than that in 59 ordinary houses (residents with no SHS symptoms) of Miyagi prefecture. The toluene concentrations in 10 rooms within the 93 rooms (8%) exceed the criterion of guideline (260 µg/m³). The p-dichlorobenzene concentrations in 14 rooms (15%) exceed the criterion of guideline (240 µg/m³). The ethyl benzene and xylene concentrations in all rooms were below the guideline. TVOC concentrations in 61 rooms (66%) exceed the recommended value (400 µg/m³).

Figure 6 shows the relationship between chemical substances concentrations and building age. These values include the houses where a follow-up survey was conducted. The total number of houses measured is 53 (one time measurement in 20 houses, two times in 12, three times in 3). Formaldehyde concentration does not show much decrease, even the building age increases. But toluene concentration decreases as building age increases. TVOC concentration is similar to the behavior of toluene concentration, but high concentration was detected in houses using moth crystals (sign * shows in the figure). In retrofitted houses, formaldehyde concentration value is higher.
Case of House A (Completion: Mar-1998, Total floor area: 133.3m², Ventilation: Mechanical supply and exhaust system)

Case of House B (Completion: Jul-1993 (renovation: 1997), Total floor area: 150m², Ventilation: Mechanical supply and exhaust system)

Fig. 7. The secular change of chemical substance concentration for three years (2 houses)

Fig. 8. The secular change of severity of subjective symptoms for three years (2 Occupants)

Housewife of House A

Child of House B
Figure 7 shows the change of indoor chemical concentrations in two houses which have been investigated over a period of three years. It is found that VOC concentrations are generally reduced during this period, but formaldehyde concentration does not change. This similar tendency was also observed in other residences.

Figure 8 shows the changes of severity of subjective symptoms by QEESI in these two houses. The House A reported various symptoms in the initial investigation, but no report was received by the time of third investigation. In contrast, the House B had shown a progressive worsening of symptoms with the focus on central nervous system. The scores of the neuromuscular symptoms (lightheadedness, difficulty focusing eyes) and gastrointestinal symptoms (abdominal bloating, diarrhea) were shown high following with cognitive, affective, musculoskeletal and airway/mucous membrane symptoms.

Figure 9 shows the relationship between TVOC concentrations and the score of symptom by QEESI. There were some patients with high score of symptoms severity in spite of relatively low concentration of TVOC. TVOC concentrations were not clearly correlated to the scores of symptom.

Conclusions
1) The average values of formaldehyde concentration and TVOC of the 35 investigated houses from this study are 0.124ppm and 1557 $\mu$g/m$^3$ respectively. The formaldehyde concentration in 65 rooms (71%) exceeds the guideline from the Ministry of Health, Labor and Welfare of Japan.
2) The most frequently described symptoms are respiratory disorder (eye irritation, sore throat, cough). In addition, many patients have allergic diseases.
3) Chemical intolerance was suggested to 33 patients (48%) according to the risk criteria of QEESI.
4) It is found that VOC concentrations are generally reduced over three years period, but formaldehyde concentration doesn’t change much.
5) There are patients with high score of symptoms severity in spite of relatively low concentration of TVOC. The relationships between the measurement results and the symptoms by questionnaire are not clear.
6) In future, the relationship between each symptom and each substance would be investigated.

Acknowledgment
This study was supported by a grant from Ministry of Welfare and Health, Japan (Study on the symptom analysis, diagnosis, medication of Sick House Syndrome, chairperson; Satoshi Ishikawa) and the Asahi Glass Foundation (Research on indoor air quality and health hazard in sick house and development of evaluation method, chairperson; Hiroshi Yoshino). Authors acknowledge people who supported this study.

References
1) Miller CS and Prihoda TJ. 1999. The Environmental Exposure and Sensitivity Inventory (EESI), a standardized approach for measuring chemical intolerances for research and clinical applications, Toxicology and Industrial Health, pp 370-385.
2) S. Ishikawa and T. Miyata. 1999. Multiple Chemical Sensitivity, Allergology & Immunology, Vol. 6, No. 7, pp 990-998.
3) H. Yoshino, K. Amano et al. 2002. Field survey on indoor air quality and occupants’ health conditions in sick houses. Proceedings: 9th International Conference on Indoor Air Quality and Climate, Indoor Air 2002, Vol. 4, pp 119-124, Monterey: Indoor Air 2002.
