Field Survey on the Relation between IAQ and Occupants' Health in 40 Houses in Southern Taiwan

Lin-lin Huang*, Koichi Ikeda, Che-Ming Chiang, Naoki Kagi, Sachiko Hojo, and U Yanagi

1 Graduate School of Architecture, National Cheng Kung University, Taiwan
2 Professor, Department of Architecture, Dr. Eng., College of Science and Technology, Nihon University, Japan
3 Professor, Department of Architecture, Dr. Eng., National Cheng Kung University, Taiwan
4 Leader, Urban Environment Section, Department of Healthy Building and Housing, Dr. Eng., National Institute of Public Health, Japan
5 M.D., Professor, Department of Living Environment, Shokei Gakuin University, Japan
6 Professor, Department of Architecture, Dr. Eng., Kogakuin University, Japan

Abstract
Taiwan and Japan are similar in life style and customs. Taiwan is geographically situated in a subtropical climate zone which is deemed as a future model of Japanese climate if global warming continues. It is therefore advantageous for Japanese to know the present IAQ (Indoor Air Quality) situations in Taiwan.

The research was carried out in two phases. The first phase used questionnaire surveys to collect the relevant information of the occupants and their living environments, and QEESI questionnaires (Chinese version) for information regarding their health conditions. In the second phase, IAQ measurements were conducted in the 40 houses which were selected among volunteers of the first survey. Measurement items were temperature, humidity and concentrations of carbonyl compounds and VOCs (Volatile Organic Compounds). Verification measurements were conducted to investigate the hypothesis in the two houses, A and B, selected from 40 measured houses. The amount of furnishing materials in the two houses was quite different.

Finally, the questionnaire results, QEESI (Quick Exposure Sensitivity Inventory) scores, and IAQ data were compared accordingly to determine the factors that cause SHS (Sick House Syndrome).

The results are as follows.
1. For areas deficient in SHS and/or MCS (Multiple Chemical Sensitivity) diagnoses, combining QEESI investigations and IAQ measurements in the surveys is successful in screening SH and discovering SHS.
2. To reduce indoor air pollution effectively, it is insufficient just to regulate the materials and the quantity of interior furnishings. Construction process, ventilation rate, airflow path, and an overall plan with strict assessment should all be included in the regulations.

Keywords: sick house syndrome; field survey; IAQ; occupant's health; southern Taiwan

1. Introduction
The increase in the number of people suffering from so-called "sick house syndrome (SHS)", or sick building syndrome (SBS) in dwellings, is considered to be one of the serious health effects resulting from global warming, as well as infectious diseases.
Thus, collaborative research between Taiwan and Japan, where studies on the SHS and preventive measures are preceding 1) ~ 5), was launched in 2001 with the aim of establishing preventive measures regarding IAQ issues.

2. The Research
The research was carried out in two phases. The first phase used questionnaire surveys to collect the relevant information of the 658 volunteers selected throughout Taiwan, and their living environments and health conditions were also investigated using QEESEI questionnaires (Chinese version).

In the second phase, IAQ measurements were conducted in the 40 houses, which were selected among volunteers of the first phase survey and met the following criteria:
1. Located in urban area of southern Taiwan
2. An apartment complex or a townhouse (Note 1)
3. A new building or less than 5 years inclusive after remodeling

Finally, questionnaire results, QEESEI scores, and IAQ data were compared accordingly to determine the factors that cause SHS, and to suggest effective ways for resolving the problems.

3. Summary of the Survey
3.1 Background of the survey
The geographic coordinates of Taiwan span an area of 36,188 km², lying at a latitude of 23°N, with a length of 394 km north to south and width of 144 km east to west. The Tropic of Cancer runs through the island. Due to the central mountain range running north to south over the backbone of the island with the tallest peak of 3,952 meters in height, Taiwan’s climate sometimes is temperate. Tainan City and Kaohsiung City, the two largest cities to the south of the Tropic of Cancer, were selected as survey locations. The climatic conditions are shown in Table 1.

Table 1. Climate in Tainan and Kaohsiung (Taiwan Central Weather Bureau, 1971-2000)

| City       | Yearly average temperature (°C) | Yearly relative humidity (%) | Highest monthly ave. temperature (°C) | Lowest monthly ave. temperature (°C) |
|------------|---------------------------------|------------------------------|---------------------------------------|-------------------------------------|
| Tainan     | 24.1                            | 78.4                         | 32.9                                  | 13.7                                |
| Kaohsiung  | 24.7                            | 77.7                         | 31.5                                  | 15.1                                |

The Taiwan Government has dedicated itself to the improvement of indoor environment quality. However 'the Management of Indoor Air Quality Act' is still in the draft proposal phase, and is not yet officially introduced in legislation. Therefore, ventilation is not regulated strictly at present, and the indoor air exchanging paths are often neglected.

In the private real estate market, interior furnishings in new buildings are not under the control of any law.

Thus, the possibility of indoor air pollution caused by decoration is relatively high in comparison to public buildings. In addition, outdoor heat, air pollution and the urban heat island effect compels people to stay in an air conditioned room, and the ventilation is reduced for electricity saving. Thus, due to excessive formaldehyde, the levels of cancer risk are believed to be 100 to 1000 times the acceptable carcinogenic risk. (P.-C. Wu et al., 2002)³

3.2 Field survey on IAQ
3.2.1 Target houses of the survey
Forty houses in Tainan City and Kaohsiung City were selected as research subjects for assessing IAQ. To investigate the relation between indoor and outdoor air quality, three measuring points per household were selected, one outdoors and two indoors, 120 points in total, consisting of 30 apartment complexes and 10 townhouses (Table 2.). The subject buildings were either new or had been remodeled within the past 5 years, and were occupied by dwellers who spend most of their time at home.

Table 2. Assessment Point of Target Houses Concerning IAQ Survey

| Assessment Point | Carbonyl Compounds | Volatile Organic Compounds | Sub-total |
|------------------|--------------------|---------------------------|-----------|
| Outdoor P-1      | 40 point           | 40 point                  | 80 point  |
| Indoor P-1       | 40 point           | 40 point                  | 80 point  |
| Indoor P-2       | 40 point           | 40 point                  | 80 point  |
| Total            | 120 point          | 120 point                 | 240 point |

3.2.2 Method of IAQ field survey
IAQ field surveys were conducted during the periods of Jan. 14 ~ 23, Feb. 13 ~ Mar. 2, and Mar. 9 ~ 14, 2009. The measurement items were the concentration levels of carbonyl compounds, which is consisted of formaldehyde, acetaldehyde, acetone and acrolein, and TVOC (Total Volatile Organic Compound), which is a total of all organic chemical compounds from hexane to hexadecane converted into toluene concentration. The methods of measurement and analysis, and measuring time are shown in Table 3.

3.3 Questionnaire
In the first phase of the research, there were two questionnaires. One to collect information concerning

Table 3. Outline of the IAQ Measurements

| Measurement Time       | Two runs beginning from 10:00 am and from 1:30 pm |
|------------------------|---------------------------------------------------|
| Sampling period        | Net sampling time was 30 min. each. It took a total of 120 to 150 min. for the instrument preparation. |
| Measuring points       | Samplers were located 120 cm above the floor and 100cm away from the walls |
| Measured factors       | Temperature | Humidity | Carbonyl compound | Volatile organic compounds |
| Samplers or sensors    | Semi-conductor | Capacitance method | Active gas tube (Sibada) | Tenax tubes (Gestel) |
| Sampling method        | Direct reading | Directreading | Active sampling (11L/min, 30mins) | Active sampling (0.167L/min, 30mins) |
| Analytical method      | - | - | Solvent extraction method | Thermal desorption |

Notes: Living conditions were kept normal.
the occupants and their living environments (Table 4),
and the other was the QEESI questionnaire (Chinese
version) (Table 5). Both were administered from Nov.
through Dec. 2008. The respondents were general
individuals living in Taiwan. Eight hundred and fifty
questionnaires were distributed and six hundred and
seventy-eight questionnaires were returned (response
ratio 80%). After excluding invalid answers, which
were uncompleted in one or more questions, the valid
number was 658 (effective response ratio 77%). The
QEESI questionnaire comprises 5 subscales, with
10 questions in each subscale, making 50 in total,
among which only subscale 4 'masking' is answered
by 'Y/N', with a score of one for 'Y' and zero for
'N'. Other subscale answers are scored from 0 to 10

Table 4. Survey Items Concerning Volunteers and Their Living
Conditions

| Survey Items | Survey Details | Number of Questions |
|--------------|----------------|---------------------|
| Personal information | Sex, age, allergic history, family history, time spent in the home, license of the SH inspector | 7 |
| Information on the residential building | Building style, construction year, number of stories, causes of the renovation, floor area, floor materials, ventilation system and so forth. | 6 |
| Indoor environment conditions and living style | Number and kind of pets, use of insecticide, aromatics and/or incense, amount of tobacco smoking | 6 |
| Surrounding outdoor environments | Kinds of the site surrounding the surveyed house | 2 |

Table 5. Contents of the QEESI Form

| Question # (Scale of the Symptoms) | Items Related to the Symptoms | Seriousness Levels of the Symptoms |
|-----------------------------------|-------------------------------|----------------------------------|
| Q1 Chemical inhalant intolerance scale | Tobacco smoke, insecticides, paints, thinner | Low: 0-19, Med: 20-39, High: 40-100 |
| Q2 Other intolerance scale | Food additives, caffeine, alcohol, pollen, etc | Low: 0-11, Med: 12-24, High: 25-100 |
| Q3 Symptom severity scale | Muscles, ligament, conjunctiva, mucous membrane, head, skin | Low: 0-19, Med: 20-39, High: 40-100 |
| Q4 Masking Index | Smoking, drinking, stimulus foods, perfumes, etc | Low: 0-3, Med: 4-5, High: 6-10 |
| Q5 Life impact scale | Meals, work, study, family relations, housekeeping | Low: 0-11, Med: 12-23, High: 24-100 |

Table 5. Contents of the QEESI Form

| Sites | HCHO | TVOC |
|-------|------|------|
| Outdoor | 14.9 | 205 |
| Indoor-1 | 360 | 42.4 |
| Indoor-2 | 55.0 | 231 |
| S. D. | 12.0 | 47 % |
| Max. | 60.0 | 306 |

4. Survey Results
4.1 Results of IAQ survey
The results of the IAQ survey on 40 chosen
households are listed in Table 6. The average HCHO
(formaldehyde) concentration of outdoor air is 14.9 μg/ m³, and 205 μg/m³ for TVOC, 0% and 24% exceeding
the Japanese guidelines and target level respectively.
Those of the indoor points (IN-1) are HCHO 42.4 μg/ m³, TVOC 360 μg/m³, and 7.5% and 47% exceeding
the guidelines respectively, and of the indoor points
(IN-2) are HCHO 55.0 μg/m³, TVOC 397 μg/m³, and exceeding 7.5% and 61% respectively. Not much
difference was found between IN-1 and IN-2 within
the same household, while the concentrations in the IN-2
of 21 out of the 40 households is higher than those in
the IN-1.

Table 6. Results of the Measurements at 40 Homes (μg/m³)

As for HCHO I/O ratios, the mean values are 2.85
~ 3.69, and the medians 2.08 ~ 2.74, while maximum
values are 1.99 ~ 2.39. As for TVOC, the mean I/O
ratios are 1.76 ~ 1.94, and the medians 1.30 ~ 1.70,
while the maximums are 2.68 ~ 3.64. The values
obtained at IN-2 are higher than those at IN-1 (Table
7). The results of interviews at the locations indicate that
the frequency of opening windows is low owing to
the interviewees' reluctance to open them in order to
reduce the pollution from outdoor air and dust.
Furthermore, because most of the interviewees are
dual-career couples, the time between arriving home
and going to bed is not long enough to let in outside
air for sufficient ventilation, and the use of perfume,
cosmetics, and hair dressing products is more frequent in the master bedroom than in other home spaces.

4.2 The differences in subscales between SHS sufferers and non-SHS persons

When the IAQ surveys were under-way, the interviews of the occupants were conducted simultaneously. It was found that SHS was often associated with MCS. That is, the SHS sufferers were especially sensitive to chemical substances, and obviously exhibited more discomfort symptoms. To clarify the relevant mechanisms, the means of each subscale score of the QEESI questionnaire were divided into two groups of SHS (11 persons) and non-SHS (54 persons) and compared. The English version SPSS 15.0 was used for the analysis.

4.2.1 Chemical inhalant intolerances

The patterns in Radar Charts of both SHS and non-SHS groups were similar. Among the ten items, the only significant difference was found concerning 'gasoline fumes' item (*p<0.05; SHS 6.3: non-SHS 5.3, ratio 1.2). The remaining nine items did not show significant differences. However, the scores of 'insecticide' (SHS 6.8: non-SHS 6.0, ratio 1.2), and 'paint and thinner' (SHS 6.6: non-SHS 5.9, ratio 1.1) for both groups were fairly high. These phenomena can perhaps be explained by the fact that intolerance regarding such irritating fumes makes no difference to people whether they suffer from SHS or not (Fig.1).

4.2.2 Other intolerances

The radar chart shows that the item 'allergens' was the most significantly different among all items, and the result of t-test confirmed this result (p<0.001). This is also consonant with the results of interviews at the locations (SHS was often associated with MCS). Perhaps because SHS and MCS are not yet covered by the National Health Insurance, it is highly possible that they could have been diagnosed as 'hypersensitivity'. Other significantly different items (p<0.05) were 'specific food', 'habitual food', 'caffeine toxic reaction' and 'skin contacts' (Fig.2.).

If 'caffeine toxic reaction' was compared with 'caffeine intake reaction', the mean scores of 'caffeine intake reaction' of both SHS and non-SHS were 1.2 and 1.6 respectively. The difference was minor. But the mean score of 'caffeine toxic reaction' of the SHS group was 3.6, 2.3 times the score of the non-SHS group. The difference was significant (*p<0.05). The comparison of the two items and the opinions of SHS interviewees: "caffeine intake may alleviate hypersensitivity and the SHS" seems to point to a certain level of causality.

4.2.3 Symptom severity

At the interview locations, the results of t-tests revealed that self-judgments concerning physical discomfort from the SHS group were more than those from the non-SHS group. The phenomena appeared mostly in item 'skin' and item 'airway/mucous membranes' with mean score ratios of 3.1 and 2.8 respectively, and resulting in a significantly different t-test result (p<0.001). Both significances were easily understandable, even without specialist examination, and the main reasons for most individuals to accept further precise examinations. Other significantly different items were 'musculoskeletal (p<0.01)', 'neuromuscular (p<0.05)', and 'affective (p<0.05)' (Fig.3.).

Table 7. Measurement Results of I/O Ratios at 40 Homes

|        | HCHO | TVOC |
|--------|------|------|
| IN-1   | 2.85 | 3.69 |
| IN-2   | 1.76 | 1.94 |
| Medians| 2.08 | 2.74 |
| Maximum| 1.99 | 2.39 |

Fig.1. Comparison between SHS and Non-SHS Concerning Chemical Inhalant Intolerance Scale
(*p<0.05, **p<0.01, ***p<0.001)

Fig.2. Comparison between SHS and Non-SHS Concerning Other Intolerance Scale
(*p<0.05, **p<0.01, ***p<0.001)

Fig.3. Comparison between SHS and Non-SHS Concerning Symptom Severity Scale
(*p<0.05, **p<0.01, ***p<0.001)
4.2.4 Life impact

Significant differences (p<0.05) were found by t-test concerning items of 'choice of home furnishings (ratio 3.4)', 'choice of clothing (ratio 4.9)' and 'relationships with spouse and family (ratio 2.4)'. If related symptoms such as 'skin' and 'airway/mucous membranes' were examined and compared, the SHS sufferers were more sensitive to the fumes of home furnishings and clothing than the non-SHS individuals. (Fig.4.)

4.2.5 Masking

Studies in Japan (Hojo, 2004) based on the 'masking' subscale showed that items to which the answer 'Y' was given were classified into two categories: 6 items in the SHS < non-SHS group were 'cigarette smoking', 'alcoholic beverage consumption', 'caffeine intake', 'perfumes or other personal care products', 'living with a smoker', and 'fabric softeners'; 4 items in the non-SHS < SHS group were 'pesticides', 'chemical exposure at work or in hobbies', 'gas appliances', and 'medications'. As for the results of the survey conducted in Taiwan, 3 items in the SHS < non-SHS group were 'perfumes or other personal care products', 'chemical exposure at work or in hobbies', and 'fabric softeners', and all were suspected to be the main causes of their illnesses. Results similar to those in Japan were: 'cigarette smoking', 'living with a smoker', 'alcoholic beverage consumption', and 'caffeine intake'. Because of the similarity it is assumed that patients will avoid exposing themselves to the illness causing factors aggressively. However, in the case of item 'pesticides', which was quite different from Japan, the mean score of SHS was lower than that of non-SHS. The average concentration of formaldehyde in 'SHs' is 60μg/m$^3$, while in 'non-SHS' it is 43μg/m$^3$, and both are lower than the guideline 100μg/m$^3$ made by the Ministry of Health, Labor and Welfare of Japan (MHLWJ). However, the results of t-test did not reveal a significant difference either (Fig.6.). As for VOCs, the significant difference only appeared in the concentration of xylem between 'SH' and 'non-SH' (p=0.038<0.05). In total VOC score, the result of t-test reached borderline significant (p=0.053), it showed some evidence that TVOC was higher in the 'SH' group rather than the 'non-SH' group (Fig.7.).

4.3 Comparative studies between SH and non-SH

As mentioned above, if anyone of the family members is suspected to have SHS, then the houses they live in are sick houses (SH). It is possible that the suspect's illness is caused by factors outside the house, and it is also possible that a non-SH is a non-SH only because none of its occupants is a SHS patient. However, in reality, the concentration of pollution substances in the air of the house may be high.

The results of IAQ measurement were categorized into 'SH' and 'non-SH' and compared by substance accordingly (Figs.6. & 7.). In the case of carbonyl compounds, the concentrations of formaldehyde, acetaldehyde, acetone, and acrolein were measured, and except for acrolein, were found to be higher in 'SHs'. The average concentration of formaldehyde in 'SHs' is 60μg/m$^3$, while in 'non-SHS' it is 43μg/m$^3$, and both are lower than the guideline 100μg/m$^3$ made by the Ministry of Health, Labor and Welfare of Japan (MHLWJ). However, the results of t-test did not reveal a significant difference either (Fig.6.). As for VOCs, the significant difference only appeared in the concentration of xylem between 'SH' and 'non-SH' (p=0.038<0.05). In total VOC score, the result of t-test reached borderline significant (p=0.053), it showed some evidence that TVOC was higher in the 'SH' group rather than the 'non-SH' group (Fig.7.).

The measurements in the locations were conducted in winter. Due to the warm weather, many households were ventilated by opening the windows. This could possibly make the average concentration lower than what it might be in reality. Contrarily, in summer, the
5. Verificatory Measurements

To verify the hypothesis, two target houses, which had higher concentrations, were selected from the 40 targets of Phase II. The amounts of furnishing materials of the two houses were quite different. To compare the results of Phase II, the method used in VM was set to be the same as Phase II, the measurements were taken in airtight conditions only to simulate the situations of air-conditioning or long-time absence.

5.1 Outlines of the two target houses

Outline of the two measured houses are shown in Table 8.

5.2 Results of verificatory measurements

5.2.1 Case A

All materials and furnishing methods will emit highly concentrated toxic chemical substances, and the decorations are heavy. Judging from the measurement results, the possibility of the target object being a SH is high.

In Phase II, in order to adhere to the occupants' real living mode, the main French windows, opening onto a balcony and facing southwest, were kept open during measurement. Due to the strong wind, the outcome figures were below the guideline. However, the occupants only returned home every 3 days because of their out-of-town jobs. According to his description, the son experienced dermal symptoms such as eczema or rash, which were alleviated gradually two hours later. Thus, following the train of logic, it is presumed that the concentration of pollution substances will rise if the rooms are kept closed.

While the VM was conducted according to the authors' request, the openings of the target subjects were kept closed for over 8 hours to simulate the situation of away-for-work, and sampling was conducted under the 'Active method'. As the openings were re-opened, the average ventilation frequency was
3.8 times per hour, assessed by the CO₂ concentration decay method.

The results are as follows: As shown in Figs. 8.-1 and 8.-2, the formaldehyde concentration of VM in the living room is 23 times that of Phase II, and in the master bedroom 13 times. (Indoor temperature rose 0.5°C and relative humidity rose 12%). As for VOC concentrations, the figures in the living room are 10 times that of Phase II, and in the bedroom are 8 times. One thing worth mentioning is that the formaldehyde concentration of VM is almost 80% that of the guideline even when the windows are open, and 10 times (1056 μg/m³) when the windows are shut. Meanwhile, TVOC of the VM in both the living room and master bedroom are 8 to 9 times that of Phase II, 814 μg/m³ in the living room (twice that of the Japanese target level) and 1339 μg/m³ in the master bedroom (3.3 times).

5.2.2 Case B

Putting aside the comparison with Case A, the decorations of Case B are even simpler than a regular residence. When interviewed for the first time, the occupants mentioned that respiratory symptoms had been bothering them. It was judged that this could be simply because of their sensitivity, and the furnishings were never suspected.

The first measurement results (Phase II) of formaldehyde and TVOC in IN-1 were very close to the guidelines. This demonstrates that it is not accurate to judge the space of a sick house simply by seeing its decorations with the naked eye. (Figs. 9.-1 & 9.-2)

Both suites were kept closed at all times, no matter when the occupants went out for work during the daytime or when they came back from work and turned on the air conditioners. This further worsened the indoor air quality. Thus, VM were implemented.

The measurement method is the same as Case A. The results are shown in Fig. 9., and as follows: The concentration of formaldehyde in IN-1 is 5.4 times that of the guideline and 5.8 times that of the figure with opened-window. TVOC is 3 times that of the guideline and 3.3 times that of the figure with opened-windows. In IN-2, the concentration of formaldehyde is 4.6 times that of the guideline and 9.48 times that of the figure with opened-windows. TVOC is 2.2 times that of the guideline and 2.7 times that of the figure with opened-windows. By excluding the furnishing materials, the adhesive or the plywood used as backing boards is assumed to be the source of pollution.

To effectively reduce indoor air pollution, it is insufficient just to regulate the materials and the quantity of interior furnishings. Construction process, ventilation rate, airflow path, and an overall plan with strict assessment should all be included in the regulations.

6. Conclusions

The research subjects were general individuals living in Taiwan. This was a brand new trial to simultaneously implement IAQ measurement in the locations with QEESI questionnaires. The results are as follows:

1. For areas deficient in SHS and/or MCS diagnoses, combining QEESI investigations and IAQ measurements in the surveys is successful in screening SH and discovering SHS.
2. The results of VM show that to effectively reduce indoor air pollution, it is insufficient just to regulate the materials and the quantity of interior furnishings. Construction process, ventilation rate, airflow path, and an overall plan with strict assessment should all be included in the regulations.
3. According to the survey, the winter outdoor temperature in subtropical and tropical zones such as in southern Taiwan is mild. Most buildings are well-ventilated by letting the natural outdoor air flow through the openings. The wind speed is higher in winter than in other seasons. This helps to dilute the concentration of pollution substances of indoor air. However, the prolonged summer in southern Taiwan
compels people to shut their windows and turn on air conditioners. And this always leads to a low ventilation rate.

4. There are many more areas like Taiwan that lack knowledge concerning SHS and MCS, which are not yet covered by the National Health Insurance, and patients are very likely not treated properly. In other words, the treatments merely alleviate the symptoms, without providing a radical cure. This is a waste of medical resources and prolongs the sufferings of patients.

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Note

The townhouse is a type of building popular in southern Taiwan and is made of concrete only. Houses of this type usually have 4 to 5 stories, and cluster together in a long row sharing walls with adjacent townhouses. Openings are on the front and rear sides only, and their ventilation systems are usually poor.

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