Over views of the researchs on indoor environmental comforts effected by IAQ
-In the case of sick building syndrome in residential buildings-

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Abstract
The reviews on the indoor air environment researches starting from the history, followed by the situation of the study about the indoor air quality (IAQ) problems brought by artificialization of the indoor environments are made. The author also describes the effects of the ventilation and establishment of environment guideline as technical and administrative measures.

Keywords: Indoor, air, quality, ventilation, guidelines

1. Introduction
Humans have been producing artificial environments to make comfortable environment for themselves in the severe natural environments.

In the early stage of their development, they used caves which existed near in their neighborhood, and gradually built bigger and more sophisticated structures around them to produce the more preferable environments artificially. And such tendencies will be increasing widely, and they will spread out of global land and reaching to beneath water and ground, and mankind contemplates the road map to the habitation on space and other planets.

There are enormous advantages obviously in such artificial environments compared to the environments where do not so, but demerits also do exist.

The physical environments are consisted of 4 elemental factors, sound, thermal, lighting and air. While previous 2 factors have a lot of merits by artificialization of the environments, latter 2 factors do not necessarily have the merits which excel demerits. Especially, the demerits in air environment by artificialization are enormously big, and the demerits are far exceeding the merits. It is not exaggerated that the air environmental problems are biggest problem in indoor environments.

2. Historical perspective of researchs on IAQ and ventilation rates in residential buildings
Indoor air qualities (IAQ) are often to be poorer than those of outdoors, because of various pollutant sources there. Human beings were, therefore, making efforts to ventilate the indoor air to the outdoors, since they began to live inside of houses as a shelter. Humans inhabiting in this country, where the climates were semitropical weather in summer, were also using cross-ventilation techniques in order to improve thermal comfort, in side of the houses.

The famous historical literature on the effectiveness of ventilation or cross ventilation, stating that “Building construction of a house should be summer living oriented” (Yoshida, 1349). We can live any type a house in winter is an evidence that people were taking a measure to cope with summer environments in Japan from the ancient times. The description on indoor air pollutions was, on the other hand, seen in a noble, titled” Zenigata Heuji Torimonohikae (Cop Heiji Zenigata’s Notes on the Criminal Investigations)” written by Kodo Nomura (Nomura, 1931). The author was told this by the Takaeshi Hekine, former Professor of Hiroshima University, who is passed away already, although I myself did not read it. There is a description that “Someone got a headache while he is staying in the room where a brazier was used as heating appliance, while doors and windows were tightly closed”.

As the descriptions on the importance of IAQ and ventilation written in scientific literatures, there is an article “Notes on Nursing” written by famous Florence Nightingale (1860). In the 1st chapter, which was consisted with more than 20 pages, she stated that ventilation and warming (heating) are most important to
maintain indoor air qualities and thermal comforts of patients as a first principal of nursing. She also mentioned precisely how nurses should open windows in order to improve IAQ, how the nurse should ventilate not to feel cold the patients, cold air is not necessarily fresh air and so forth. It is well known that Rintaro Mori (he is very famous Nobelist known as Ougai Mori), hygienic researcher stated the importance of ventilation and cross ventilation (Sekine, 1988). He was deemed as a herald of ventilation research.

However, these literatures are remaining just to insist the importance of ventilation, not showing the quantitative data which are applicable for engineering purposes, such as how much was ventilation rate and indoor pollutant concentrations in actual residential buildings.

3. Actual status of the ventilation rates in residential buildings

Table 1 shows the quantitative data on ventilation rates in houses which were obtained from literature reviews (Ikeda, 1992). As each data differs in measurement objectives, conditions and methods, it is impossible to compare each other in a same level. However, in the case of lower limit values, all the data were obtained in a relatively similar condition where doors and windows were closed, and outdoor wind were rather calm. As they were also closely related to an air tightness of the objective buildings, the author focused on them.

As seen in Table 1, lower limit values of ventilation rates in Japanese houses were quite high compared to those of Europe and American countries. In the case of old Japanese houses, very few houses of which ventilation rates are less than 0.5 ACH (air change per hour), standard value defied by Japanese Building Code revised in 2001 (The Ministry of Education, Culture, Sports, Science and Technology, 2001). But ventilation rates recent Japanese houses are getting lower. Houses with less than 0.1 ACH are often seen because of a polarization of the 24-hours mechanical ventilation systems.

4. Benefits and problems resulting from artificialization of the residential environments.

It is not exaggerated that the artificialization of residential buildings is only demerit so far as indoor air quality problems. If we do not have rainy and windy weather, no fear for the security and have no troubles related to thermal, acoustical and luminous environments, we do not have necessity to build the artificial environment. If we dearly look for the cases where we have a necessity to make indoor environments artificial building barrier toward outdoors, they would be the cases where people and/or things are severely affected.

| Researchers | Objective Buildings | Measuring Methods | Air Change Rates | Range (ACH) |
|-------------|---------------------|-------------------|-----------------|-------------|
| Takatsuki (1924) | Researcher’s Home | CO₂ Decay | 1 | 1.5~2.7 |
| Nomura (1924) | A Representative Japanese Home | CO₂ Decay | 2 | 1.5~6.5 |
| Ohtani (1929) | Seven Cubic House Models | CO₂ Decay | 3 | 0.3~2.83 |
| Shouda (1953) | A RC Structured Apartment Home | CO₂ Decay | 4 | 0.8~5.0 |
| Ikeda, et. al. (1985) | Seven Typical Japanese Homes | CO₂ Decay | 5 | 0.5~3.6 |
| Yamamoto, et. al. (1987) | A Concrete Apartment House | CO₂ Decay | | 0.2~1.7 |
| Ikeda, et. al. (1987) | 3 Prefabricated Experimental Houses | CO₂ Decay | | 0.07~8.0 |
| Bahnfleth et. al. (1953) | 2 Experimental Houses | He Decay | 1 | 0.16~0.43 |
| Tamura et. al. (1964) | 2 Canadian Houses with Occupants | He Decay | 2 | 0.06~0.63 |
| Tamura et. al. (1979) | Same 2 Homes as Above | He Decay | 3 | 0.05~0.43 |
| Goldschmit et. al. (1979) | 2 Mobil Homes | CO₂ Decay | 4 | 0.1~2.0 |
by;
① strong outdoor winds
② high outdoor air concentrations of suspended particulate matters, pollen, radioactive particles, toxic gases and so forth.

But these cases are seldom happened in a normal society. Outdoor air qualities are usually far better than those of indoors although the outdoor air is considered very contaminated because of the increased attention of the air pollution problems. But in fact, indoor air qualities are quite contaminated by tobacco smoke, exhaust gas from unvented combustion appliances and other sources of the various indoor pollutants compared to those of outdoor air.

In fact, some places where outdoor air concentrations of contaminants, such as, NOx and/or SOx, in question may exist, but outdoor air quality of other pollutants, even in such places, would be far better than indoors. There is no necessity to artificialize the indoor air environments to improve or protect from the outdoor environments by containment. It brings surely bad effects to air environments, and is made to improve other environmental factors, such as thermal or visual environments. It can also be said that air environment is sacrifice of the environmental artificialization.

However, the author is not insisting that the artificialization of environmental improvements other than air environments are difficult to accept. The mankind does not exist in only the purpose which “creates good air environments”. An important thing is to consider a balance with the other environments and make the better environments overall. If artificialization is necessary to improve other environmental factors, it should be admitted even if air environment undergoes considerable influence by that depending on the case.

5. So-called “Sick House Syndrome”

The most serious effects of the artificialization of air environments were known as so-called “sick house syndrome (SHS)” in Japan, or sick building syndrome in residential buildings. By the way, SHS is Japanese English and is not used internationally.

The energy crisis happened in the latter half of 1970’s affected various effects on the societies, including many kinds of buildings. The airtightness of building construction intensified, and the ventilation rates were minimized in order to conserve the energy for the HVAC (heating, ventilating, and air conditioning). As a result, indoor air qualities were getting worse and contradiction between the energy cost and the quality of the indoor air has been clarified at the same time. It is the problem called as sick building syndrome (SBS) to show this matter clearly (WHO, 1982). Owners and tenants of the buildings were complaining to public sectors of the nations, and states that the tenants had symptoms of dizziness, nausea, malformation of a headache and sense of balance in their eyes, nose, throat and/or other parts of the whole body while they were staying in buildings, so-called “energy efficient building” in many part of Europe and America in early 1980’s. Sick building is a building that is a building with unhealthy environments resulting from the extremely reduced ventilation rates as an energy conservation measures, and sick building syndromes are health effects, or “syndrome” that emerge in the people who are working and inhabiting in those buildings. Such problems were also seen before 1960’s but had begun in early 1980’s mostly.

SBS was deemed as a quite big social problem in Europe and America in 1980’s, and there is a person who wore gas mask necessary for protecting the poisonous gases in a serious example. The person taking an interview of NHK (Nihon Hosokyokai, or Japanese Broad Casting Association) was also a staff of the EPA (Environmental Protection Agency) which is an American administration which regulates environmental policies of the USA ironically. Several investigations were performed reflecting such trend.

Some of the symptoms above-mentioned were found by more than 15 % of person from an investigation which was conducted for 1500 Danish citizen (15-67 years old) subjects, for example. There were also some complaints by the tenants or owners of the buildings according to an investigation performed at 200 North American buildings (Sterling et al., 1983). There are two types of SBS. One is called as “acute SBS”, and it happens just after construction or renovation of the building. This type of SBS is caused by pollutants emitted from the building material newly introduced, and it is resolved with elapsing of the time (Sterling et al., 1983). The other one is called as “chronic SBS”, and it is resulting from essential character of buildings, and passage of the time does not solve the problems. This is a “true SBS”. Characteristic futures of these buildings are, according to Sterling (Sterling et al., 1983), as follows;
① HVAC of the building adopts partial recirculation air system. Positions of the outdoor air intake were sometime inadequate and there is leakage of the pollutants from exhaust to intake air in the all-heat-exchanger, depending on the buildings. These facts read to lack of fresh air rates.
② Structure of the buildings were relatively new and light type, and airtightness is high generally. These facts also read to lack of fresh air intake rates.
③ Interior was finished with textile and carpet. Surface area was rather wide compared to its room capacity. These are read to increase of pollutant emission rate.
④ Ventilation rates of the room were reduced in order to accomplish high energy efficiency. This fast read to reduction of the ventilation rates.
⑤ Airtightness of the building in question was usually high, and this also read to reduced ventilation rate.

As shown above facts, the cause of SBS can be considered as 2 factors, one is decrease in ventilation air volume and the other is increase in the emission rate of all kind of the pollutants. But relationships between pollutants and symptom are not simple pattern, such as one pollutant related to a single symptom. Various physical factors, for instance, carbon monoxide, carbon dioxide, dust, radon and formaldehyde, are connected in a complicated manner. It is often difficult to probe epidemiological relationships between them.

Researchers of EPA, Virginia Institute of Technology and so forth established definition or characteristic of SBS as follows;
① More than 20 % of a building resident complains of dissatisfaction related to some health;
② The cause or causes cannot be specified easily;
③ But the symptoms are disappeared after going to outdoors out of indoors.

They on the other hand, define the BRI or “Building Related Illness” as follows (Teichman, 1993);
① More than two people (no matter how many the number of all residents are) are recognized as “clinically defined illness”; 
② The cause or causes are clearly identified;
③ The symptoms do not go off immediately even if going outdoors.

According to the definitions, Legionnaire’s disease happed in Philadelphia, Pennsylvania and a tubercular mass outbreak through the air conditioning system in the office happened in Tokyo are typical BRI.

There may be a question, who is the person who used a word as this SBS first. It started to be used by the people who participated in a meeting on IAQ held at WHO Europe office in 1990’s, according to Professor Fanger of Technical University of Denmark. The term “sick house syndrome” is, however, more famous than sick building syndrome in Japan. This term is Japanese word, “sick house syndrome”, first. At least 2 people are insisting, that they are the godparent of “sick house”, so far as the author knows. Anyway, it is from the second half of 1990’s, when the guideline value established by the Ministry of Health and Welfare about formaldehyde, that the word as “sick house” and “sick house syndrome” started to be used extensively in this country.

When “sick house” is interpreted as the housing which became a “sick building”, it will be “the house suffered”. How are the residential buildings suffered? Indoor environments of the houses in Japan are “suffered” by the pollutants, such as, formaldehyde and chemicals of volatile organic compounds (hereinafter, VOCs), which are emitted from building material and furniture inside the rooms. And “sick house syndrome” is the symptoms such as an irritation in eyes and the throat, and unidentified complaints of a headache, weariness and impatience which attack the residents in such houses.

The term, “multiple chemical sensitivity (MCS)”, is often mistakenly understood that it is same symptoms as this “sick house syndrome”. It should be defined as follows.

In the MCS, a human is made “susceptible” by being exposed to certain kind of high concentration chemicals. Once he and/or she become susceptible, then they react to the same or similar chemicals even if concentrations of the chemicals are far lower than previous level. The reactions are, moreover, getting worth gradually. The MCS is brought by the living in sick house, but also brought by exposure to high concentration chemicals. Nurses and workers of chemical industries are apt to be encountered such chemicals.

Although main symptoms of sick house syndrome and MCS is almost similar, we do not confuse them. When entering a polluted house like this, human shows the symptoms which happen to everyone in a sick house. Causes are in the house. In this case “polluted” means that pollution levels in the house is exceeded the guideline level that was established by the Ministry of health (MHLW), labor and welfare of Japan. On the other hand, MCS also appears at the indoor concentration level where ordinary people do not have any problem (The levels is below the guidelines set by MHLW and is difficult to evaluate as “polluted”). There are no problems with a house in this case, because there will be health problems with residents, and some medical treatments to the residents are needed. In
another words, the symptoms which happen over the MHLW guideline value should be called as sick house syndrome, and the one which happen below the guideline value should be called as MCS. This is author’s individual definition. Such definition is, somehow, difficult to get an overall approval from medical specialists. Perhaps it’ll be because they are going to define it based on the clinical condition absolutely. It might be incompatible for them to introduce environmental factor like an indoor air concentration. What the author wants to insist is that a turning point of a definition is a located turning point of responsibility. In another words, it is an architectural engineer (a person who makes a building) to cure sick house syndrome, and it is a medical doctor to cure MCS.

6. Importance of the regulatory control to protect the indoor air quality

The way to appear SBS in Europe and America was quite drastic. The problems happened in this country were, however, not so sever compared to European and American cases. It is considered, as the first reason, that enough ventilation had been supplied because the energy conservation effect by reducing the outdoor air rates was less effective compared to European and American countries as the climate in Japan was rather gentle compared to these countries. However, there was still the time when Japanese tried to reduce ventilation rates in design and management because of a socio-economic buildup pressure on the energy cost. Such pressure was especially strong in large-scale buildings equipped with HVAC system. The social situations in this country were different from a European and American case, and ventilation rates could not be reduced easily as there is a Law, so-called “Building Maintenance Law” (Yuki, 1982). The Law regulates only the environments of specific office buildings, that is, the law regulates about the concentrations of carbon monoxide, carbon dioxide and SPM (Suspended Particulate Matters), temperature and humidity, but it considerably affected to the indoor environment design and management. It was also effective even to the non-regulatory buildings. Therefore, indoor air pollution problems, so-called “SBS”, did not occur intensely in this country unlike European and American countries. There was, however, something similar to those. Mass outbreak of tuberculosis infection via the air conditioning systems was reported in a small commercial building which was not object of the Law because the total floor area was far smaller (Minowa, 1983). One patient was suspected as a spreader of the infection. An investigation by the health center was conducted along with IAQ investigation conducted by the author. The investigation items were indoor air qualities including bacterial pollution. A tuberculosis bacillus was found from nowhere as a result. Outside air intake dampers were closed perfectly because it was not the building to which The Law was applied. For it, for example, the indoor carbon dioxide concentration indicated the values which are far exceeded to standard Value, 1,000 ppm of the Law. This example shows clearly that the miscellaneous problems concerned with indoor air pollution like SBS also happen in our country if there were no law like the Building Management Law.

Outbreak of SBS was not seen in case of any office in Japan, because of the effect of the Law. There was, however, a possibility of occurring the SBS in housing because there was nothing such at all before 1997 in case of housing. And it appeared as the “sick house syndrome in 1990s” actually. After that, the rise of the social interest of this matter was enormous. Indoor air quality Guidelines for residential buildings, which was thought that it did not match to regulate by laws and guidelines up to that time, were established (Ministry of Health Labor and Welfare, 2000). Then it was come up with changes in the Building Standards Law (Sekine, 1988), Building maintenance Law in school health (The Ministry of Education, Culture, Sports, Science and Technology, 2001) and so forth.

Field measurement results on indoor formaldehyde in 5000 homes by the Ministry of Land, Infrastructure and Transport showed the effects of such administrative measure (Osawa et al., 2003). Fig. 1 shows a relation between formaldehyde concentrations and year after construction of the surveyed residential buildings.

As seen in Fig. 1, survey results showed that indoor concentrations in the houses getting higher according to the years after construction get older until 5 years. It means that concentrations in the house constructed 4-5 years ago were getting higher than newer houses. Indoor formaldehyde concentrations in homes are normally getting lower according to year after construction getting older, as emission rates of the formaldehyde in the building material deease gradually. One of the reasons of the fact shown Fig. 1-3 is considered as follows. One is decrease in emission rates from the
building materials of newer houses, and the other is strengthened in indoor concentration decrease measures introduced to the newer houses. It was middle of 1990s when the homes in question were built as this investigation was conducted after year 2000, and it had passed 4 or 5 years since then. Guidelines of MHLW were not established yet at that time. This fact that concentrations obtained from newer residential buildings, where higher concentrations would be observed if there was no guideline, were lower than those obtained form older ones clearly showed that indoor concentrations in newer houses were decreased by effects of the guidelines established by MHLW.

7. Conclusions

The indoor air quality is controlled effectively by ventilation technically, and also regulated by appropriate government guidelines administratively.

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