— Review —

# A Review of Indoor Air Pollution and Health Problems from the Viewpoint of Environmental Hygiene: Focusing on the Studies of Indoor Air Environment in Japan Compared to Those of Foreign Countries

**Koichi Harada,*, [a] Asako Hasegawa,[b] Chan-Nian Wei,[c] Keiko Minamoto,[c] Yukari Noguchi,[d] Kunio Hara,[e] Osamu Matsushita,[f] Kosuke Noda,[g] and Atsushi Ueda[c]**

*[a]Department of Biomedical Laboratory Sciences, Faculty of Life Sciences, Kumamoto University, 4–24–1 Kuhonji, Kumamoto 862–0976, Japan, [b]Graduate School of Science and Technology, Kumamoto University, 39–1 Kurokami 2-chome, Kumamoto 860–8555, Japan, [c]Department of Prevention and Environmental Medicine, Faculty of Life Sciences, Kumamoto University, 1–1–1 Honjo, Kumamoto 860–8556, Japan, [d]Department of Health Sciences, Faculty of Medical Sciences, Kyushu University, 3–1–1 Maidashi, Higashi-ku, Fukuoka 812–8582, Japan, [e]Faculty of Regional Health Therapy, Teikyo Heisei University, 4–1 Uruidominami, Ichihara 290–0193, Japan, [f]Department of Public Policy, Graduate School of Law, Kumamoto University, 40–1 Kurokami 2-chome, Kumamoto 860–8555, Japan and [g]Innovation Promotion Office, Kumamoto Software Co. Ltd., 2081 Taharu, Mashiki-cho, Kamimashiki-gun, Kumamoto 861–2202, Japan*

(Received May 29, 2010)

Excessive indoor air pollution can cause sick building syndrome (SBS), cases of which still occur in Japanese homes despite strict regulations on the value of indoor chemical substances established by the Ministry of Health Labour and Welfare. Idiopathic environmental intolerance (IEI), so-called multi-chemical sensitivity (MCS) has become another issue because it is caused by an extreme low concentration of chemical substances. These problems are discussed from the viewpoint of environmental hygiene in the present study. First, indoor air quality and its adverse effect on health is reviewed according to the history of sick buildings. Next, the factors concerning indoor air quality are indicated, and then measures to combat these problems are considered to improve the indoor environment. No ideal solution has been found: however, we summarize important knowledge on research to regain patient health as a result SBS and MCS.

**Key words** —— sick building syndrome, indoor air quality, volatile organic compounds, sick house syndrome, multi-chemical sensitivity, health

## INTRODUCTION

Indoor air pollution by chemicals and its adverse effect on human health are a global subject of public concern. Much attention has focused on sick building syndrome (SBS), chemical sensitivity (CS), and mycotoxicosis.[1)] In Japan, these issues were addressed by establishing guideline values for indoor formaldehyde concentration in 2000[2)] and the Ministry of Land Infrastructure and Transport amended the Building Standard Law in 2003 to control indoor chemical pollution.[3)] According to this law, architectural materials that emit a significant amount of formaldehyde must not be used and the air exchange rate must exceed $0.5\,h^{-1}$ consistently with a mechanical ventilation system. Historically, back-to-back houses were common in England in 19th century as the industrial revolution led to the rapid urbanization. Housing such as these back-to-backs and courtyards in Liverpool were typical in 1830 s. One third of the population in Liverpool lived in the cellars of these houses, which had dirt floors without ventilation and sanitation, and which led to a cholera epidemic.[4)] This indicates that factor occupants' health can be affected by poor environmental condition in buildings.

*To whom correspondence should be addressed: Department of Biomedical Laboratory Sciences, Faculty of Life Sciences, Kumamoto University, 4–24–1 Kuhonji, Kumamoto 862–0976, Japan. Tel. & Fax: +81-96-373-5462; E-mail: haradako@kumamoto-u.ac.jp

Overcrowded dwelling can cause health problems easily. Miura observed that the infectious incidence of tuberculosis was higher in houses with narrow rooms compared to wider rooms in 1950 s.[5] People living in metropolitan areas complained of narrowness of their houses in the 1960 s. At the time, airtight houses started to be built in urban area, and air pollution due to a lack of fresh air because of the low ventilation rate had been recognized.[6, 7] Higher airtight window frames were made from aluminum instead of iron or wood in those days.

Egyptian and Syrian forces launched coordinated attacks on Israeli forces in the Sinai and Golan Height in 1973. Known as the October war (called the Fourth Middle Eastern war in Japan), the conflict lasted until late October. This war had a great impact on international society. Energy crises were caused by the Organization of the Petroleum Exporting Countries (OPEC), who took oil as a strategic move against the war and restricted the global trade in oil export. This is still known as the Arab oil embargo.[8, 9] The idea of saving energy spread throughout in the world as a result of this incident. Architectural methods were also influenced, and the highly airtight construction method became common. Urea formaldehyde resin was introduced and utilized in the insulation material; however, Elinson discussed the scientific evidence on adverse effects of urea foam insulation on human health.[10] A report from World Health Organization (WHO) revealed that some people of new and remodeled buildings worldwide might be linked to symptoms of SBS, which is a combination of ailment associated with an individual's place of work or residence.[11]

In Japan, the environmental conditions of buildings with over 3000 $m^2$ floor area have been controlled to improve public health since 1970 by the "Act for Maintenance of Sanitation in Buildings"; however, small buildings and individual residences are not included, and the substances in indoor air and their concentrations from the 1970s to 2000 in Japan have been summarized by Arashidani *et al.*[12] Outdoor air pollution was also a serious issue from the 1960s to early 1970s in Japan. On this basis, the committee on sick house syndrome (SHS) by the Ministry of Health, Labour, and Welfare of Japan announced the guideline value of formaldehyde first and individual volatile organic compounds (VOCs).[13, 14]

In Japan, occupants of newly built residence, small buildings, schools, and cars, have reported SHS. The definition of SHS was proposed as "health impairments caused by indoor air pollution, regardless of the place, causative substance, or pathogenesis."[15] The health effect of air pollution in schools has been discussed in Japan.[16] The main cause is inefficient ventilation of tightly sealed rooms; however, the symptoms are similar between SBS and SHS. In Japan, SBS is named as SHS, because most patients complain of similar symptoms of SBS occurring in its early history in people living in houses. SBS is therefore here described as SHS. A pilot study revealed that VOCs and carbonyl compounds in Chinese indoor environments were influenced by factors inside the house, such as furniture and decoration.[17]

## SYMPTOMS OF SHS

Building-related symptoms are as follows: "tired or stained eyes," "dry, itching, or irritated eyes," "unusual tiredness, fatigue, or drowsiness," "headache," "tension, irritability, or nervousness," "pain or stiffness in the back, shoulders, or neck," "stuffy or runny nose, or sinus congestion, "sneezing," "sore or dry throat," "difficulty remembering things or with concentration," "cough," "dry or itchy skin," "feeling depressed," "dizziness or lightheadedness," "chest tightness," "nausea or upset stomach," "shortness of breath," and "wheezing" by the Building Assessment Survey Evaluation study.[18] These symptoms are almost identical to those of SBS.

The prevalence of symptoms is higher among individuals livening in poorly ventilated dwellings built in the 1990 s.[19, 20] It is difficult to confirm that SBS is identical to SHS, which is defined in Japan based on diseases related to habitation. The cause of the disease onset relates to a house, symptoms occur within the house, symptoms are less serious or disappear when the patient is away from the house, and when the patient enters the house, the symptoms always occur.[21] SHS is also classified into four types: type 1 (symptoms of chemical intoxication), type 2 (symptoms developed possibly due to chemical exposure), type 3 (symptoms developed not because of chemical exposure but rather because of psychological or mental factors) and type 4 (symptoms developed due to allergies).[22] Imai *et al.* identified the psychosocial aggravating factors of SHS.[23] The Japanese Society for Hygiene presented their opinion about "sick house syndrome" in 2005 in response to the controversy.[24]

## MULTI CHEMICAL SENSITIVITY

There is another ailment, known as multi-chemical sensitivity (MCS), which is a chronic medical condition characterized by symptoms that the affected person attributes to exposure to low levels of chemicals. A report indicated that the rate of school children with MCS-like symptoms, allergies, particularly to offensive odors, increased with age.[25] Consensus criteria were identified by researchers for the diagnosis and definition of MCS,[26] and were later revised in 1999. "The symptoms are reproducible with (repeated chemical) exposure." "The condition is chronic," "Low levels of exposure (lower than previously or commonly tolerated) result in manifestations of the syndrome." "The symptoms improve or resolve when exposure is removed." "Responses occur to multiple chemically unrelated substances." And "symptoms involve multiple organ systems."[27] In 1996 WHO/International Program on Chemical Safety (IPCS) Workshop suggested replacing MCS with the broader term "idiopathic environmental intolerances (IEI)," in order to incorporate "a number of disorders sharing similar symptomatologies."[28] In Japan, it is sometimes assumed that SHS and MCS as the same, because they have been confused by the media.[29] A systemic literature review was conducted to confirm and extend the U.S.A. case definition of MCS. The results showed a significant overlap of MCS, chronic fatigue syndrome (CFS) and fibromyalgie, and that no standard diagnostic procedure based on the pollution above had been established.[30] There are arguments against MCS truly depending on exposure to chemicals. When a chemical exposure test was performed as the most reliable test to diagnose MCS, some subjects showed no symptoms; furthermore, other subjects claimed symptoms before exposure to volatile organic compounds.[31] A systematic review of provocation studies concluded that individuals with MCS reacted to chemical challenges, suggesting that the mechanism of action is not specific to the chemical itself and might be related to expectations and prior beliefs.[32] It was reported that the quick environment exposure sensitivity inventory (QEESI©) was able to screen "patients suffering from a low level of environmental chemicals such as multiple chemical sensitivity (MCS) in Japan" from obscure subjects suffering from affective chemicals.[33]

## A POLLUTED ENVIRONMENT: CAUSE OF A SICK HOUSE

### Wet/Dampness/Humidity

Dampness can cause condensation, not only on the interior surface of the room but also inside walls. This phenomenon enables mold to grow, which is related to a pronounced increase of symptoms compatible with SHS.[34] An investigation in Japan revealed that higher humidity causes symptoms to increase.[29] Occupants of apartment buildings and condominiums with damp problems could have their health affected by microbial contamination.[35–37] On the other hand, physiological and psychological effects of low humidity and low air pressure in aircrafts have been reported, suggesting that special attention should be paid to low humidity in consideration of public health.[38] The relationship between moisture and temperature on skin and upper airway symptoms was investigated and showed that skin dryness and rashes, pharyngeal dryness, and nasal dryness and congestion are alleviated by higher humidity, and steam humidification results in a risk for increase perception of disorder and stuffiness.[39] The effect of building materials regulating indoor humidity on the indoor environment was studied to identify the influence on the psycho-physiologic condition of the occupants.[40]

### Temperature

The relationship between buildings-related symptoms and thermal metrics was investigated by U.S. Environmental Protection Agency (US-EPA).[41] The result suggested that a higher indoor temperature in winter was associated with an increase in most symptoms analyzed, and an indoor temperature of over 23 in summer, decreased most symptoms.[41]

### Particulate Matter

Particulate matter is suspended in the air in solid and liquid states. Previous investigations have noted that particles smaller than 2.5 μm (PM2.5) mainly contribute to an elevated death rate in polluted cites.[42, 43] The WHO published the "Air quality guidelines. Global update 2005. Particulate matter, ozone, nitrogen dioxide and sulfur dioxide."[44] The guideline for PM2.5 is 10 $\mu g/m^3$ annual mean in outdoors,[45] but the guideline remains under consideration.[46]

### Combustion Products

Air pollution due to combustion products can cause health problems. Carbon monoxide (CO), nitrogen dioxide ($NO_2$), and sulfur dioxide ($SO_2$) are common combustion gases in residences and buildings. CO is well-known to cause poisoning by CO-hemoglobin (Hb) formation, inhibiting oxygen utilization by internal organs. $NO_2$ sources in buildings include gas stoves, furnaces, fireplaces and kitchen devices,[47] and it is linked to asthma morbidity.[48] $NO_2$ emitted from biomass, wood, crop residues and animal dung has a significantly higher concentration in rural houses.[49] Direct vent-type heating and enclosed wood burners emit significantly lower levels of $NO_2$ in buildings than un-vented burning appliances.[50,51] Using kerosene space heaters with a diffuser fan,[51] the combustion of fuel for heating and power generation is considered the main source of $SO_2$ and particulate contamination, which damage human health.[52] Domestic sources of $SO_2$ are associated with the use of coal and other fuels for heating and cooking.[52]

### Biological Pollutants

Dander, mold, dust, and other organisms carried into by animals and people are biological air pollutants in buildings. Air pollutants are related to higher humidity due to flooding, bathroom or kitchen exhausts, air conditioning machines, and ventilation systems. SHS is sometimes related to microbial contamination of buildings.

### Mold/Fungi

Summer-type hypersensitivity pneumonitis is induced by exposure to *trichosporon cutaneum* as antigen for 2 months.[53] Regarding indoor airborne fungi, a patient with pulmonary aspergillus inhaled *Aspergillus fumigatus* mostly in the bedroom.[54] Saito *et al*. reported *chladospopriumew* and *uloaladium herbarum* associated with the residents' symptoms in newly built dwellings.[55] Mold damage can occur as a result of incorrect utility work,[56] in air conditioners,[57] and by using a heat exchange type of ventilator equipped with dehumidifier.[58] Indoor mold affects occupants' health and causes building-related symptoms.[59–61] Despite many reports on mold problems, no causal relationship between microbial contamination and health effects has been identified;[62] however, in the U.S.A., there are legal cases involving health problems caused by microbial contamination.[63]

### House Dust Mites

It is said that it is difficult for mites to exist at not only high but also low temperature. Household cloth dryer run at lethal temperature that will kill mites in 10 min.[64] It is also reported that indoor air is contaminated with house dust mite allergens in most Japanese dwellings.[65] *Dermatophagoides pteronyssiums*, and *Dermatophagoides farinae* are important allergens causing allergies in Japan.[66]

### Chemical Factors

VOCs are organic compounds that have high vapor pressure under normal conditions. VOCs are numerous and varied, and also harmful or toxic. Regarding indoor air pollution, the air concentration of some organic compounds is regulated. The WHO has proposed guideline value of organic compounds,[67] as has The Ministry of Health, Labor and Welfare in Japan.[68] The effect of volatile organic compounds, such as toluene, on fetuses and newborns has been discussed.[69] It was found that indoor air concentrations of 1-butanol, trichloroethylene, trimethylbenzene, and decane were significantly increased after the revision of the building standard law in 2003 in Japan.[70] The ratio of indoor (I) concentration to outdoor (O) concentration (I/O ratio) were higher than 1 for almost all organic compounds. The sources of indoor contamination were attributed to outdoor air pollution, such as automobile exhaust gas.[71] Semi-volatile organic compounds (SVOCs) with a high boiling point of 260–380°C are considered to vaporize poorly but are detected in not only indoor air but also in house dust. Phthalates and pesticides among the SVOCs are supposed to be associated with allergies or bronchial obstruction.[72] The individual chemicals are discussed below.

Formaldehyde is a flammable, colorless and readily polymerized gas at ambient temperature with the chemical formula of $CH_2O$ (systematic name: methanal), and is the simplest aldehyde.[73] It is classified as a probable human carcinogen.[73] Formaldehyde, and other organic substances have significantly higher indoor air concentrations in dwellings with SHS than in those without.[74,75] Various papers have been published related to indoor air quality in schools after renovation or when newly built. From the results, schoolrooms should be renovated early in the holidays, and VOCs should be allowed to volatize at least in part during the hot summer holidays.[76] Formaldehyde concentration often increases with summer temperature and

is positively correlated with indoor temperature.[77] The concentration of formaldehyde in newly built houses is higher than in the outdoor environment around houses, and the concentration in Japanese Tatami room is lower than that in other types of room.[77]

Toluene is an organic solvent with a typical smell of paint thinners and its chemical formula $C_7H_8$. It is widely used as raw material and as a solvent, and is the common name for methylbenzene. Its major metabolite, hippuric acid, is eliminated in urine.[78] Toluene and other chemicals, such as phenol, 2-ethylhexanol, formaldehyde, and styrene are so-called stealth chemicals emitted from old personal computers (PCs), and may influence indoor air quality.[79]

Xylene is aromatic hydrocarbon isomer which exists as ortho-, meta-, and para-isomers of dimethyl benzene, and is used as a solvent and in printing ink.[80]

Para-dichlorobenzene, 1,4-dichlorobenzene, is an organic compound with the chemical formula $C_6H_4Cl_2$, forms colorless to white crystals with a characteristic odor, and is toxic to aquatic organisms.[81] It is used as a pesticide in place of traditional naphthalene. Para-dichlorobenzene emitted from repellents is classified in the highest risk category and has a high I/O value.[82]

Ethyl benzene is an aromatic hydrocarbon with the chemical formula $C_6H_5CH_2CH_3$. At room temperature, it is a colorless liquid with a sweet gasoline-like odor.[83] It is reported that ethyl benzene is significantly related to eye symptoms.[84]

Styrene, ethenyl benzene, is an organic compound with the chemical formula $C_8H_8$, and is produced by dehydrogenation of ethyl benzene in a reaction with a catalyst.[85] Potential sources of exposure by the general population include motor vehicle exhaust, tobacco smoke, and other combustion.[85] Chemicals analysis was performed to determine the pollutants emitted by PCs serviced for 3 months and styrene was detected with phenol, toluene, 2-ethylhexanol and formaldehyde.[79] It is estimated that the indoor air concentration of styrene monomer residues from expanded polystyrene used as insulation would be 10.1 $\mu g/m^3$.[86] Exposure to low-dose styrene results in physical and neurobehavioral development delays, as well as decreased enzyme activity and neurotransmitter secretion level.[87]

Chlorpyrifos forms colorless to white crystals with a characteristic odor, and inhibits acetyl cholinesterase to control insect pests. It has the chemical formula $C_9H_{11}Cl_3NO_3PS$,[81] and may have effects on the nervous system, resulting in convulsion and respiratory depression.[81] Children exposed to prenatal to chlorpyrifos are significantly more likely to score in the clinical range for attention problems, attention-deficit/hyperactivity disorder (ADHD) problems, and pervasive developmental disorder (PDD) problems at age 3.[88] Metabolites of chlorpyrifos were higher in children living on farm where chlorpyrifos was applied than in those where it was not applied prior to urine sampling.[89] Chlorpyrifos concentration in polished rice reflected its concentration in the air of a residence treated by termicide application.[90] Chrolpyrifos was detected in household dust from houses treated with an insecticide.[91]

Di-*n*-butyl phthalate (DBP, DnBP), is soluble in most organic solvents, *e.g.* in alcohol, ether and benzene, but is only slightly soluble in water.[92] DBP is a commonly used plasticizer for nitrocellulose, polyvinyl acetate and polyvinyl chloride, and so on.[92] DBP and di-2-ethylhexyl phthalate (DEHP) among phthalates were detected predominantly in indoor air samples.[93] The dominant path of phthalates intake was the ingestion of foodstuffs compared to inhalation of indoor air by children.[94]

*n*-Tetradecane is an alkane with the chemical formula $C_{14}H_{30}$,[95] is found in vinyl flooring together with *n*-pentadecane and phenol.[96]

DEHP is an organic compound with the chemical formula $C_{24}H_{38}O_2$, and is a benzene dicarboxylic acid ester, which at room temperature is a colorless to yellow oily liquid.[97] DEHP, polycyclic aromatic hydrocarbons (PAHs) and lead via house dust ingestion by children are considered to affect their health.[98] The maximum estimated tolerance daily intake (TDI) is 40–140 g/kg per day for pregnant women in Japan, set by the Ministry of Health and Welfare.[99] These phthalates, within the range of what is normally found in indoor environments, are associated with allergies in children.[100]

Diaginon is a colorless to dark brown liquid with the chemical formula $C1_2H_{21}N_2O_3PS$, and is a contact organ phosphorus insecticide with a wide range of insecticide activity; it does not occur as a natural product.[101] A study reported the potential for pet dogs to be an important pathway for transporting diazinon residue into homes and onto its occupants following residential lawn applications.[102]

Nonanal is an alkyl aldehyde with chemical formula $C_9H_{18}O$, a colorless to light yellow liquid

with a strong fatty order.[81] The concentration of nonanal was higher in western- than Japanese-style room.[103]

Acetaldehyde is a colorless, volatile liquid with a pungent suffocating odor. The threshold is 0.09 mg/m$^3$. It is a highly flammable and reactive compound that is miscible in water and one of the most common solvents, with the chemical formula $C_2H_4O$.[104] It occurs naturally in ripe fruit, coffee, and bread, and is produced by plants as part of their normal metabolism.[104] It is said that acetaldehyde from refrigerator may cause an indoor air pollutant.[105]

Fenobucarb is one of carbamate pesticides and is used as an agricultural insecticide by disturbing activity of acetylcoline-esterase.[106] It is classified as "Moderately hazardous (class II) technical grade active ingredients in pesticides continued" by IPCS.[107] Kubota *et al*. reported that fenobucarb showed a delayed action even in the 21-day exposure test.[108]

Total volatile organic compounds (TVOCs) refers to total concentrations of multiple indoor air pollutants. It is used as a complementary indicator to decrease indoor pollution level in total and achieve healthy indoor air environment.[109] The indoor air concentration of TVOCs reached to equilibrium in three hours in a regular dwelling with full-time ventilation.[110]

**2-ethyl-1-hexanol**

2-ethyl-1-hexanol is thought to be an indicator of alkaline degradation of a plasticizer, DEHP, in polyvinyl chloride (PVC) floor material on concrete floor constructions.[111, 112] It was found to be one of the predominant volatile organic compounds in the indoor air of large-scale buildings.[113] Some studies have shown that 2-ethyl-1-hexanol caused acute symptoms in susceptible individuals at a concentration range of 408 μg/m$^3$ [114] and could be a possible causative chemical for SBS.[115] 4-Heptanone is a major DEHP metabolite in humans through 2-ethyl-1-hexanol in haemodialysis patients.[116]

**Nano-particles and Nano-materials**

The health effects of nano-particles and nano-materials have been reviewed.[117–121] Nano-materials are divided into two types: environmental nano-particles emitted from automobiles, and manufactured nano-particles, such as fullerenes, carbon nano-tubes, and ultra-fine metals/metal oxides.[117] Methods for measuring nano-particles have been reported on the basis of number, surface area, or mass.[118] General nano-particles (< 100 nm) are supposed to be permeable through the cell membrane and tissues, and may cause health effect.[119] Carbon nano-tubes aggregates, a type of nano-particle, might be correlated with asthma incidence;[121] however, there are contradictory reports on the health effects of these particles.[119]

**Heavy Metal/Lead**

Although the lead concentration in indoor air is lower in Japan than in other developed countries, the source of lead contamination in dwellings is controversial.[122, 123] A paper has indicated that lead in house dust and playground soil deserves attention when considering lead exposure in children in Japan.[124]

**Odor**

The application of semiconductor-based odor sensors can evaluate indoor air quality by measuring formaldehyde and VOCs levels in low concentrations in residential spaces.[125] A moldy order is considered one of the dampness indictors related to sick buildings.[126] Certain odors may result in psychological effects and a lack of concentration. Some building materials continually cause perceivable odors because their odor thresholds are low.[127]

**Gas/Radon**

Radon is a chemically inert, naturally occurring radioactive gas that has no smell, color or taste.[128] Radon enters homes through cracks in concrete floor-wall junctions, gaps in the floor, small pores in hollow-block walls, and sumps and drain.[128] Radon-induced lung cancers are mainly caused by low and moderate rather than indoor radon in homes at such low concentrations.[128] Many houses in Hokkaido, in the northern part of Japan, are built airtight and equipped with basements to conserve heating energy. As a result, the concentration of radon and its metabolites is increased in concrete single-family homes.[129]

**Light**

Blue light from light emitting diode (LED) is supposed to suppress melatonin secretion, which affects the circadian rhythm.[130] Koyama proposed that light exposure during night might cause asynchronization, and recommended a morning-based lifestyle as a way to reduce behavioral/emotional problems, and to lessen the likelihood of falling into

asynchronization.[131)]

### Living Style

Nakayama and Morimoto revealed the risk factors of lifestyle on symptoms of sick building syndrome, and suggested that modification of life style can alleviate symptoms.[132)] Furniture and electrical appliances in each room of Japanese residences was surveyed to identify information about indoor air pollution.[133)] Allergen-avoidance daycare centers used daily floor cleaning, weekly furniture wiping, and washing of pillows, mattresses, and curtains to improve have environments.[134)]

## ANALYTICAL METHODS

The committee on SHS supported by Japanese Ministry of Health, Labour and Welfare released a progress report describing, "Indoor air pollutants subject to the analysis." This report includes sampling and analytical methods. Sampling and analysis procedures for formaldehyde involve the collection of air into cartridges coated with 2,4-dinitrophenylhydrazine (DNPH) and subsequent analysis by high performance/pressure liquid chromatography (HPLC) with detection by ultraviolet absorption. Sampling and analysis procedures for VOCs involve the collection of air into sorbent tubes or stainless sampler (canister) and subsequent analysis by gas chromatography with mass spectrometer.[109)]

## MEASURE FOR THE POLLUTION

### Ventilation

Ventilation is an effective method to reduce the concentration of pollutants in indoor air.[135)] A ventilation system including a dielectric barrier discharger (DBD) and UV-photo catalyst (UVP) filters effectively decreased the concentration of VOCs, such as benzene, toluene, and xylene.[136)] Day nurseries in Japan that take care of preschool children for a long time need to maintain good-quality indoor air by ventilation.[137)] Appropriate air ventilation in facilities such as Internet Cafes is also needed as part of a tuberculosis control program in metropolitan areas.[138)]

### Bake-out Method

The bake-out method could allow VOCs to escape from building materials at an early stage, by keeping the entire room heated as at 30°C or higher for several consecutive days, and subsequently ventilating the room to accelerate VOCs emission.[139)] Intermittent bake-out using air conditioner is thought to be a practical process for reducing indoor air pollution.[140)] A filter system with an air cleaner effectively decreased airborne microbes compared to a system using ion emission.[141)] It has been found that VOCs can be adsorbed by charcoal carbonized at temperature exceeding 600°C.[142)] A paper has reported that running air conditioners at 40 for 10 min per a day by operating the air conditioner in heating mode effectively regulated fungal contamination.[143)]

### Titanium Dioxide

A study reported the potential of water photolysis using a titanium dioxide ($TiO_2$) electrode by radiation with ultra-visible light.[144)] $TiO_2$-based photocatalytic compounds[145–148)] or incorporated into cementitious materials[149)] are thought to decompose air pollutants, such as organic compounds. $TiO_2$ has been developed and used as a photocatalyst for indoor and outdoor air purification and to purify water contaminated with low concentrations of toxic pollutants.[150)]

## JAPANESE REGULATIONS ON FORMALDEHYDE EMISSION FROM ARCHITECTURAL MATERIALS

In 2003, the Ministry of Land, Infrastructure and Transport of Japan amended the Building Standard Law to control indoor chemical concentrations. This regulation restricts the use of formaldehyde-emitting materials and requires the installation of mechanical ventilation to keep the air exchange rate over 0.5 times per hour. The Building Standard Law is applied to all buildings, and must be followed by architects. Simultaneously, a new standard was added to the Japanese Industrial Standard (JIS) that the method of measuring the chemical emission rate from architectural materials should be divided 4 grades.[151)] The best grade is $F^{****}$ and the lowest is $F^{*}$. According to the Building Standard Law, $F^{*}$ material cannot be used as interior material, but $F^{****}$ can be used freely. Recently, $F^{*}$ material disappeared from the Japanese market and the infection rate of SHS in newly built residences has fallen significantly compared to before these amendments;

however, prior to the installation of new furniture in new residences, chemical substances emitted from old furniture might affect the health of residents. The regulation of chemical emission from furniture and the education of residents are required.

## COMMUNICATION BETWEEN MEDICAL INSTITUTIONS AND REGIONAL HEALTH CENTERS

The Ministry of Health, Labour and Welfare in Japan disseminated knowledge about anti-SHS measure to medical institutions. The ministry has designated SHS as a disease that can be claimed under medical insurance at the request of medical institutions. When medical institutions run by prefectures or designated cities plan to build clean rooms to diagnose and consult with patients, they will receive one third of the budget from a national subsidy. The Ministry also included CS as a disease that can be claimed under medical insurance at the request of medical institutions in 2009.

Most regional health centers had staff members who can assess the indoor environment, but their ability to discuss on health-related issues is limited; therefore, establishment of a hub regional health is recommended for a comprehensive consultation and referral system that can meet local needs in dealing with SHS.[152)]

## CONCLUSION

Healthy indoor air is a fundamental right for people studying in schools, working in offices and living in residences. Indoor air quality plays an important role in the health of residents. Many factors are associated with polluted indoor air and cause health problems, including SHS, SBS, or MCS; however, these problems are not understood well in our society. The task of the authors is to encourage not only the public, but also the medical specialist, such as medical doctors, nurses, and architectural engineers, to acknowledge these problems. The review addresses health issue due to inferior indoor air quality from the viewpoint of environmental hygiene, but it is not sufficient. Continuous efforts should be made to improve the health of both of the individuals and the public.

## REFERENCES


1) Chang, C. and Gershwin, M. E. (2004) Indoor air quality and human health: truth vs mass hysteria. *Clin. Rev. Allergy Immunol.*, **27**, 219–239.
2) The Ministry of Health Labour and Welfare, The guideline value of indoor formaldehyde concentration report of chemical substances small committee, specialty section to establish standards for health residences, http://www1.mhlw.go.jp/houdou/1206/h0629-2_13.html, (cited 19 May, 2010).
3) The Ministry of land, Infrastructure and Transport in Japan, The amendments of Building Standard Law, http://www.mlit.go.jp/jutakukentiku/build/sickhouse.html, (cited 19 May, 2010).
4) Ashton, J. R. (2006) Back-to-Back housing, courts, and privies: the slums of 19th century England. *J. Epidemiol. Community Health*, **60**, 654.
5) Miura, U. (1957) *JYUKYO TO EISEI*, Kouseikan, Tokyo, pp. 1–8 (in Japanese).
6) Miura, T. (1981) *SEIKATSU NO EISEIGAKU*, Roudoukagakukenkyusho, Tokyo, pp. 142–147 (in Japanese).
7) Miura, T. (1993) *KAITEKIKANKYOU NO FOHKUROA—SIZEN TO JINKOUKANKYOU—*, Roudoukagakukenkyusho, Tokyo, pp. 279–307 (in Japanese).
8) The Asahi Shinbun Company (1999) "SEKIYU-KIKI" NI ABURIDASARETA HIYOWANA NIPPON. *Asahi Chronicle/Weekly the 20th Century*, **31**, 2–6 (in Japanese).
9) U.S. Department of State, Second Arab Oil Embargo, 1973–1974, http://www.state.gov/r/pa/ho/time/dr/96057.htm, (cited 13 February, 2010).
10) Elinson, L. (1984) Health policy and epidemiology: The scientific evidence for a ban of urea-formaldehyde foam insulation. *J. Public Health Policy*, **5**, 513–537.
11) World Health Organization (1983) Indoor air pollutants; Exposure and Health Effects Assessments. Working Group Report, Nordlingen, *Euro Reports and Studies*, **78**, 1–42.
12) Arashidani, K., Akiyama, Y. and Kunugita, N. (2009) Study of Indoor Air Pollution. *Indoor Environ.*, **12**, 71–86 (in Japanese).
13) Irie, T. (2007) Historical review on the indoor environment and health. *Indoor Environ.*, **10**, 129–135 (in Japanese).
14) Committee on sick house syndrome, Indoor air pollution progress report No. 4, http://www.nihs.go.jp/mhlw/chemical/situnai/kentoukai/rep-eng4.html, (cited 20 February, 2010).
15) Seki, A., Takigawa, T., Kishi, R., Sakabe, K.,

Torii, S., Tanaka, M., Tanaka, M., Yoshimura, T., Morimoto, K., Katoh, T., Kira, S. and Aizawa, Y. (2007) Review of Sick House Syndrome. *Jpn. J. Hyg.*, **62**, 939–948 (in Japanese).
16) Ichiba, M., Takahashi, T., Yamashita, Z., Takaishi, K., Nishimura, K., Kamachi, M., Kondoh, T., Matsumoto, A., Ueno, D. and Miyajima, T. (2009) Approach to Sick Building Problem in Schools: A Workshop "Saga Forum on environment" project. *Jpn. J. Hyg.*, **64**, 26–31 (in Japanese).
17) Ni, Y., Kumagai, K., Yoshinaga, J., Yoshino, H., Shinohara, N. and Yanagisawa, Y. (2007) A pilot study on VOCs and carbonyl compounds in Chinese residences. *Indoor Environ.*, **19**, 61–73 (in Japanese).
18) Brightman, H. S., Milton, D. K., Wypij, D., Burge, H. S. and Spengler, J. D. (2008) Evaluating building-related symptoms using the US EPA BASE study results. *Indoor Air*, **18**, 335–345.
19) Yoshida, T., Matsunaga, I., Oda, H., Miyake, Y., Sasaki, S., Ohya, Y., Miyamoto, S. and Hirota, Y. (2007) Residential air pollution by chemicals (HCHO, $NO_2$, VOC and SVOC) under normal living conditions in Osaka prefecture. *Indoor Environ.*, **9**, 83–85 (in Japanese).
20) Azuma, M., Niiya, M., Morita, Y. and Hikita, Y. (2000) Survey on the symptoms of illness possibly related to chemical substances in living environments. *Indoor Environ.*, **3**, 23–33 (in Japanese).
21) Torii, S., Hirayama, K., Akiyama, K., Ikezawa, Z., Uchino, E., Okamoto, Y., Ogura, H., Takahashi, K., Nishima, S. and Torii, S. (2006) Trial of isolation of sick house syndrome and unclassified multiple chemical sensitivities—Definition of sick house syndrome, and symptoms. *Arerugi*, **55**, 1515–1530 (in Japanese).
22) Ishibashi, M., Tonori, H., Miki, T., Miyajima, E., Kudo, Y., Tsunoda, M., Sakabe, K. and Aizawa, Y. (2007) Classification of patients complaining of sick house syndrome and/or multiple chemical sensitivity. *Tohoku J. Exp. Med.*, **211**, 223–233.
23) Imai, N., Imai, Y. and Kido, Y. (2008) Psychosocial Factors that aggravate the symptoms of sick house syndrome in Japan. *Nurs. Health Sci.*, **10**, 101–109.
24) Aizawa, K. (2005) An Opinion against Sick House Syndrome. *Jpn. J. Hyg.*, **60**, preface (in Japanese).
25) Sugita, O., Nakagawa, I., Nigorikawa, A., Soda, K., Murooka, K. and Sakamoto, C. (2007) Questionnaire survey on multiple chemical sensitivity-like symptoms in schoolchildren (6–12 years of age). *Indoor Environ.*, **10**, 137–145 (in Japanese).
26) Nethercott, J. R., Linda Lee Davidff, L. L. and Barbara Currow, B. (1993) Multiple Chemical Sensitivities Syndrome: Toward a working Case Definition. *Arch. Environ. Health*, **48**, 19–26.
27) 1999 Consensus on Multiple Chemical Sensitivity (1999) Multiple Chemical Sensitivity: A 1999 Consensus. *Arch. Environ. Health*, **54**, 147–149.
28) Anonymous (1997) Report of a multiple chemical sensitivities (MCS) workshop: International Program on Chemical Safety (IPCS)/German Workshop on Multiple Chemical Sensitivities, Berlin, Germany, 21–23 February 1996. *Int. Arch. Occup. Environ. Health*, **69**, 224–226.
29) Kishi, R., Takeda, M., Kanazawa, H. and Araki, A. (2008) Sikkuhausu-shoukougunn no ekigaku—saikinn no tikenn—, *Nippon Iji Shinpo*, **4370**, 73–76 (in Japanese).
30) Lacour, M., Zunder, T., Schmidtke, K., Vaith, P. and Scheidt, C. (2005) Multiple Chemical Sensitivity Syndrome (MCS)—suggestions for an extension of the US MCS-case definition. *Int. J. Hyg. Environ. Health*, **208**, 141–151.
31) Hasegawa, M., Ohtomo, M., Mizuki, M. and Akiyama, K. (2009) Diagnosis of multiple chemical sensitivity by chemical compounds exposure tests. *Arerugi*, **58**, 112–118 (in Japanese).
32) Das-Munshi, J., James Rubin, G. J. and Wessely, S. (2006) Multiple Chemical Sensitivities: A systematic review of provocation studies, *J. Allergy Clin. Immunol.*, **118**, 1257–1264.
33) Hojo, S., Sakabe, K., Ishikawa, S., Miyata, M. and Kumano, H. (2009) Evaluation of subjective symptoms of Japanese patients with multiple chemical sensitivity using QEESI©. *Environ. Health Prev. Med.*, **14**, 267–275.
34) Engvall, K., Norrby, C. and Norback, D. (2001) Sick building syndrome in relation to building dampness in multi-family residential building in Stockholm. *Int. Arch. Occup. Environ. Health*, **74**, 270–278.
35) Saijo, Y., Nakagi, Y., Ito, T., Sugioka, Y., Endo, H. and Yoshida, Y. (2009) Relation of dampness to sick building syndrome in Japanese public apartment houses. *Environ. Health Prev. Med.*, **14**, 26–35.
36) Saijo, Y., Kishi, K., Sata, F., Katakura, F., Urashima, Y., Hatakeyama, A., Kobayashi, S., Jin, K., Kurahashi, N., Kondo, T., Gong, Y. Y. and Umemura, T. (2004) Symptoms in relation to chemicals and dampness in newly built dwellings. *Int. Arch. Occup. Environ. Health*, **77**, 461–470.
37) Saijo, Y., Yoshida, T. and Kishi, R. (2009) Dampness, Biological Factors and Sick House Syndrome. *Jpn. J. Hyg.*, **64**, 665–671 (in Japanese).
38) Maehara, N., Watanabe, A. and Kurosawa, S. (1991) Physiological and Psychological Effects of Low Humidity and Low Air Pressure Environment in Pas-

senger Aircrafts. *J. Sci. Labour*, **67**, 1275–1292 (in Japanese).
39) Reinikainen, L. M. and Jaakkola, J. J. (2003) Significance of humidity and temperature on skin and upper airway symptoms. *Indoor Air*, **13**, 344–352.
40) Ogawa, H., Nakamura, M., Shibahara, K., Nishigaki, Y., Itou, K., Naruse, T., Fujimaki, G., Matsui, E., Orii, K. and Kondo, N. (2009) Study on effect of building materials to regulate an indoor humidity on indoor environment and psychophysiologic conditions. *Indoor Environ.*, **12**, 125–131 (in Japanese).
41) Mendell, M. J. and Mirer, A. G. (2009) Indoor thermal factors and symptoms in office workers: findings from the US EPA BASE study. *Indoor Air*, **19**, 291–302.
42) Davis, M. L. and Cornwell, D. A. (1998) *Introduction to Environmental Engineering*, 2nd Ed., WCB/McGraw-Hill, Boston, pp. 459–549.
43) Jimenez, E., Linares, C., Rodriguez, L. F., Bleda, M. J. and Diaz, J. (2009) Short-term impact of particulate matter (PM2.5) on dairy mortality among the over-75 age group in Madrid (Spain). *Sci. Total Environ.*, **407**, 5486–5492.
44) World Health Organization, Air quality guidelines global update 2005, Particulate matter, Ozone, nitrogen dioxide and sulfur dioxide, http://www.euro.who.int/_data/assets/pdf_file/0005/78638/E90038.pdf, (cited 3 July, 2010).
45) World Health Organization, WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide, global update 2005, Summary of risk assessment, http://whqlibdoc.who.int/hq/2006/WHO_SDE_PHE_OEH_06.02_eng.pdf, (cited 7 July, 2010).
46) World Health Organization, Development of WHO guidelines for indoor air quality, Report on a working group meeting, Bonn, Germany, 23–24 October 2006, http://www.euro.who.int/_data/assets/pdf_file/0007/78613/AIQIAQ_mtgrep_Bonn_Oct06.pdf, (cited 3 July, 2010).
47) Okudaira, J. and Tanaka, T. (2005) Behavior of nitrogen dioxide in the indoor environment. *Indoor Environ.*, **8**, 27–34 (in Japanese).
48) Diette, G. B., McCormack, M. C., Hansel, N, N., Breysse, P. N. and Matsui, E. C. (2008) Environmental Issues in Managing asthma. *Respir. Care*, **53**, 602–617.
49) Kumie, A., Emmelin, A., Wahlberg, S., Berhane, Y., Ali, A., Mekonnen, E. and Brandstrom, D. (2009) Magnitude of indoor $NO_2$ from biomass fuel in rural settings of Ethiopia. *Indoor Air*, **19**, 14–21.
50) Gillespie-Bennet, J., Pierse, N., Wickens, K., Crane, J., Nicholls, S., Shields, D., Boulic, M., Viggers, H., Baker, M., Woodward, A. and Howden-Chapman, P. (2008) Sources of nitrogen dioxide ($NO_2$) in New Zealand homes: findings from a community randomized controlled trial of heater substitutions. *Indoor Air*, **28**, 521–528.
51) Matsumura, T., Osada, E. and Ando, M. (1998) Measurement results of personal exposure levels of nitrogen dioxide and formaldehyde. *Indoor Environ.*, **1**, 19–26 (in Japanese).
52) International Program on Chemical Safety (IPCS) (1979) Sulfur oxides and suspended particulate matter. *Environmental Health Criteria 8*, World Health Organization, Geneva.
53) Amemiya, Y., Shirai, R., Ando, S., Fujii, H., Iwata, A., Kai, N., Otani, S., Umeki, K., Ishii, H. and Kadota, J. (2008) Familial summer-type hypersensitivity pneumonitis in a husband and his wife. *Arerugi*, **57**, 1182–1187 (in Japanese).
54) Kawakami, Y. and Takahashi, Y. (2007) Indoor airborne fungi in the house of a patient with pulmonary aspergillosis. *Indoor Environ.*, **10**, 155–162 (in Japanese).
55) Saito, Y., Sata, F., Mizuno, S., Yamaguchi, K., Sunagawa, H. and Kishi, R. (2005) Indoor Airborne Mold Spores in Newly Built Dwellings. *Environ. Health Prev. Med.*, **10**, 157–161.
56) Nishiguchi, T., Kawakami, Y. and Miyaoka, T. (2009) Damage case by fungi caused because of wrong utility work, and about the trial afterwards. *Indoor Environ.*, **12**, 13–24 (in Japanese).
57) Abe, K. (1998) Fungal Index and Contamination in Air Conditioners when cooled. *Indoor Environ.*, **1**, 41–50 (in Japanese).
58) Yamashita, N., Matsumoto, Y. and Abe, K. (2009) Inhibitive Effect for Mold Growth Inside of the Room using a Heat Exchange Type of Ventilator Equipped with Dehumidification Function. *Indoor Environ.*, **12**, 143–150 (in Japanese).
59) Yanagi, U. (2008) Healthy influence and the regulations on mold. *Indoor Environ.*, **11**, 111–116 (in Japanese).
60) Kawakami, Y. (2006) An outbreak of *Aspergillus ochraceus* Wilhelm in a House in Yokohama, Kanagawa Prefecture. *Indoor Environ.*, **9**, 37–43 (in Japanese).
61) Yamasaki, Y., Wang, B., Sakano, N., Wang, D. and Takigawa, T. (2006) Relationship between indoor air pollutants and living environment and subjective symptoms. *Indoor Environ.*, **9**, 25–36 (in Japanese).
62) Hardin, B. D., Kelman, B. J. and Saxon, A. (2003) Adverse human health effects associated with molds in the indoor environment: American College of Oc-

cupational and Environmental Medicine (ACOEM) evidence-based statement. *J. Occup. Environ. Med.*, **45**, 470–478.
63) Shimizu, S. (2007) Introduction to mold in American buildings. *Indoor Environ.*, **11**, 167–168 (in Japanese).
64) Miller, J. D. and Miller, A. (1996) Ten minutes in a clothes dryer kills all mites in blankets. *J. Allergy Clin. Immunol.*, **97**, 423.
65) Takeda, S., Mori, Y., Inada, T., Sato, Y. and Itagaki, K. (2008) The measurement of house dust mite allergen by several tools for determination and the comparison of their value. *Indoor Environ.*, **11**, 1–9 (in Japanese).
66) Fukutomi, Y., Yasuda, H., Nakazawa, T., Taniguchi, M. and Akiyama, K. (2009) Indoor Mite and Insect Allergens and Allergic Disease. *Indoor Environ.*, **12**, 87–96 (in Japanese).
67) World Health Organization, Air quality and health; WHO air quality guidelines for Europe, 2nd Ed., http://www.euro.who.int/_data/assets/pdf_file/0005/74732/E71922.pdf, (cited 3 July, 2010).
68) Ministry of Health Labour and Welfare, Committee on Sick House Syndrome: Indoor Air Pollution Progress Report No. 4—Summary on the discussions at the 8th and 9th meetings—, http://www.nihs.go.jp/mhlw/chemical/situnai/kentoukai/rep-eng4.html, (cited 7 July, 2010).
69) Nakajima, D., Tsukahara, S., Kageyama, S., Shiraishi, F. and Fujikami, H. (2008) Current status and progress of research on the effects of volatile organic compounds (VOCs) on fetuses and infants. *Indoor Environ.*, **11**, 103–109 (in Japanese).
70) Inoue, H., Sera, Y., Ohtani, M., Sato, M., Ichinose, M. and Tamura, Y. (2007) Annual changes of the amount of volatile organic compounds (VOC) in indoor air. *Indoor Environ.*, **10**, 147–154 (in Japanese).
71) Chikara, H., Iwamoto, S. and Yoshimura, T. (2009) Indoor Air Pollution of volatile organic compounds—Indoor/Outdoor concentration, sources and exposure—. *Jpn. J. Hyg.*, **64**, 683–688 (in Japanese).
72) Kanazawa, A. and Kishi, R. (2009) Potential risk of indoor semivolatile organic compounds indoors to human health. *Jpn. J. Hyg.*, **64**, 672–682 (in Japanese).
73) IPCS (1989) *Environmental Health Criteria 89 Formaldehyde*, World Health Organization, Geneva.
74) Takeda, M., Saijo, Y., Yuasa, M., Kanazawa, A., Araki, A. and Kishi, R. (2009) Relationship between sick building syndrome and indoor environmental factors in newly built Japanese dwellings. *Int. Arch. Occup. Environ. Health*, **82**, 583–593.
75) Hara, K., Mori, M., Ishitake, T., Harada, K., Wei, C. N., Ohmori, S. and Ueda, A. (2007) Changes in the airborne concentrations of formaldehyde and volatile organic compounds in an elementary schoolroom over two years after renovation. *Indoor Environ.*, **9**, 97–103 (in Japanese).
76) Otsuka, K., Matsumura, T. and Hamada, M. (2002) A survey of chemical substances in residences. *Indoor Environ.*, **5**, 23–35 (in Japanese).
77) Amagai, T., Ohmura, T., Sugiyama, T., Fusaya, M. and Matsushita, H. (2000) A survey of Indoor and Outdoor air pollution by aldehydes in summer in Fuji, Shizuoka. *Indoor Environ.*, **3**, 35–43 (in Japanese).
78) IPCS (1985) *Environmental Health Criteria 52 Toluene*, World Health Organization, Geneva.
79) Bako-Biro, Z. Waargocki, P, Weschler, C. J. and Fanger, P. O. (2004) Effects of pollution from personal computers on Perceived air Quality, SBS symptoms and productivity in offices. *Indoor Air*, **14**, 178–187.
80) IPCS (1997) *Environmental Health Criteria 190 Xylene*, World Health Organization, Geneva.
81) IPCS, Chemical Safety Information from Intergovernmental Organizations, http://www.inchem.org/, (cited 4 July, 2010).
82) Azuma, K., Uchiyama, I. and Ikeda, K. (2007) The Risk Screening for Indoor Air Pollution Chemicals in Japan. *Risk Anal.*, **27**, 1623–1638.
83) IPCS (1996) *Environmental Health Criteria 186 Ethylbenzene*, World Health Organization, Geneva.
84) Saijo, Y., Kishi, Y., Sata, F., Katakura, Y., Urashima, Y., Hatakeyama, A., Kobayashi, S., Jin, K., Kurahashi, N., Kondo, T., Gong, Y. Y. and Umemura, T. (2004) Symptoms in relation to chemicals and dampness in newly built dwellings. *Int. Arch. Occup. Environ. Health*, **77**, 461–470.
85) IPCS (1983) *Environmental Health Criteria 26 Styrene*, World health organization, Geneva.
86) Katsuyama, Y., Saito, A., Kumagai, K., Shinohara, N., Fujii, M. and Yanagisawa, Y. (2004) Emission of pollutants from polystyrene by the dissolution in solvents. *Indoor Environ.*, **7**, 1–6 (in Japanese).
87) Katakura, Y. and Kishi, R. (2005) Significance of laboratory studies of neurobehavioral and developmental toxicities—Transgenerational effects of styrene exposure—. *Jpn. J. Hyg.*, **60**, 411–417 (in Japanese).
88) Virginia, A. R., Garfinkel, R., Perera, F. P., Andrews, H. F., Hoepner, L., Barr, D. B., Whitehead, R., Tang, D. and Whyatt, R. W. (2006) Impact of prenatal chlorpyrifos exposure on neurodevelopment in the

first 3 years of life among inner-city children. *Pediatrics*, **118**, 1845–1859.
89) Curwin, B. C., Hein, M. J., Sanderson, W. T., Striley, C., Heederik, D., Kromhout, H., Reynolds, S. J. and Alavanja, M. C. (2007) Urinary Pesticide Concentration among children, mothers and fathers living in farm and non-farm households in Iowa. *Ann. Occup. Hyg.*, **51**, 53–65.
90) Yoshida, S., Taguchi, S., Hori, S. and Hori, S. (2004) Chlorpyrifos and S-421 residue in indoor air and polished rice around nine years after application for termite control. *Indoor Environ.*, **7**, 7–15 (in Japanese).
91) Yoshida, S., Taguchi, S., Tanaka, Y. and Hori, S. (2003) Investigation of insecticide residue in household dust as an index for residential exposure to pesticide. *Indoor Environ.*, **6**, 1–8 (in Japanese).
92) IPCS (1997) *Environmental Health Criteria 189 Di-n-butyl phthalate*, World Health Organization, Geneva.
93) Saito, I., Seto, H. and Seto, H. (2002) Determination of phthalates in indoor air. *Indoor Environ.*, **5**, 13–22 (in Japanese).
94) Fromme, H., Lahrz, T., Piloty, M., Gehhart, H., Oddoy, A. and Ruden, H. (2004) Occurrence of phthalates and milk fragrances in indoor air and dust from apartments and kindergartens in Berlin (Germany). *Indoor Air*, **14**, 188–195.
95) Japan Chemical Substance Dictionary Web service, Easy Textual Search, Advanced Textual Search, Chemical Structure Search, http://nikkajiweb.jst.go.jp/nikkaji_web/pages/top_e.html, (cited 4 July, 2010).
96) Steven, S. C., Little, J. C. and Hodgson, A. T. (2002) Predicting the Emission Rate of Volatile Organic Compounds from Vinyl Flooring. *Environ. Sci. Technol.*, **36**, 709–714.
97) IPCS (1992) *Environmental Health Criteria 131 Diethlhexyl Phthalate*, World Health Organization, Geneva.
98) Takagi, M. and Yoshinaga, J. (2009) Risk assessment of chemical via house dust ingestion in Japanese children. *Indoor Environ.*, **12**, 103–114 (in Japanese).
99) Fujimaki, K., Yoshinaga, J., Watanabe, C., Serizawa, S., Shiraishi, H. and Mizumoto, Y. (2006) Estimation of Intake Level of Di (2-ethylhecyl) phthalate (DEHP) of Japanese pregnant woman based on measurement of concentrations of three urinary metabolites. *Jpn. J. Hyg.*, **61**, 340–347 (in Japanese).
100) Bornehag, C. G., Sundell, J., Weschler, C. J., Sigsgaard, T., Lundgren, B., Hasselgren, M. and Hagerhed-Engman, L. (2004) The association between asthma and allergic symptoms in children and phthalates in house dust: a nested case-control study. *Environ. Health Perspect.*, **112**, 1303–1397.
101) IPCS (1998) *Environmental Health Criteria 198 Diazinon*, World Health Organization, Geneva.
102) Morgan, M. K., Stout, D. M., Jones, P. A. and Barr, D. B. (2008) An observational study of the potential for human exposure to pet-borne diazinon residue following lawn applications. *Environ. Res.*, **107**, 336–342.
103) Onuki, A., Saito, I., Seto, H. and Urehara, S. (2005) Establishment of an analysis method for nonanal and decanal using 2,4-dinitrophenylhydrazine—HPLC and a survey of indoor air. *Indoor Environ.*, **8**, 1–8 (in Japanese).
104) IPCS (1995) *Environmental Health Criteria 167 Acetaldehyde*, World Health Organization, Geneva.
105) Murata, S., Sekine, Y. and Butugan, M. (2008) Measurement of carbonyl compounds in air of household refrigerators by DNPH-HPLC system. *Indoor Environ.*, **11**, 75–82 (in Japanese).
106) IPCS (1986) *Environmental Health Criteria 64 Carbamate Pesticides; A General Introduction*, World Health Organization, Geneva.
107) IPCS, The WHO recommended classification of pesticides by hazard and guidelines to classification 2004, http://www.who.int/ipcs/publications/pesticides_hazard_rev_3.pdf, (cited 4 July, 2010).
108) Kubota, S., Shono, Y., Mito, N. and Tsunoda, K. (2008) Termiticidal efficacies of Fenobucarb and permethrin against Japanese subterranean termites *Coptotermes formosunus ans Reticulitermes speratus* (Isoptera: Rhinotermitidae). *Jpn. J. Environ. Entomol. Zool.*, **19**, 31–37.
109) Ministry of Health Labour and Welfare, Committee on sick house syndrome: Indoor air pollution, Progress repot No.1—Summary on the discussions from the 1st to 3rd meetings—, http://www.nihs.go.jp/mhlw/chemical/situnai/kentoukai/rep-eng1.html, (cited 4 July, 2010).
110) Mizoguchi, T. and Hori, M. (2008) Study on measurement of formaldehyde, VOC, and SVOC for IAQ improvement in apartment houses. *Indoor Environ.*, **11**, 83–92 (in Japanese).
111) Norback, D., Wieslander, G., Nordstrom, K. and Walinder, R. (2000) Asthma symptoms in relation to measured building dampness in upper concrete floor construction, and 2-ethyl-1-hexanol in indoor air. *Int. J. Tuberc. Lung Dis.*, **4**, 1016–1025.
112) Manabe, R., Kunugita, N., Katoh, T., Kuroda, Y., Akiyama, Y., Yamamoto, Y., Uchiyama, I. and Arashidani, K. (2008) Investigation of Air Pollution in a Shopping Center and Employees' Personal Ex-

posure Level. *Jpn. J. Hyg.*, **63**, 20–28 (in Japanese).
113) Sakai, K., Kamijima, M., Shibata, E., Ohno, H. and Nakajima, T. (2009) Annual transition and seasonal variation of indoor air pollution levels of 2-ethyl-1-hexanol in large-scale buildings in Nagoya, Japan. *J. Environ. Monit.*, **11**, 2068–2076.
114) Kamijima, M., Sakai, K., Shibata, E., Yamada, T., Itohara, S., Ohno, H., Hayakawa, R., Sugiura, M., Yamaki, K. and Takeuchi, Y. (2002) 2-Ethyl-1-hexanol in indoor air as a possible cause of sick building syndrome. *J. Occup. Health*, **44**, 186–191.
115) Kondo, F., Ikai, Y., Goto, T., Ito, Y., Oka, H., Nakazawa, H., Odajima, Y., Kamijima, M., Shibata, E., Torii, S. and Miyazaki, Y. (2007) Two sensitive sick-building syndrome patients possibly responding to p-dichlorobenzene and 2-Ethyl-1-hexanol: Case Report. *J. Health Sci.*, **53**, 119–123.
116) Wahl, H. G., Hong, Q., Hildenbrand, S., Risler, T., Luft, D. and Liebich, H. (2004) 4-Heptanone is a metabolite of the plasticizer di(2-ethylhexyl) phthalate (DEHP) in haemodialysis patients. *Nephrol. Dial. Transplant.*, **19**, 2576–2583.
117) Hirano, S. (2008) Health effects of nanoparticles and nanomaterials (I) recent overview of health effects of nanopartocles. *Jpn. J. Hyg.*, **63**, 36–41 (in Japanese).
118) Fujitani, Y. and Hirano, S. (2008) Health effects of nanoparticles and nanomaterials (II) Methods for Measurement of Nanoparticles and Their Presence in the Air. *Jpn. J. Hyg.*, **63**, 663–669 (in Japanese).
119) Hirose, A. and Hirano, S. (2008) Health effects of nanoparticles and nanomaterials (III) Toxicity and Health effects of Nanoparticles. *Jpn. J. Hyg.*, **63**, 739–745 (in Japanese).
120) Hirano, S. (2009) A current overview of health effect research on nanoparticles. *Environ. Health Prev. Med.*, **14**, 223–225.
121) Murr, L. E., Garza, K. M., Soto, K. F., Carrasco, A., Powell, T. G., Ramirez, D. A., Guerrero, P. A., Lopez, D. A. and Venzor, J., III (2005) Cytotoxicity Assessment of Some Carbon Nanotubes and Related Carbon Nanoparticle Aggregates and Implications for Anthropogenic Carbon Nanotube Aggregates in the Environment. *Int. J. Environ. Res. Public Health*, **2**, 31–42.
122) Ishibashi, Y., Yoshinaga, J., Tanaka, A., Seyama, H. and Shibata, Y. (2008) Lead and cadmium in indoor dust in Japanese houses—relationship with outdoor sources. *Indoor Environ.*, **11**, 93–101 (in Japanese).
123) Nakamura, Y., Yakagi, M., Yoshinaga, J., Tanaka, A., Seyama, H. and Shibata, Y. (2008) Element Composition of Japanese House Dust and the Source of Lead. *Indoor Environ.*, **11**, 11–20 (in Japanese).
124) Aung, N. N., Yoshida, J. and Takahashi, J. (2004) Exposure Assessment of Lead among Japanese Children. *Environ. Health Prev. Med.*, **9**, 257–261.
125) Yamaguchi, M., Okada, H., Tomioka, K. and Suzuki, M. (1989) The Application of Semiconductor-based Odor Sensors Capable of Measuring and Evaluating Indoor Air Quality. *Indoor Environ.*, **1**, 27–34 (in Japanese).
126) Kishi, R., Saijo, Y., Kanazawa, A., Tanaka, M., Yoshimura, T., Chikara, H., Takigawa, T., Morimoto, K., Nakayama, K. and Shibata, E. (2009) Regional differences in residential environmenets and the association of dwellings and residential factors with the sick house syndrome: a nationwide cross-sectional questionnaire study in Japan. *Indoor Air*, **19**, 243–254.
127) Wolkoff, P., Wilkins, C. K., Clausen, P. A. and Nielsen, G. D. (2006) Organic compounds in office environments—sensory irritation, odor, measurements and the role of reactive chemistry. *Indoor Air*, **16**, 7–19.
128) World Health Organization (WHO), fact sheet No.291 Radon and cancer, http://www.who.int/mediacentre/factsheets/fs291/en/, (cited 4 July, 2010).
129) Yokoyama, S., Tsukidate, T., Aoki, T., Saigan, E., Uchida, H., Ikeda, K. and Iida, T. (2003) Measurements of indoor radon and its daughters in Hokkaido. *Indoor Environ.*, **6**, 9–17 (in Japanese).
130) Iwata, T. (2008) Indoor light environment and visual environment. *Indoor Environ.*, **11**, 117–123 (in Japanese).
131) Kohyama, J. (2009) A newly proposed disease condition produced by light exposure during night: Asynchronization. *Brain Dev.*, **31**, 255–273.
132) Nakayama, K. and Morimoto, K. (2009) Risk factors for lifestyle and way of living for symptoms of sick building syndrome: Epidemiological Survey in Japan. *Jpn. J. Hyg.*, **64**, 689–698 (in Japanese).
133) Shinohara, N., Futatsuyama, M. and Gamo, M. (2009) Survey of possession of furniture, items and electrical appliances in each room of Japanese residential houses, categorized according to the activity. *Indoor Environ.*, **12**, 115–124 (in Japanese).
134) Brroms, K., Svardsudd, K., Sundelin, C. and Norback, D. (2006) A nationwide study of indoor and outdoor environments in allergen avoidance and conventional daycare centers in Sweden. *Indoor Air*, **16**, 227–235.
135) Takekuma, M., Ohmura, A. and Saito, K. (2005) Measures for reducing the levels of chemical compounds in the indoor air of schools—A study of the

effect of ventilation—. *Indoor Environ.*, **8**, 35–39 (in Japanese).

136) Park, J. H., Byeon, J. H., Yoon, K. Y. and Hwang, J. (2008) Lab-scale test of a ventilation system including a dielectric barrier discharger and UV-photocatalyst filters for simultaneous removal of gaseous and particulate contaminants. *Indoor Air*, **18**, 44–50.

137) Otsuki, C. (2008) Indoor environment of a nursery school. *Indoor Environ.*, **11**, 33–35 (in Japanese).

138) Furusawa, H., Nagamine, M. and Watanabe, T. (2009) Use of a mathematical model to estimate turberculosis transmission risk in an Internet café. *Environ. Health Prev. Med.*, **14**, 96–102.

139) Liu, Y. (2002) Evaluation of the bake-out method to decrease indoor air pollution caused by volatile organic compounds. *Indoor Environ.*, **5**, 1–6 (in Japanese).

140) Kitamura, Y., Otani, M., Okada, M., Omura, M. and Monna, Y. (2005) Examination of reduction of indoor chemical pollutants using air conditioners. *Indoor Environ.*, **8**, 41–46 (in Japanese).

141) Abe, K., Suyama, Y., Yagami, U., Okuda, S. and Otsuka, T. (2007) An activity news flash of microbe working group—Evaluation of an air cleaner on removal performance of airborne microbe—. *Indoor Environ.*, **10**, 163–166 (in Japanese).

142) Nakajima, D., Suzuki, K., Goto, S., Yajima, H., Ishii, T., Yoshizawa, S., Watanabe, I. and Sakai, S. (2005) The effective of carbonization temperature on the ability of charcoal to adsorb mixed volatile organic compounds. *Indoor Environ.*, **8**, 9–14 (in Japanese).

143) Sato, S. and Abe, K. (2004) Suppression of fungal growth inside air-conditioners using the intermittent short-time-heating method. *Indoor Environ.*, **7**, 25–30 (in Japanese).

144) Fujishima, A. and Honda, K. (1972) Electrochemical photolysis of water at a semiconductor electrode. *Nature*, **238**, 37–38.

145) Jo, W. K. and Kim, J. T. (2009) Application of visible-light photocatalysis with nitrogen-doped or unmodified titanium dioxide for control of indoor-level volatile organic compounds. *J. Hazard. Mater.*, **164**, 360–366.

146) Yang, C. C., Chang, S. H., Hong, B. Z., Chi, K. H. and Chang, M. B. (2008) Innovative PCDD/F-containing gas generating system applied in catalytic decomposition of gaseous dioxins over V2O5-WO3/TiO2-based catalysts. *Chemosphere*, **73**, 890–895.

147) Mo, J., Zhang, Y., Xu, Q. and Yang, R. (2009) Effect of TiO2/adsorbent hybrid photocatalysts for toluene decomposition in gas phase. *J. Hazard. Mater.*, **168**, 276–281.

148) Wang, L., Sakurai, M. and Kameyama, H. (2009) Study of catalytic decomposition of formaldehyde on Pt/TiO2 alumite catalyst at ambient temperature. *J. Hazard. Mater.*, **167**, 399–405.

149) Chen, J. and Poon, C. S. (2009) Photocatalytic activity of titanium dioxide modified concrete materials—Influence of utilizing recycled glass cullets as aggregates, *J. Environ. Manage.*, **90**, 3436–3442.

150) Puma, C. L., Bono, A., Krishnaiah, D. and Collin, J. G. (2008) Preparation of titanium dioxide photocatalyst loaded onto activated carbon support using chemical vapor deposition: A review paper. *J. Hazard. Mater.*, **157**, 209–219.

151) Determination of the emission of volatile organic compounds and aldehydes for building products—small chamber method, JIS A 1901:2003.

152) Hasegawa, T. and Kigawa, M. (2009) Sick house syndrome: government actions and challenges. *Jpn. J. Hyg.*, **64**, 699–703 (in Japanese).