

Session II-1

Sick House/ Building Syndrome in Japan - Current Status and Practical Research on Indoor Air Quality -

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Abstract

Many Japanese today are suffering from health disorders related to their living environment, such as allergies and hypersensitivity to chemical substances. The Sick House/Building Syndrome has been a serious problem since 1996, due to low level exposure to hazardous chemicals such as formaldehyde and volatile organic compounds (VOCs) emitted in airtight houses. This paper aims to show current status of the syndrome in Japan and practical researches to promote prevention of, and improvement to indoor air pollution due to chemicals.

Introduction

Many Japanese today are suffering from health disorders related to their living environment, such as allergies and hypersensitivity to chemical substances. In particular, indoor air pollution by volatile organic compounds (VOCs) has been a serious problem since 1996 or so and became a matter of great social concern. The cases are popularly known as the Sick House Syndrome among Japanese people rather than the familiar Sick Building Syndrome, because majority of the patients consists of housewives and children living in newly-built apartment or detached houses. Besides, recent serious indoor air pollution problems in school facilities produced the new word, the Sick School Syndrome.

Traditional Japanese houses had been made of natural wooden materials and well ventilated, adapting to warm and humid climate. Nowadays, modern houses are being built with higher air-tightness (air change rate without mechanical ventilation is smaller than 0.2/h) to realize greater heating and cooling efficiency and hence save energy. In order to supply large number of such types of houses in a stable manner and low cost, highly processed building materials using chemical substances must be used such as plywood, particle board, MDF, paper walls and so on. In these highly airtight houses, indoor air was polluted by hazardous chemicals emitted from the materials and then caused idiopathic environmental intolerance of residents, also known

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as multiple chemical sensitivities (MCS).

Although there are potentially numeral risks caused by environmental chemical substances, for example dioxins, endocrine disrupters, heavy metals and pesticides for agricultural uses, countermeasures regarding the syndrome have a higher priority to be carried out because of the fact the victims are consciously or in many cases unconsciously facing fear from the invisible gaseous chemicals. This paper aims to describe present status of the syndrome in Japan and practical researches to promote prevention from, and improvement to indoor air pollution by chemicals.

Case study in Tokyo (Kawashima et al, 2003)

A woman, who had moved and lived alone in a newly-built apartment house at Tokyo in April 1999, began to feel unpleasant odor in the house. She gradually became annoyed from health disorders such as eye mucus, throat pain, bronchus irritation, headache, unpleasant feeling with muscles, diarrhea, fatigue and failure of memory. As she was working at a public library, she made a literature search by herself and suspected they were typical symptoms of the Sick House Syndrome. Then, she tried to grasp present status of air quality using a conventional gas monitor and found indoor air concentrations of formaldehyde at the living room ranged from 0.14 to 0.23ppm. These values were much higher than the indoor air quality guideline level (0.08ppm). In March 2000, she was referred to a hospital and diagnosed as a possible patient of the multiple chemical sensitivities. Most patients are forced to either move to other houses (aged and stand in suburban area) or replace building materials suspected to emit the hazardous chemicals at great expense. However, those manners were not practical for her. She then decided to reduce indoor concentrations of chemicals by introducing air cleaning methods as shown in Fig. 1. The front

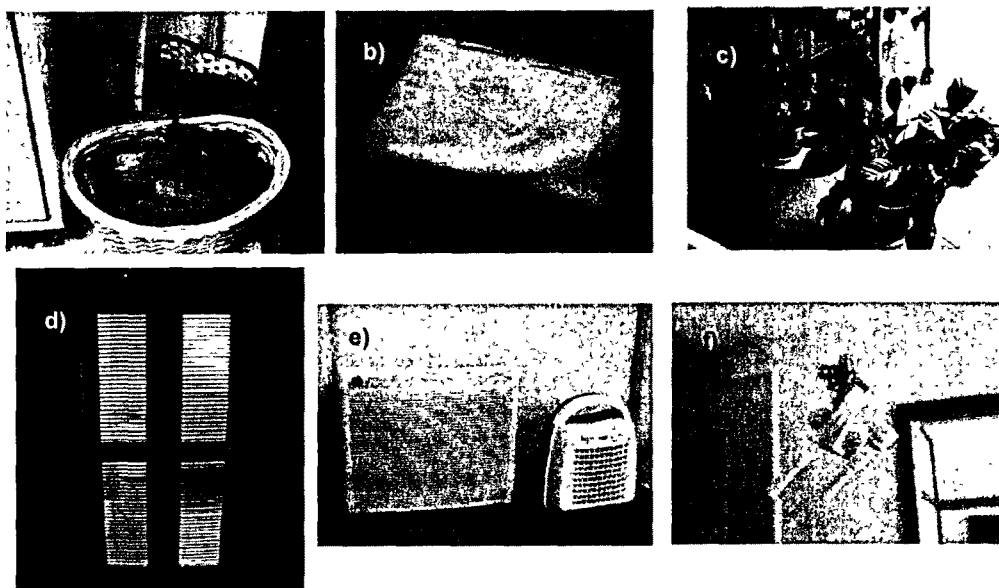


Fig. 1. User-friendly techniques employed by the patient, a) bamboo charcoal, b)pillow filled with charcoal flakes, c) plants which absorb VOCs, d) front door with air pathway, e) air cleaners, d) passive samplers for air quality monitoring.

doors with parallel open slits increased air exchange rate in the house. Air cleaners, bamboo charcoals and plants must have reduced indoor concentration of formaldehyde and VOCs. Significant field measurements using passive samplers conducted in 2002 proved effect of those efforts on the improvement of indoor air quality; concentrations of formaldehyde decreased to approximately 0.03ppm.

In this case, the patient fortunately got over the symptom by identifying and removal of causing substances employing user-friendly techniques such as air cleaners and simple measurement devices. However, many patients do still suffer from the symptom. A questionnaire survey was conducted against 4,000 adults (older than 20) via interviews using the Environmental Exposure and Sensitivity Inventory (Miller, 1999) and showed 0.74 % of the respondents had a potential risk for chemical sensitivities (Uchiyama and Murayama, 2003). This result, however, seems to be underestimated due to a bias of specific questionnaire to western people (it should be revised for Japanese people) and lack of data on children, probably more sensitive to environmental impurities.

Political countermeasures

Indoor air quality guidelines have been set for concentrations of chemical substances in indoor air by Ministry of Health, Labour and Welfare, Japan (MOHLW). Chemical substances subjected to the guideline were added stepwise as shown in Table 1. Committee of the Ministry has also prepared manuals on the standard sampling and analytical procedures for each pollutant in a newly-built and occupied house, employing both active and passive sampling methods. These guidelines and manuals were aggressively referred by stakeholders on this matter, particularly by house-builders to consider the indoor air quality of houses. The indoor environment was then recognized as one of the housing performance. In accordance with the Housing Quality Assurance Act (2002), measurement of concentrations of chemical substances (formaldehyde, toluene, xylene, ethylbenzene and styrene) was included in fields of the Housing Performance Indication System, which enables a housing purchaser to compare housing from the view point of performance. Even though house-builders are not obliged to the system and measurements are carried out only when the client requests it, a number of builders have been voluntarily adopting the indoor air quality monitoring following the manuals to enhance reliability on the houses they built.

Ministry of Land, Infrastructure and Transport, Japan (MLIT) have conducted a nation-wide survey on indoor air concentrations of chemical substances for approximately 4,600 housing units in 2000 (Murakami, 2003). The results showed priority should be given to taking measures to reduce formaldehyde concentration, because 27.3% of the units showed a higher value than the guideline with 0.071ppm in average. Furthermore, toluene should receive priority after formaldehyde, because 12.3% of the units showed a higher value than the guideline (0.07ppm) with 0.038ppm in average.

The amended Building Standard Law, which stipulates minimum standards for building lots, structure and facilities, was enforced in July 2003, considering those results and strong toxicity on nerve system of anti-ant agent. This is a first regulation on a housing regarding the Sick House Syndrome, covering formaldehyde and chlorpyrifos as chemical substances subject to the

Table 1. Chemical substances given priority for political countermeasures regarding the Sick House Syndrome in Japan.

Indoor Air Quality Guidelines			Housing Performance Indicat System	Standard for School Environ Sanitation	Amended Building Standard Law	major usage for housing
MOHLW			MLIT	MEXT	MLIT	
date	chemicals(CAS No)	concentration*	Subject to measurement of indoor air concentration		Subject to regulations	
1997 6	formaldehyde(50-00-0)	100 $\mu\text{g}/\text{m}^3$ (0.08ppm)	○	○	○	synthetic resin used for plywood, particle board etc and adhesives for wall paper
2000 6	toluene(108-88-3)	260 $\mu\text{g}/\text{m}^3$ (0.07ppm)	○	○	-	paints, interior furnishing mat
	xylene(1330-20-7)	870 $\mu\text{g}/\text{m}^3$ (0.20ppm)	○	○	-	paints, interior furnishing mat
	p-dichlorobenzene (106-46-7)	240 $\mu\text{g}/\text{m}^3$ (0.04ppm)	-	○	-	insecticide
2000 1	ethylbenzene(100-41-4)	3800 $\mu\text{g}/\text{m}^3$ (0.88ppm)	○	○	-	paints, interior furnishing mat
	styrene(100-42-5)	220 $\mu\text{g}/\text{m}^3$ (0.05ppm)	○	○	-	insulator
	chlorpyrifos(2921-88-2)	1 $\mu\text{g}/\text{m}^3$ (0.07ppb) 0.1 $\mu\text{g}/\text{m}^3$ (0.007ppb) for infant	-	-	○	anti-ant agent
	di-n-butylphthalate (84-74-2)	220 $\mu\text{g}/\text{m}^3$ (0.02ppm)	-	-	-	plasticizer for paints
	TVOC	400 $\mu\text{g}/\text{m}^3$ **	-	-	-	
2001 7	tetradecane(629-59-4)	330 $\mu\text{g}/\text{m}^3$ (0.04ppm)	-	-	-	paints, etc
	di-2-ethylhexylphthalate (84-66-2)	120 $\mu\text{g}/\text{m}^3$ (7.6ppb)	-	-	-	plasticizer for wall paper
	diazinone(33-41-5)	0.29 $\mu\text{g}/\text{m}^3$ (0.02ppb)	-	-	-	insecticides
	nonanal(124-19-6)	41 $\mu\text{g}/\text{m}^3$ (7.0ppb)**	-	-	-	paints, etc
2002 1	acetaldehyde(75-07-0)	48 $\mu\text{g}/\text{m}^3$ (0.03ppm)	-	-	-	synthetic resin for plywood etc
	fenobucarb (3766-81-2)	33 $\mu\text{g}/\text{m}^3$ (3.8ppb)	-	-	-	Insecticide

MOHLW, Ministry of Health, Labour and Welfare, MLIT Ministry of Land, Infrastructure and Transport

MEX Ministry of Education, Culture, Sports, Science and Technology

* () converted at 25 degC

**draft value due to lack of enough information on hazardous properties, etc

regulation. The use of building materials containing chlorpyrifos is prohibited. Technical standards concerning formaldehyde are briefly as follows.

- Area size of formaldehyde-emitting materials used for interior furnishing is restricted according to the type of habitable room and the frequency of ventilation.
- Installation of ventilation equipment, which enables 24h ventilation, is mandatory in all buildings, considering the emissions from furniture.

The formaldehyde-emitting building materials are classified under four categories according to their formaldehyde emission rates; Type1, whose emission rate of formaldehyde is greater than 0.12mg/m²/h, is prohibited for the use of interior furnishing materials. Type 2 (emission rate: 0.02-0.12mg/m²/h) and Type 3 (0.005-0.02mg/m²/h) are allowed to use in a limited area. No restriction was set for the materials whose emission rate is up to 0.005mg/m²/h. The emission rates are strictly determined by an established small chamber method (JIS A 1901, 2003).

It must be noted that the law allows following types of habitable rooms are exempted from the restriction: rooms equipped with centrally controlled air conditioner and those approved by the Minister as rooms in which it is possible to maintain the formaldehyde concentration at no more

than 0.1mg/m³(0.08ppm) throughout the year. In the latter case, the use of air cleaning materials which remove formaldehyde gases by adsorption and decomposition are allowed to use.

Removal of formaldehyde and VOCs

Numerous studies relating to removal of formaldehyde and VOCs by air-cleaning materials have been conducted in Japan. There are also many kinds of commercially available products, such as air cleaners, ventilation system with purifying filters, passive type air cleaning materials, paints, spray and so on, based on various principles as shown in Table 2.

Author has developed air-cleaning materials consisting of activated carbon particles and manganese oxides, by which formaldehyde is decomposed into carbon dioxide even at room temperature (Sekine and Nishimura, 2001a). According to the results of screening of reactivity between metal oxides and formaldehyde vapor, MnO₂ showed highest removal efficiency with a significant production of carbon dioxide in vapor phase (Fig.2) and without emissions of harmful byproducts such as formic acid and carbon monoxide (Sekine, 2002a).

Table 2. Methods and materials used for removal of formaldehyde and VOCs.

principle	methods/materials	mechanism
physisorption	activated charcoal	adsorption by charcoals having micro porous structures
	porous ceramics	adsorption by natural and synthesized ceramics (zeolite, sepiolite, silica etc)
	natural fibers	adsorption by fibers and unwoven clothes such as cellulose, wool and so on
chemisorption	inorganic compounds	fixation of HCHO by chemical reactions with inorganic compounds(metal complex, ammonium sulfate)
	organic compounds	fixation of HCHO by chemical reaction with organic compounds having a NH ₂ group, normally impregnated on the solid sorbent.
	extracts	fixation of HCHO by chemical reaction with natural products such as chitin, chitosan, green tea catechins
decomposition	photocatalyst	oxidative decomposition of VOCs by photocatalyst (typically TiO ₂) under UV/Visible light
	ozonolysis	oxidative decomposition of VOCs by ozone (attention; ozone is harmful)
	catalytic decomposition	oxidative decomposition of VOCs by metal/metal oxides at room to elevated temperature
	modified charcoal	decomposition of HCHO by KMnO ₄ supported on charcoal
	plasma discharge	decomposition of VOCs by radicals produced during plasma discharge
	minus ions	definition and effect of "minus ions" are controversial (suspicious)
	activated oxygen	oxidative decomposition of VOCs by activated oxygen produced by a catalyst
digestion	bacterial	bacterial digestion of VOCs
blocking	resins	coating of resins on the building materials

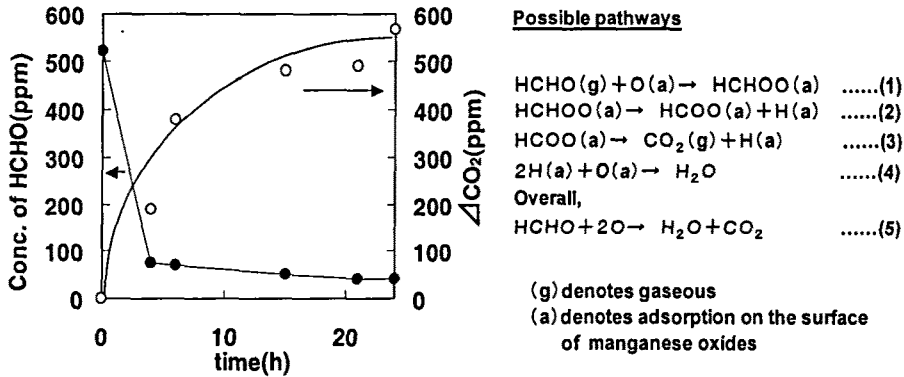


Fig. 2. Time courses of concentrations of HCHO (●) and produced CO₂ (○) through the reaction between fine MnO₂ and HCHO at 21 °C.

The removal efficiency of a board-like air-cleaning material was investigated in a passive mode using a kinetic approach. First order removal rate constant(/h), k corresponding to air change rate was characterized for the board as a function of the loading factor (ratio of applied board area to space volume, m^2/m^3), L/V , and was found directly proportional to L/V with a slope of 25 at 25 °C. When the performance of the board was evaluated in a full-size laboratory with a constant gas generation, the board suppressed the increase of indoor formaldehyde concentration and the time course fitted to a theoretical curve. Then, field tests of the air-cleaning board were conducted in newly constructed multi-family houses in Japan. The board not only reduced indoor formaldehyde concentration from 0.21ppm to 0.04ppm for more than 7 months (Fig.3), but also enhanced the loss of formaldehyde gas from building materials in the houses.

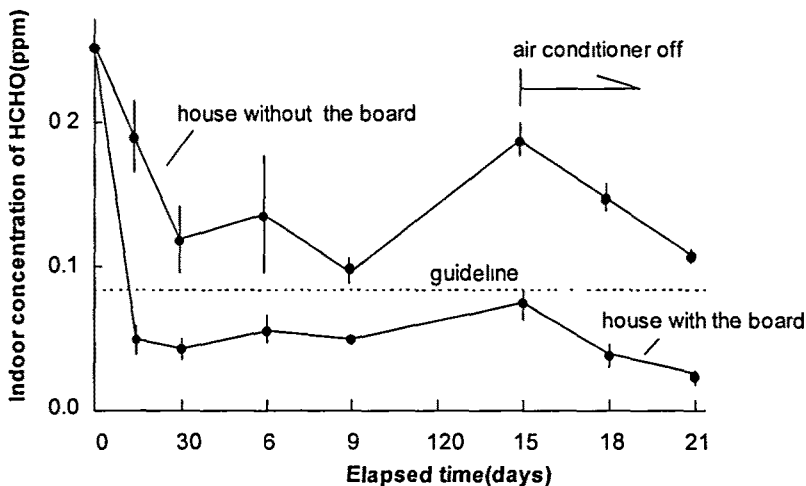


Fig. 3. Variation of indoor concentrations of formaldehyde(HCHO) normalized at 20 °C in apartment houses with 9.8m² of air-cleaning board ($L/V=0.043m^2/m^3$, $k=1.1/h$) and without the board(reference). Air conditioners were operated to prevent dew condensation for the first five months.

A honey-comb type filter was also prepared and applied to an air cleaner for the reduction of concentrations of formaldehyde in indoor air of school (Sekine,2002b). When two of the air cleaners, whose space velocity was set at 57,500(/h), were operated in the classroom (for IT education use, volume=416m³, air change rate=0.95/h), the concentration significantly decreased with time, as was predicted by a mass balance model introducing pre-evaluated equivalent ventilation rate of the device. These results led us the conclusion that certain air cleaning materials and devices, when properly evaluated and applied, prove beneficial to practical use.

Passive samplers

The use of passive sampling method has greatly increased in recent years to monitor concentrations of indoor air pollutants, because the method has been recognized as an efficient alternative to pumped sampling according to its ubiquitous, cost-effective and user-friendly properties (Brown,2000). Passive samplers, which employ diffusion process based on Fick's law and hence do not require power supply or other services, are suitable for monitoring personal exposure or indoor concentrations of gaseous components at ppb level. Then, authors have developed new passive samplers consisting of a porous plastic tube uniformly packed with powder-like adsorbent as a trapping media with greater sampling rates. For example, Fig.4 illustrates construction of the passive sampler for carbonyl compounds employing 2,4-dinitrophenylhydrazine (DNPH) coated silica gel. The porous tube is made of sintered polyethylene particles with 34.5% of porosity and work as a diffuser which limits influence of wind or turbulence on the diffusive movement of gases; sampling rate of such type of samplers does not vary with the wind speed between 0.2 to 4.0m/s (Sekine, 2001b).

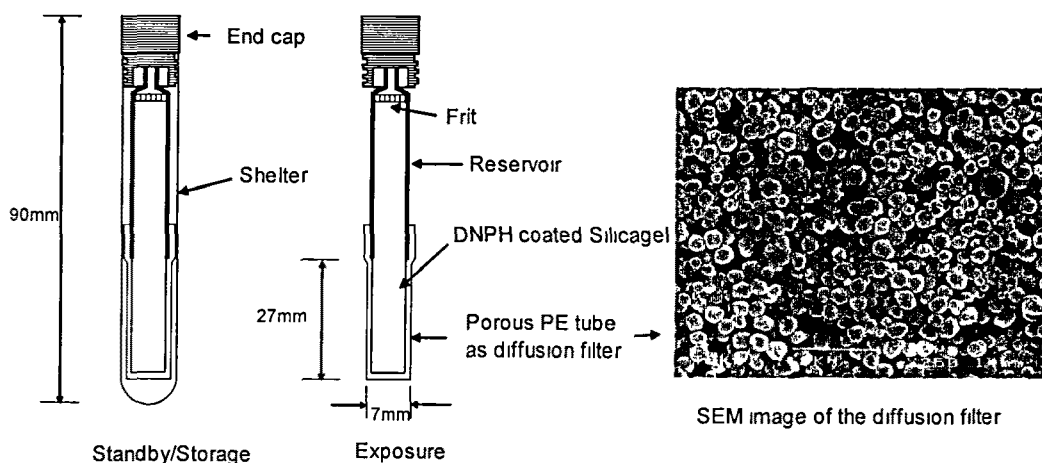


Fig. 4. Construction of passive sampler for carbonyl compounds.

When measuring concentrations of VOCs such as benzene, toluene, xylene, ethylbenzene, styrene, *p*-dichlorobenzene and limonene, carbon molecular sieves were used as collection media for solvent extraction and thermal desorption of analytes (Sekine et al, 2002c, 2004). The VOCs were then determined by GC/FID or GC/MS. Authors has been currently developing a new

sampler, which employs *o*-(4-cyano-2-ethoxybenzyl) hydroxylamine phosphate (CNET) as a reactive adsorbent of carbonyl compounds. The CNET is stable in storage and less hazardous than the previous DNPH.

Using such passive samplers, sampling rate, α is a dominant factor for analytical liability. As shown in Eq.(1), collected amount of analyte on adsorbent, W could be converted to air concentration, C using exposure time, t and α , if the adsorbent reduces the concentration of the given analyte at the end of diffusion layer ideally to zero due to sorption or chemical reaction (Brown,2000).

$$C=W/(\alpha t) \quad \dots(1)$$

Therefore, the sampling rate was determined in advance for each air pollutant by a small chamber experiment, deriving them from a slope of linear regressions between air concentrations in the chamber and collected amount of analyte at a certain exposure time. Table 3 shows typical performance of the passive sampler.

Table 3. Performance of the passive samplers employing porous PE tube as diffuser for determinations of formaldehyde and toluene in indoor air.

analyte sampler	formaldehyde		toluene	
	DSD-DNPH	CNET-P	VOC-SD	VOC-TD
company	Supleco	SCAS*	Supleco	Supleco
collection media	DNPH/silica gel	CNET/silica gel	carbon molecular sieves	
analyte eluted by,	acetonitrile	acetonitrile	carbon disulfide	thermal desorption
analyzed by,	UV/HPLC	UV/HPLC	GC/FID, MS	GC/FID, MS
sampling duration	8 - 24h	8 - 24h	24h	2h
sampling rate				
α in ml/min	89	74	42	49
α_w in $\mu\text{g}/(\text{mg}/\text{m}^3)/\text{h}$	5.4	4.4	2.5	2.9
α_v in $\mu\text{g}/\text{ppm}/\text{h}$	6.7	5.4	9.7	11
detection limit (S/N=3)	0.31ppb(24h)**	0.12ppb(24h)	7.1ppb	0.022ppb

*Sumika Chemical Analysis Service, ** $3\sigma_b$

The passive samplers were applied for filed measurements at residential houses in Japan, and successfully used for determination of carbonyl compounds and VOCs at ppb level and gave similar results to active samplings. The results show excellent linearity of the technique and suggest that reasonable accuracy can be expected after establishing the sampling rate under given exposure conditions.

Indoor air chemistry

In modern living environments, we are exposed numerous types of pollutants in indoor air. However, secondary emission products generated through chemical reactions have not been fully concerned in relation to the Sick House Syndrome. Authors focused on formic acid (HCOOH) suspected to have impact on human health such as chemical sensitivity due to its low irritant level. Our previous study performed in multi-family houses suggested that a room temperature

and photochemical oxidants, which ordinarily came from outdoor air by ventilation, had potential influences on the formation of indoor formic acid from formaldehyde. Furthermore, laboratory studies using small and large chambers showed that a heterogeneous reaction between formaldehyde and nitrate radical on the surface of plywood played an important role of the indoor formic acid production. These findings suggest scientists should continue to explore and identify the hazardous substances in indoor environment.

Concluding remarks

Air pollution is one of the typical worries for human well-being and yet we are unable to see the pollution, until the appearance of severe impacts on human health, such as the Sick House Syndrome. Author believes air quality watching with a strong scientific basis and collaboration of stakeholders plays an important role in enhancing a freedom of individuals from fear of environmental risks and leads to useful scientific inputs in political decision-making for environmental protection.

References

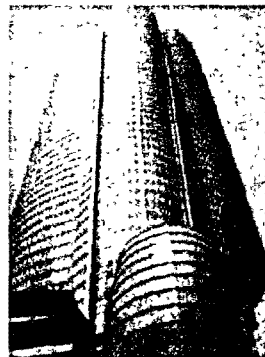
- Brown, R. H.: Monitoring the ambient environment with diffusive samplers: theory and practical considerations, *J Environ. Monit.*, 2000(2), 1-9, 2000.
- Kawashima, Y., Sekine, Y., Takahashi, D., Matsuo, A, Ro, S.: Efforts on control of indoor air pollution by a resident, *J Soc of Indoor Environ* , 5(2), 86-87, 2002.
- Miller, C.S., Prihoda, J.P.: The Environmental Exposure and Sensitivity Inventory (EESI): a standardized approach for measuring chemical intolerance for research and clinical application, *Toxic. Ind. Health*, 15, 370-385, 1999.
- Murakami, S.: Introduction of regulations for countermeasures regarding sick house issues in Japan, *Proc. of 2003 Intern Symposium on Indoor Air Quality and Health Hazards*, 251-261(2003)
- Sekine, Y., Nishimura, A.: Removal of formaldehyde from indoor air by passive type air-cleaning board, *Atmospheric Environment*, 35, 2001-2007. 2001a.
- Sekine, Y., Butsugan, M., Usuki, H. and Kitahara, T.: Evaluation of the diffusion sampling device for the determination of formaldehyde in indoor air, *J Environ Chem* , 11, 511-516, 2001b.
- Sekine, Y.: Oxidative decomposition of formaldehyde by metal oxides at room temperature, *Atmospheric Environment*, 36, 5543-5547. 2002a.
- Sekine, Y, Oikawa, D., Kadora, M., Kawata, H.: Study on control of indoor air pollution in school, *J. Soc of Indoor Environ.*, 5(2), 85-86, 2002b.
- Sekine, Y., Hirota, C. and Butsugan, M.: Evaluation of solvent extraction type diffusion sampler for determination of VOCs in ambient air, *J. Environ. Chem.*, 12, 847-854, 2002c.
- Sekine, Y., Matsuo, A. and Butsugan, M.: Evaluation of thermal desorption type diffusion sampler for determination of VOCs in ambient air, *J Environ. Chem.*, 14, 343-350, 2004.
- Uchiyama, I., Murayama, R.: Studies in current situation of chemical sensitivity in Japan, *Proc. of 2003 Intern. Symp. on Indoor Air Quality and Health Hazards*, 186-190. 2003.

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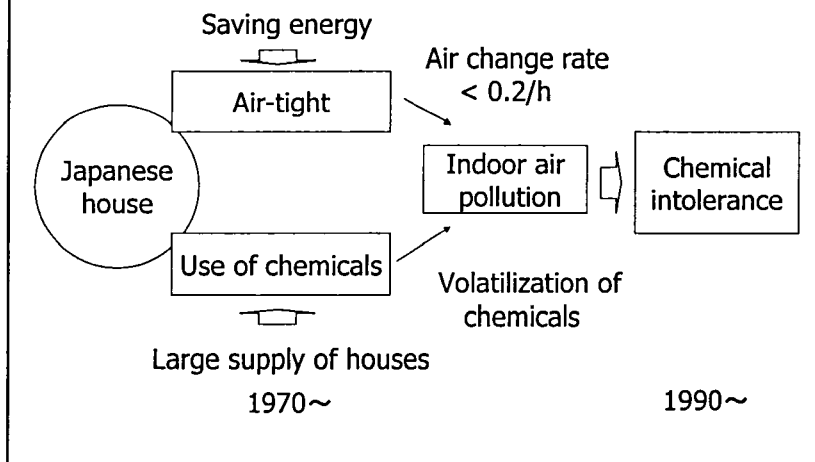
Sick House/Building Syndrome in Japan

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Houses and Buildings



Indoor air pollution by chemicals

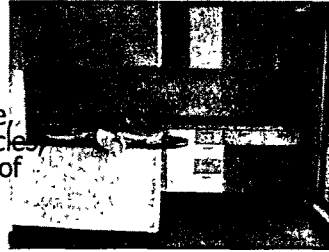


“Sick House Syndrome”

- ◆ “Sick Building Syndrome”
- ◆ Majority of patients: housewives and children in newly-built houses
- ◆ “Sick School Syndrome”
- ◆ Typical air pollutants
 - Formaldehyde (HCHO)
 - Volatile Organic Compounds (VOCs)

Case of a woman in Tokyo

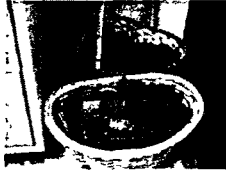
- ◆ Moved to a newly built apartment house in Tokyo (Apr.1999)
- ◆ Health disorder
 - eye mucus, throat pain, bronchus irritation, headache, unpleasant feeling with muscles, diarrhea, fatigue and failure of memory
- ◆ Diagnosis at Hospital (Mar.2000)
 - Multiple Chemical Sensitivity



Multiple Chemical Sensitivity

- ◆ Medically unexplained symptom
 - different from allergy, acute poisoning
- ◆ Damage on nerve system etc.
- ◆ Repeated and intermittent exposure to chemicals (non-specific structure, property)
- ◆ Cross-sensitization
 - drugs, physical or psychological stress
- ◆ Most patients : forced to either move to other houses or replace building materials

Effort of reduction of chemicals



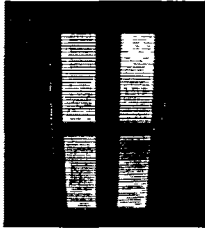
Bamboo coal



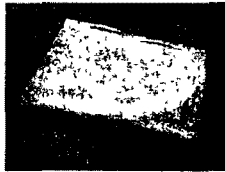
Air cleaners



Plants



Door with air pathway

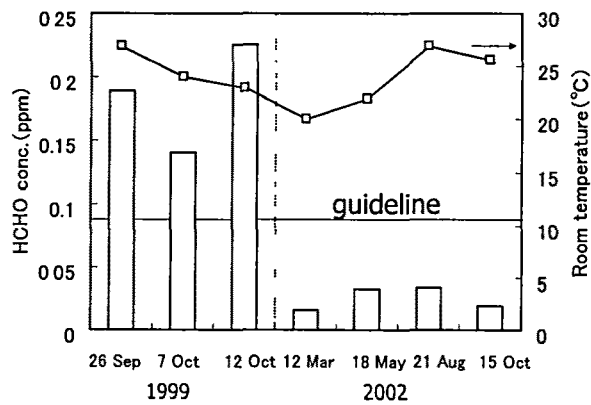


Pillow with coal



Passive sampler

Concentration of formaldehyde



Nation-wide survey

- ◆ Questionnaire study for Japanese 4,000 adults (> age 20) (Uchiyama,2003).
- ◆ Quick Environmental Exposure and Sensitivity Inventory (QEESI)
 - developed by C. Miller (1998)
- ◆ Results
 - respondents: 2,851
 - suspected as chemical sensitivity: 0.74%
- ◆ Underestimate?

Indoor Air Quality Guidelines

- Ministry of Health, Labour and Welfare, Japan

date	chemicals	CAS No.	concentration
1997 6	formaldehyde	50-00-0	100 $\mu\text{g}/\text{m}^3$ (0.08ppm)
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	xylene	1330-20-7	870 $\mu\text{g}/\text{m}^3$ (0.20ppm)
2000.12	<i>p</i> -dichlorobenzene	106-46-7	240 $\mu\text{g}/\text{m}^3$ (0.04ppm)
	ethylbenzene	100-41-4	3800 $\mu\text{g}/\text{m}^3$ (0.88ppm)
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	chlorpyrifos	2921-88-2	1 $\mu\text{g}/\text{m}^3$ (0.07ppb)
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	TVOC		220 $\mu\text{g}/\text{m}^3$ (0.02ppm)
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() covered at 25 degC, *Draft value

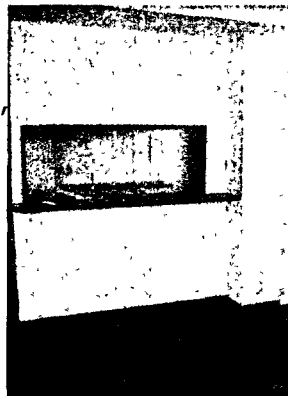
Housing Quality Assurance Law

- Ministry of Land, Infrastructure and Transport

- ◆ IAQ : one of the housing performance
- ◆ Measurement of indoor concentrations included in fields of the Housing Performance Indication System
- ◆ House builders-not obliged, must do when purchase request it
- ◆ Methods: Standard protocol by MOHLW

Formaldehyde (HCHO)

- ◆ Emission source adhesives used for
 - plywood, MDF, particle board,
 - vinyl wall paper
- ◆ Indoor concentrations Survey for 4,600 housing units in 2000 (by MLIT)
 - average 0.071ppm
 - 27.3% of the units > the guideline



The amended Building Standard Law

- ◆ Enforced in July, 2003
- ◆ Use of Chlorpyrifos is prohibited
- ◆ Formaldehyde
 - area size of HCHO-emitting materials used for interior finishing is restricted
 - installation of 24h-ventilation system is mandatory

HCHO-emitting materials

Formaldehyde emitting building materials	Emission rate	Restrictions on interior finishing materials
Type 4	up to $5\mu\text{g}/\text{m}^2\text{h}$	No restrictions
Type 3	$5\sim 20\mu\text{g}/\text{m}^2\text{h}$	Limited area
Type 2	$20\sim 120\mu\text{g}/\text{m}^2\text{h}$	
Type 1	over $120\mu\text{g}/\text{m}^2\text{h}$	Prohibited

Determined by a small chamber method (JIS A 1901,2003)

Exemption from the restrictions

Habitable room

- equipped with centrally controlled air conditioner
 - in which the HCHO concentration can be maintained at no more than $0.1\text{mg}/\text{m}^3$, approved by the Minister
- air-cleaning materials are allowed to use

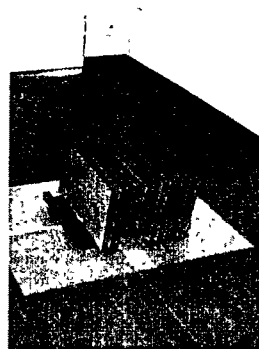
Air-cleaning materials



Air cleaners

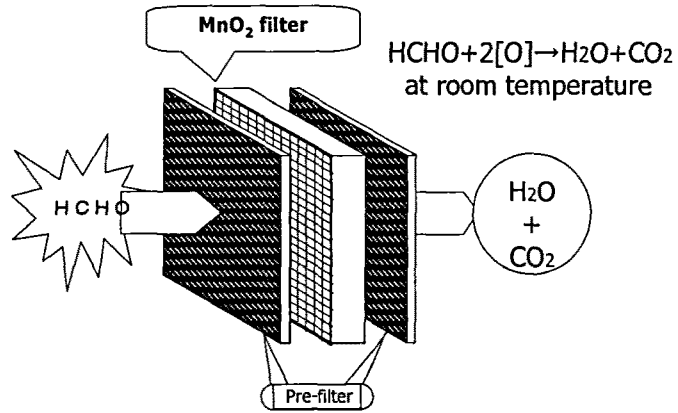


Paints

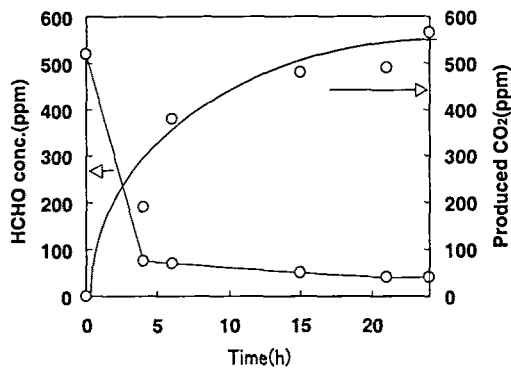


Air cleaning boards

HCHO decomposition

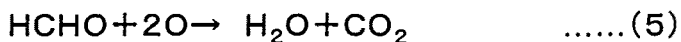
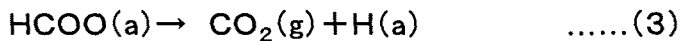
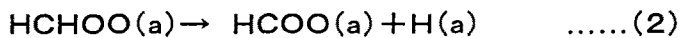


Manganese dioxide



(MnO₂: 10g, PTFE Bag: 100L, 21°C)

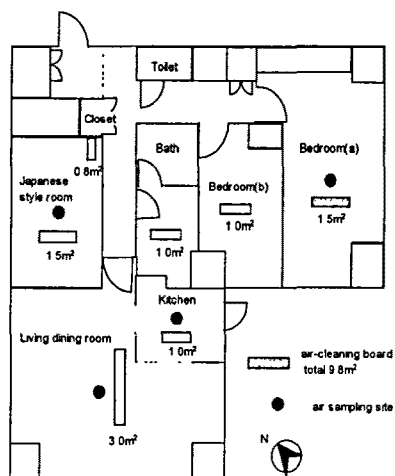
Possible pathways



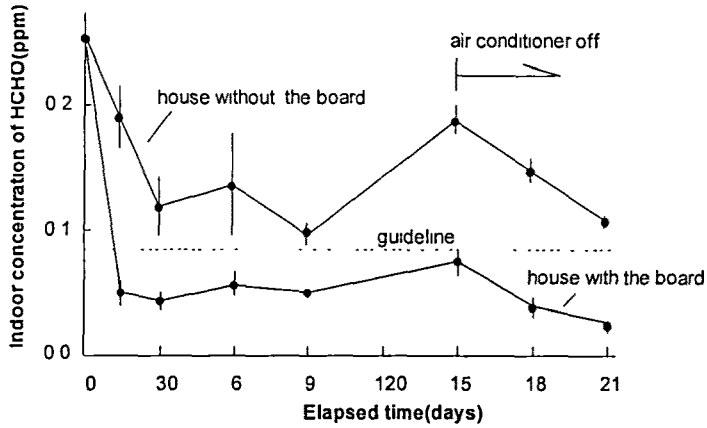
(g): gaseous, (a): adsorption on MnO_2

Field tests

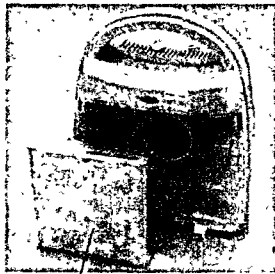
- Air-cleaning board
- Newly built and unoccupied apartment houses
- 3LDK(230m³)
- N=0.15/h
- May – Nov., 1998



Variation of HCHO concentration



Application to air cleaner



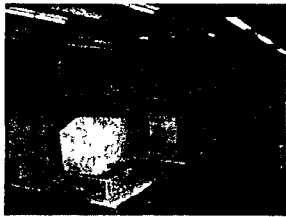
Honey-comb filter

Removal rate of HCHO

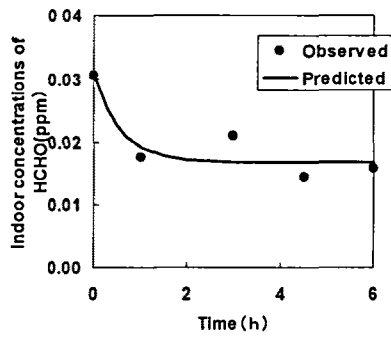
Q (m ³ /h)	SV (1/h)	P (-)	S (-)	Q' (m ³ /h)
180	30612	0.91	0.7	115
240	40816	0.89	0.7	150
300	51020	0.87	0.7	183

Q flow rate of air cleaner (m³/h)
 SV space velocity, Q/Volume of the filter, (1/h)
 P removal efficiency at given SV, one-pass tests (-)
 S circulation loss factor (-)
 Q' removal rate of the air cleaner, QPS (m³/h)

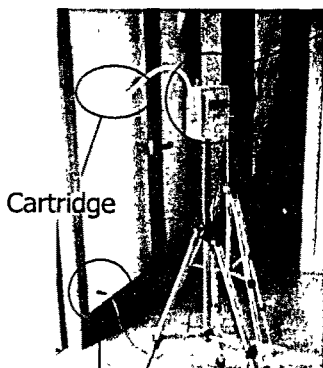
Field tests at school classroom



High school classroom for
IT education
(416m³, N=0.95/h)

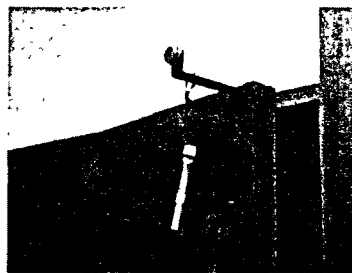


Sampling of air pollutants



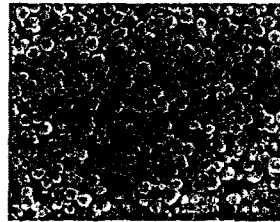
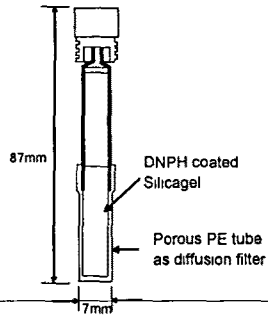
Power supply

Air pump

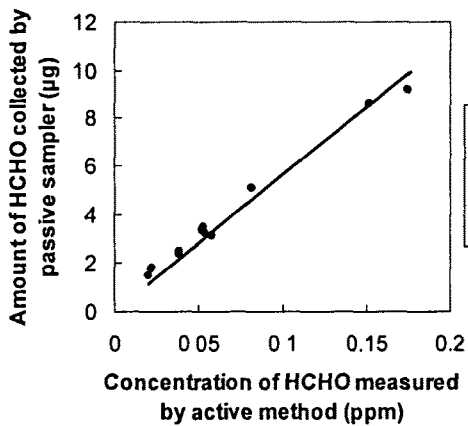
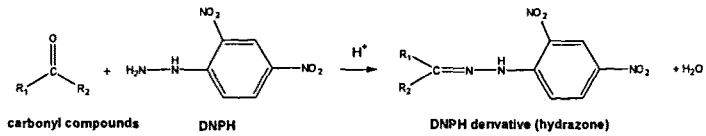


Passive sampler

Passive sampler for HCHO



SEM image of the diffusion filter



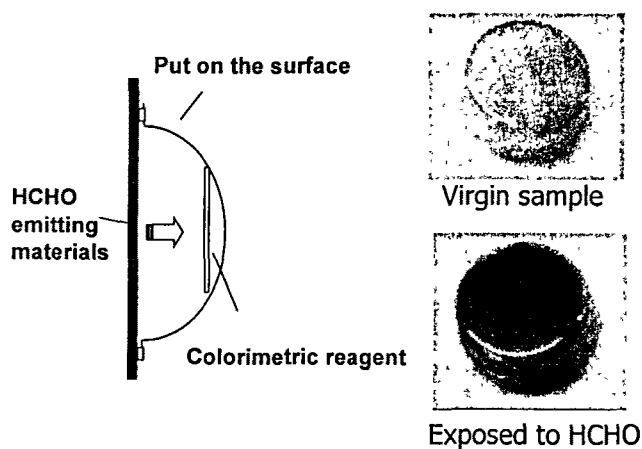
$$C(\text{ppm}) = \frac{W(\mu\text{g})}{\alpha \cdot t(\text{h})}$$

C: conc. of HCHO (ppm)
W: collected amount of HCHO(µg)
t : exposure time(h)
α : sampling rate

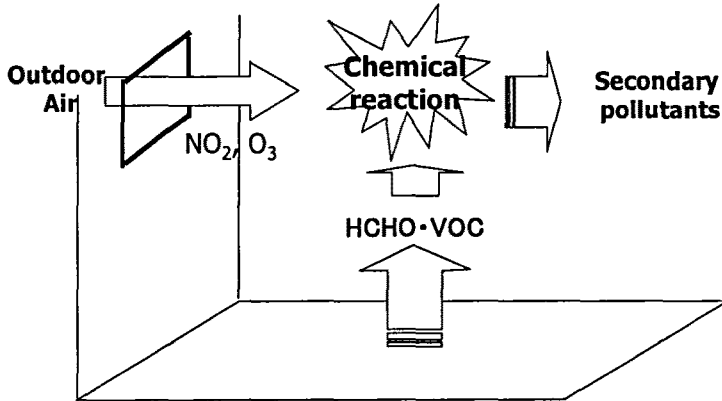
Sampling performance

- ◆ Sampling rate: 89ml/min
 - ◆ No influence of temp., R.H. and wind speed under indoor environment
 - ◆ Detection limit :0.31ppb of HCHO (24h)
 - ◆ Reproducibility: 4.5% for 50ppb
 - ◆ Passive sampler for VOCs
- Practically used for IAQ monitoring

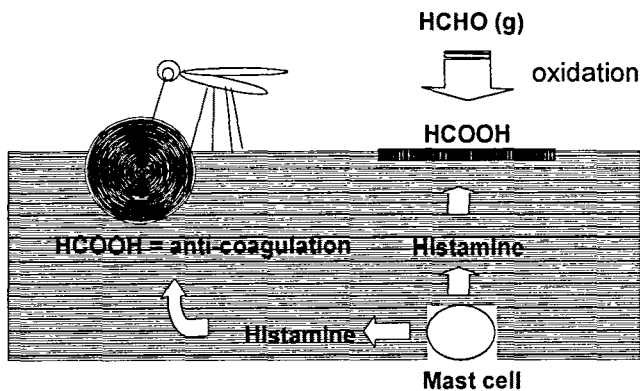
Colorimetric detection of HCHO



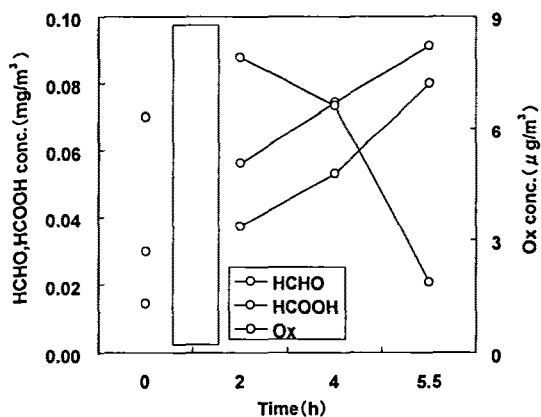
Indoor Chemical Reaction



Formic acid as suspect



Formation of HCOOH



monitoring at detached house (May, 2001)

Collaborate and solve
common environmental
problems