Overview on Indoor Thermal Environment and Air Quality Issues for Residential Buildings in Japan

Hiroshi Yoshino, Professor, Tohoku University

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Overview on Indoor Thermal Environment and Air Quality Issues for Residential Buildings in Japan

Hiroshi Yoshino¹

¹Professor, AIJ, Tohoku University

Abstract

For the purpose of energy conservation and protection of global warming, requirement of the quality in thermal performance of newly constructed residential buildings in Japan becomes very high. In these houses, the building envelope is airtight and then air infiltration rate is very low. On the other hand, many kinds of building materials, furniture and utensils, which include chemical compounds are used in present houses. Therefore, indoor air is easily polluted with such as volatile organic compounds. Nowadays, there are not a few occupants with sick building syndrome (SBS) due to the chemical compounds in newly constructed houses. For this, the Building Standard Law was partially revised in July, 2002. Following this revision, in July, 2003, the regulations for application of requirements of amended law for preventing sick buildings was enforced. This paper deals with energy consumption and the problems of indoor environment found in residential buildings. Especially, the issue of SBS in houses and the current research and development for preventing the SBS will be introduced.

Keywords: Indoor Air Quality, Sick Building Syndrome, Energy Conservation

1. Introduction

Geographically, the mountainous islands of Japan archipelago form a crescent off the eastern coast of Asia. As the coastlines of Japan are very long, one is facing onto the Pacific Ocean on the right and the other one is facing the Sea of Japan on the left, climatic conditions are different between each district due to the geographical location. In Hokkaido (northernmost district of Japan) and Honshu (Main part of Japan) islands, the weather is very cold in the winter season. In particular, the coastal area along the Sea of Japan, severe snowfall is often experienced due to the humid wind from the northeast. During the summer, the weather is hot and humid in all Japanese islands except for the Hokkaido district. The space heating is commonly used in Japan during the winter, and the space cooling has also become popular for the summer season in big cities like Tokyo and Osaka because of urban heat island effect. Requirement of the quality in thermal performance of newly constructed residential buildings situated in the northern areas of Japan become very high for the purpose of energy conservation and protection of global warming. However, due to the use of airtight building envelope, problems of indoor air quality in the buildings become very serious.

2. Actual conditions of energy consumption in residential buildings

The ratio of annual energy consumption for the building sector to the total energy consumption of Japan is 26.3%(1998). In the building sector, 55% of energy is consumed by the residential buildings. The ratio for the industrial sector is 50% and the energy consumption has not increased since the oil crisis in 1973, due to the introduction of the energy conservation technologies. On the other hand, the energy consumption in residential sector increases after the oil crisis and the increase rate is 10% in the last ten years. Figure 1 shows the usage of energy consumption in residential buildings that is divided into four ways via, space heating, space cooling, hot water heating and the others including cooking, lighting, electric appliances etc. The ratios of these usages are 28%, 2%, 35% and 35%. However, the energy consumed for space heating is greater in cold climate regions. In all these usages, energy consumption increases and especially the increase rate in consumption for hot water and electric appliances is relatively large.

In 1980 after the oil crisis, the law for energy conservation in residential buildings was formulated and have been revised twice in 1992 and 1999. The latest version of the energy conservation law prescribes high quality standard of thermal performance in residential buildings. The high quality standard is becoming popular through the mortgage system of the residential financial agency. As the result, the level of thermal building
performance and space heating in Japan becomes better and better.

3. Problems in indoor environment of residential buildings

So far, it has been pointed out that the main problem in indoor environment of residential buildings is cold during the winter. In most houses except for the Hokkaido district, the living and dining rooms have been only heated during the winter and the indoor temperatures of bathroom, lavatory and corridors are very low. Figure 2 and Figure 3 shows measured detached house and several space heating apparatuses.

Figure 4 shows the temperature differences between living room and another rooms of two hoses in winter. House A in rural area has no thermal insulation. House B in local city is insulated and airtight. There are large differences of temperature between living room and another rooms from house A.

Therefore, the temperature difference between rooms give the thermal stress to occupants and influence their health conditions. Many people in Japan were died of cerebral vascular disease that is so-called stroke. It is told that the reason of stroke is the temperature difference in the house. Nowadays, the stroke is the third mortal illness in Japan. There are still many houses in Japan without enough thermal performance, where room temperature is low, but the concerns is how to prevail the high quality standard houses and to enlighten people to take into consideration of the global warming issues.

On the other hand, due to increase in airtightness performance level of building envelope, the amount of natural ventilation rate decreases causing the problem of indoor air pollution appeared nowadays. Because portable kerosene heaters are popular in many Japanese houses, indoor air pollution caused by the combustion gas is serious in the winter. In addition, emission rate of chemical compounds from building materials increases under the condition of higher indoor temperature. Then in the summer season, indoor air is polluted by chemical compounds. In these days, sick building syndrome in houses due to chemical compounds become big issue in Japan.

4. Brief history of strategies of energy conservation and sick building problems

After oil crises in 1973, Japanese Government has begun to put in serious efforts to tackle energy conservation problems. Table 1 shows the brief history...
of energy conservation strategies by the Government, institutions, etc., and sick house problem. In 1980, firstly issued was the energy conservation law for all of industrial, commercial and residential sectors. The law for the residential sector introduced the thermal insulation standard and prescribed the level of the thermal insulation according to the climatic conditions of district. This standard is not mandatory but voluntary base. In 1992, the standard was revised and the airtightness level of the building envelope was prescribed. It is recommended that, in cold climate region, residential building should be airtight. In those days, the sick building syndrome in residential buildings began to appear and to be taken up in the mass media. In 1997, Kyoto protocol for preventing the global warming was issued. In the same year, the guideline of indoor air concentration of formaldehyde was announced by the Ministry of Health and Welfare.

In 1999, the energy conservation standard was again revised because of enforcement of energy conservation for preventing the global warming. The standard prescribes the higher thermal insulation to be installed and recommended all the new houses to be airtight. Since the sick house syndrome problem was pointed out in the House of Representatives in 1996, many projects for research and development related with SBS problems have been launched by the government, associations and institutions.

In the autumn, 2000, the research group of indoor air quality treatment organized by the Government

<table>
<thead>
<tr>
<th>Year</th>
<th>History of Residential Energy Conservation in Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td>1973</td>
<td>The first oil crisis</td>
</tr>
<tr>
<td>1979</td>
<td>The second oil crisis</td>
</tr>
<tr>
<td>1980</td>
<td>The energy conservation standard for residential buildings</td>
</tr>
<tr>
<td>1992</td>
<td>The new energy conservation standard for residential buildings</td>
</tr>
<tr>
<td></td>
<td>Rating system for residential building air tightness</td>
</tr>
<tr>
<td></td>
<td>Project for environmental symbiosis buildings</td>
</tr>
<tr>
<td>1996</td>
<td>Project for healthy houses for preventing SBS</td>
</tr>
<tr>
<td>1997</td>
<td>COP3 -The Kyoto Protocol</td>
</tr>
<tr>
<td></td>
<td>Guidline of formaldehyde</td>
</tr>
<tr>
<td></td>
<td>Development project for creative technologies of residential environment</td>
</tr>
<tr>
<td>1998</td>
<td>Research Committee on Indoor Air Pollution by Organic Compounds (IAPOC)</td>
</tr>
<tr>
<td>1999</td>
<td>The revised energy conservation standard for residential buildings</td>
</tr>
<tr>
<td></td>
<td>Rating system for residential building performance</td>
</tr>
<tr>
<td>2000</td>
<td>Research committee of indoor air quality</td>
</tr>
<tr>
<td></td>
<td>Guidline of 8 chemical substances (toluene, chlorpyrifos, etc.)</td>
</tr>
<tr>
<td>2001</td>
<td>Revised rating system for residential building performance (concentration measurement)</td>
</tr>
<tr>
<td></td>
<td>Guidline of 8 chemical substances (tetradecane, acetaldehyde, etc.)</td>
</tr>
<tr>
<td>2002</td>
<td>Amendment of the Building Standard Law for preventing sick buildings</td>
</tr>
<tr>
<td>2003</td>
<td>Government ordinance of the building standard for preventing sick buildings</td>
</tr>
</tbody>
</table>
investigated the formaldehyde concentration in 4500 houses picked up in whole Japan, and revealed that the formaldehyde concentration of 27.3% houses were over the guideline. Taking the serious situation, the Building Standard Law was amended in July, 2002, following the issue of the application of the requirements of the amended law in July, 2003. The description of the law will appear in later.

5. Indoor air quality of Sick Building Syndrome

In order to determine the etiological factor of SBS, field survey of indoor air quality were carried out continuously about summer periods from 2000, in 35 houses where occupants are suspected of suffering from the SBS, in the Miyagi prefecture of Japan. This survey consisted of the measurements of indoor air pollutants (the concentration of formaldehyde and volatile organic compounds (VOC)), air tightness and ventilation rate, together with questionnaire regarding environmental conditions, subjective symptoms and lifestyle. Medical examination was also conducted to occupants having heavy symptoms. In addition, 15 houses out of 35 houses was investigated continuously for two or three years.

5-1 Chemical substance concentrations of indoor air

A few typical rooms of each house were chosen for the measurements. The chemical substance concentrations (carbonyl compounds and VOCs) were measured at a height of 1.2 m above the floor. The openings of the rooms were closed as much as possible at the time of measurement. Indoor air was sampled for the period of 24 hours. Table 2 gives the results of typical indoor chemical substances concentrations.

Figure 5 shows the cumulative frequency of the formaldehyde, toluene and TVOC concentrations. These values were obtained from the initial measurement (35 houses). These substances were detected in over 70% rooms. The formaldehyde concentrations in 65 rooms within the 91 rooms (71%) exceed the criterion of the guideline (0.08ppm) from the Ministry of Health, Labor and Welfare of Japan. These formaldehyde concentrations are found higher than that in ordinary houses (residents without Sick House Syndrome) of Miyagi prefecture. The toluene concentrations in 10 rooms within the 93 rooms (8%) exceed the criterion of guideline (260mg/m³). The p-dichlorobenzene concentrations in 14 rooms (15%) exceed the criterion of guideline (240mg/m³). The ethyl benzene and xylene concentrations in all rooms were below the guideline. TVOC concentration in 61 rooms (66%) exceeded the recommended value (400mg/m³).

5-2 Relationship between chemical compound concentrations and building age

Figure 6 shows the relationship between chemical compound concentrations and building age. Formaldehyde concentration does not show much decrease, even the building age increases. But toluene concentration decreases as building age increases. TVOC concentration is similar to the behavior of toluene concentration, but high concentration was detected in houses using moth crystals (sign * shows in the figure). In retrofitted houses, formaldehyde concentration value is higher.

5-3 Relationship between formaldehyde concentration, airtight performance and ventilation rate

Figure 7 shows relationship between formaldehyde concentration and equivalent leakage area and ventilation system. The relation between formaldehyde concentration and airtightness isn’t so clear, because the ventilation rate varies in the houses. There were many houses where the amount of ventilation has not satisfied 0.5 air change rate per hour. Formaldehyde concentrations in those houses were relatively high.

5-4 Changes of the chemistry substance concentration in an investigation example

Figure 8 shows the change of indoor chemical concentrations in the houses which have been investigated over a period of three years. It is found that VOCs concentrations are generally reduced during this period, but formaldehyde concentration does not change. This similar tendency was also observed in other residences. It is found that VOCs concentrations decreased rapidly after the construction.

### Table 2. Result of measurement of indoor concentration about chemical substances compared with the guidelines from the Ministry of Health, Labour and Welfare of Japan

<table>
<thead>
<tr>
<th>Substance</th>
<th>Unit</th>
<th>Indoor concentration</th>
<th>Guideline from MHLW</th>
<th>The number of detected data (over guideline)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Average</td>
<td>Median</td>
<td>Max</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>ppm</td>
<td>0.124</td>
<td>0.111</td>
<td>0.315</td>
</tr>
<tr>
<td>Acetaldehyde</td>
<td>ppm</td>
<td>0.128</td>
<td>0.12</td>
<td>0.412</td>
</tr>
<tr>
<td>Toluene</td>
<td>mg/m³</td>
<td>138.4</td>
<td>43.2</td>
<td>2530.0</td>
</tr>
<tr>
<td>Ethylbenzene</td>
<td>mg/m³</td>
<td>15.9</td>
<td>10.1</td>
<td>140.0</td>
</tr>
<tr>
<td>Xylene</td>
<td>mg/m³</td>
<td>28.0</td>
<td>17.0</td>
<td>196.1</td>
</tr>
<tr>
<td>p-Dichlorobenzene</td>
<td>mg/m³</td>
<td>452.9</td>
<td>38.5</td>
<td>16065.5</td>
</tr>
<tr>
<td>α-pinene</td>
<td>mg/m³</td>
<td>178.0</td>
<td>12.5</td>
<td>3350.0</td>
</tr>
<tr>
<td>TVOC</td>
<td>mg/m³</td>
<td>1556.5</td>
<td>701.7</td>
<td>16815.8</td>
</tr>
</tbody>
</table>
5-5 Relationship between indoor chemical substance concentration and health conditions

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

6. Prevention strategies for sick house syndrome

The technical strategies for preventing sick house syndrome are fundamentally divided into three categories. One of them is source control, that is to
Fig. 7. The relationship between formaldehyde and TVOC concentration, airtightness and ventilation rate prevent the emission of chemical compounds as much as possible. Second one is to dilute and exhaust the polluted indoor air by ventilation. Third one is to adsorb and resolve the chemical compounds of indoor air by air purifiers and special sheet and board.

6-1 Strategies for source control
For controlling the emission of chemical compounds, it is important to restrict the use of building materials, furniture, utensils and other things including the chemical compounds. It is necessary for building designers to consider the selection of the building material which has low emission rate of chemical compounds, for construction experts and carpenters to restrict the use of adhesive, paint, other materials including the chemical compounds, and for occupants to obtain in use the information of chemical compounds for the furniture, utensil, aromatic, insecticide, and so on. Another method is to restrict the emission of chemical compounds from the surface of building materials by covering some sheet. The other one is so-called bake-out, which is to accelerate the emission of the chemical compounds from building materials by increase of indoor temperature using space heaters. It is told by researchers that this method is useful for the emission of that such as formaldehyde from the inside of the building materials.

(1) House A (Completion:Mar-1998, Total floor area:133.3m², Ventilation:Mechanical supply & exhaust system)

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

Fig. 8. The secular change of chemical substance concentration for three years (2 houses)
method. Only some data of the performance test by authorized measurement methods are already on the market. Compounds, are being developed and some of them adsorbing and resolving the indoor chemical purifiers, which will may have performance of air pollution.

During not only occupancy but also construction, ventilation is also important to dilute the indoor air pollution. The base materials used in ceiling cavities, etc., must have low formaldehyde emission levels, or ventilation equipment must be designed to allow ventilation of ceiling cavities, etc.

6-3 Adsorption and resolution
Many kinds of the special sheet and board, and air purifiers, which will may have performance of adsorbing and resolving the indoor chemical compounds, are being developed and some of them are already on the market.

However all these products have not been verified for the performance by authorized measurement method. Only some data of the performance test by own company are available. The test conditions for measurement and indication methods are not standardized. It is necessary to authorizing the standard methods on performance test and indication as soon as possible.

7. Countermeasures regarding sick house issues under the Amended Building Standard Law
   The Amended Building Standard Law on sick house issues was promulgated on July 12, 2002. The regulations for application of the requirements of the amended Law were enforced on July 1, 2003. The chemical substances covered by the regulations are chlorpyrifos and formaldehyde. The use of building materials containing chlorpyrifos in buildings with habitable rooms is prohibited. Regulations concerning formaldehyde are following and shown in Figure 10:
   1) Restrictions on interior finishing materials
      The area size of formaldehyde-emitting building materials which can be used as interior finishing material are restricted according to the type of habitable room and the frequency of ventilation.
   2) Mandatory installation of ventilation equipment
      Even if no formaldehyde-emitting building materials are used, formaldehyde is also emitted by furniture. For this reason, the installation of ventilation equipment will, in principle, be mandatory in all buildings.
   3) Restrictions related to ceiling cavities, etc.*
      The base materials used in ceiling cavities, etc., must have low formaldehyde emission levels, or ventilation equipment must be designed to allow ventilation of ceiling cavities, etc.

*Ceiling cavities, etc includes cavities, attics, cavities underneath floors, wall, storerooms and other similar locations.

8. Subjects of research and development
A lot of research and development concerning sick house issues has been done and still continuing in many universities, societies, institutes of Government and private companies. Especially, the committee on Indoor Air Pollution by Organic Compounds Environment, Architecture Institute of Japan, chaired by Prof. Shuzo Murakami, Keio University, has been performing many important research works since 1998. The list of subjects of this committee is shown below for the information;
   1) Indoor monitoring and medical investigation
      -Field survey on the awareness of the occupants an residential environment
      -Elucidation on pollution load to human body and medical effect from chemical pollution
   2) Emission analysis and mitigation measures
      -Study on the measurement of the emission rate and evaluation
      -Development on the mitigation and methods in residential environment
   3) Development of optimal designing method for...
indoor environments to prevent air pollution exposures.
- Investigation on emission and diffusion of chemical pollution in a room and development of method to predict the concentration of air to be inhaled human body
  - Development of hybrid energy saving ventilation and air conditioning system to reduce personal pollution exposure
  4) Mitigation to chemical pollution for practical use and making a manual to the occupants
  5) Development of the technology for proper ventilation

9. Conclusions
1) Brief history of energy conservation strategies and sick building issues was introduced and it was described that one of the causes for sick building syndrome was airtightness of building envelope.
2) The investigation results of indoor air quality of sick houses revealed that, in more than around 70% houses, the formaldehyde and TVOC concentrations were over the guideline and target value, respectively. It was found that in there are many occupants in low concentration houses who are suffering from severe symptom.
3) Countermeasures for sick building syndrome, which can be applied for design and construction of residential building, are described.
4) The Amended Building Standard Law by the Japanese Government was summarized.
5) The subjects of research and development related with sick house issues, which has been performed by The Architectural Institute of Japan, was listed.

There are many subjects to tackle for preventing sick house syndrome in the future. For examples, the ozone reaction with chemicals from natural timber has not been verified. Combined effect of the VOCs is not clarified. It is told that the suspended particulate play an important role as the cause of sick houses. Mold growth due to the vapor condensation is also an important factor to human health.

It is so important for overcoming the sick house problems to have interdisciplinary collaboration between engineers, medical doctors, policy makers, end users, etc.

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