The current of air-tightness and ventilation system in houses of Japan

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ABSTRACT

In recent years, the insulation and air-tightness levels of newly constructed houses in Japan have been improved for purpose of energy saving. However, a reduced design of air permeability (i.e. a high level of air-tightness) will provide insufficient air through infiltration resulting in a significant and negative impact on a social problem of sick house syndrome. The Japanese Building Standard has been revised to reduce the concentration of Formaldehyde which is considered to be one of the main causes of sick house syndrome. This Standard provides guidance concerning the specific preferences, for instance, ventilation systems should be placed in the buildings and the usage extent of interior material should be restricted depending upon individual conditions of emission volume of Formaldehyde. As a result, the sick house problem seems to be declining gradually. However, this problem has not yet been solved, and health disorder caused by chemical substances, besides Formaldehyde, mould and fungus has become a big problem recently.

In this paper, the method of measurement, the actual circumstances, certification and problems of air-tightness of houses in Japan, which are deeply concerned with the problems mentioned above, is firstly stated. Secondly, the current of ventilation system, contents of Japanese Building Standard, results of measurement on ventilation rate and problems of ventilation systems, necessity of commissioning procedure for ventilation system, and subjects in the future will be described.

1. INTRODUCTION

In recent years, the insulation and air-tightness levels of newly constructed houses in Japan have been improved for purpose of energy saving. However, a reduced design of air permeability (i.e. a high level of air-tightness) will provide insufficient air through infiltration resulting in a significant and negative impact on a social problem of sick house syndrome. The Japanese Building Standard has been revised to reduce the concentration of Formaldehyde which is considered to be one of the main causes of sick house syndrome. This Standard provides guidance concerning the specific preferences, for instance, ventilation systems should be placed in the buildings and the usage extent of interior material should be restricted depending upon individual conditions of emission volume of Formaldehyde. As a result, the sick house problem seems to be declining gradually. However, this problem has not yet been solved, and health disorder caused by chemical substances, besides Formaldehyde, mould and fungus has become a big problem recently.

This paper outlines the results of the survey on the current status of air-tightness and ventilation system of houses in Japan, and indicates the scope of future works which need to be focused on.

2. AIR-TIGHTNESS

2.1 Measurement of air-tightness

Studies of building air-tightness were initially carried out about 30 years ago in Japan by Narasaki et al. (Narasaki et al, 1974), Murakami and Yoshino et al. (Sugiyama et al, 1975) (Ohta et al, 1976) and Asano et al. (Asano, 1977). Murakami and Yoshino et al. examined the air-tightness of detached houses and found that the air-tightness was very different in the investigated houses and there are many cracks besides windows and external doors (Sugiyama
et al, 1975) (Ohta et al, 1976). Based on the results, it was concluded that the air-tightness varied depending on the accuracy of construction and it could not be defined without measurement.

As an indicator for evaluating building air-tightness, it was proposed to define opening area to correspond to the size of leakages, and also to describe using numerical value per floor area under condition of 1 mmAq (9.8 Pa) which is the pressure difference in regular outdoor condition. This value of 1 mmAq (9.8 Pa) made the calculation of the corresponded opening area easy, and since then it has been commonly adopted to evaluate the air-tightness of buildings.

2.2 Grades of air-tightness

About the same time, many examples of measurement were reported outside of Japan, and standards proposed from many other countries were announced to public. Murakami and Yoshino et al. (Murakami et al, 1983) (Yoshino, 1990) tabulated the grades of air-tightness by using measurement data in Japan, which is based on the rate of opening area corresponding to the size of leakages per floor area (called corresponded leakage area). Five different grades of air-tightness, each corresponds to leakage area and measured data, were suggested. The tabulated values were prescribed based on the Renard number, which is the industrial preferred number, so that the measured values would be varied. Grade 3 is applicable to 5 cm$^2$/m$^2$, that is the standard for northern houses in Hokkaido, and this grade of air-tightness is easy to achieve. Another example is the house R2000 (originated from Canada) which is classified in Grade 1.

2.3 Energy-saving Standard and Air-tightness Certification

The Energy-saving Standard of houses was constituted in 1980 and revised in 1992. The expression of “Air-tight house” was introduced, and it is defined as the building should have corresponded leakage area less than 5 cm$^2$/m$^2$. It was described that the houses in Hokkaido must meet this standard, and in three northern prefectures of Tohoku Region it is desirable to have houses qualified for the standard. Although this standard is not enforceable, it has been implemented to houses which are subjected to loan from the housing finance corporation.

The Energy-saving Standard was revised again in 1999 under the influence of the prevention of global warming. And the value of corresponded leakage area of less than 2 cm$^2$/m$^2$ has been standardized for Hokkaido and three northern prefectures in Tohoku. The value of less than 5 cm$^2$/m$^2$ has been standardized for other areas, and this has been the standard for the rest of Japan.

Institute for Building Environment and Energy Conservation (IBEC) has provided the evaluation system for ‘Air-tight house’ soon after the revision of 1992 and endeavored popularization of Air-tight house. In the evaluation system, three levels of air-tightness; A, B and C, were provided and each corresponded leakage area was set to be 5, 2, 1 cm$^2$/m$^2$, giving the air change rates of 1.5, 3.0, 7.5 ACH at the indoor-outdoor pressure deference of 50 Pa respectively. The acknowledged residential systems are now about 170. Most of the houses in Japan have the level of less than 5 cm$^2$/m$^2$, and the level of less than 2 cm$^2$/m$^2$ has become common for the buildings when considering air-tightness.

The engineers for measuring air-tightness in houses have registered after training by IBEC since 1998, from the viewpoint of the urgency to popularize appropriate technology of air-tightness measurement nationwide. The number of engineers registered with certificate has reached about 3,800 in May, 2008.

2.4 Method of air-tightness measurement

In Japan, method of air-tightness measurement was constituted in 2003, known as JIS (Japanese Industrial Standard) A2201. In 1996, ISO was firstly constituted, namely ISO 9972, and it was revised in 2006 by referring to JIS, EN 13829 and ASTM E1824, which are basically having a mutual point as the pressure difference and airflow rate are measured. On the other hand, in the ISO standard, corresponded leakage area of JIS can be used. The original plan of ISO standard was made in TC163/SC1/WG10 and convened by Hiroshi Yoshino.
2.5 Effective factors of air-tightness

2.5.1 Pressurized method and depressurized method
In this category, the pressurized method keeps the indoor air pressure higher than outdoor while the depressurized method keeps the indoor pressure lower than outdoor pressure. The leakage area considered in the pressurized method is larger than that of depressurized method because the force from indoor inflates the building envelope. The measuring data obtained from previous studies found that the result of pressurized method was 100 – 120% of result of depressurized method (Yoshino, 1983). As engineers and equipments can be influenced by outdoor coldness in case of pressurized method, JIS does not decide which of methods should be selected.

2.5.2 Changes of air-tightness
It has been proved by some measurements that the performance of air-tightness declines due to the dryness of building materials (e.g. lumber) and the frequency of opening and closing of windows/doors. In Japan, Irie and Fukushima et al. (Irie et al, 1990) carried out twice measurements, soon after the completion and one year after respectively, in nine houses, and described that the opening area has been increased about 100cm². And also similar measurements were carried out in England (O’Sullivan et al., 1982) and Sweden (Elmoorth, 1981). New large-scale measurement data is necessary as the past data are old.

(3) Influence of humidity
The opening area gets influenced by expansion and contraction of materials, especially in those wooden houses. There are very few measurements on seasonal changes of air-tightness, however there are some measured data available in Canada (Kim et al., 1984), England (Warren et al., 1980) and Japan (Yoshino et al., 1992). All of the measurements showed that the openings became smaller right after the end of humid summer and became bigger right after the end of dry winter. The amount of seasonal changes is very different depending on measurement. In the measurement results done by Yoshino et al. (Hasegawa, 1992), the seasonal changes were ± 20% of the average of the year. This is considered to be very big, and accumulation of new data for this measurement is also necessary.

2.6 Air-tightness of building elements
There are many kinds of openings, besides those on window sashes, doors and ventilation inlets/outlets, for examples around the edge of lighting equipments, mail box and around the edge of wall socket, wiring and piping. Recently, the window sashes are designed very tight, so there are many openings in hidden places rather than the edges of windows. The measurement results on air-tightness of building elements are very few in Japan and other countries as the method of measurement is very complicated. General method is to measure the same place twice, i.e. with and without sealing the place, and the difference between these two measurements are the result of air-tightness. It has been shown that the openings differ from building to building, and it is also believed that the opening area increase after years. The availability of data is still lacking to confirm this issue.

2.7 Subjects in future
The method of air-tightness measurement in buildings are now available for use, however, the method of building elements should be developed.
As for the data of air-tightness, it is necessary to accumulate data related to deterioration from passage and influence from humidity.

3. VENTILATION SYSTEM

3.1 Actual condition of ventilation system
Air pollution in the house is caused by the presence of people and their activities. In order to safeguard our health, rooms must be properly ventilated to improve the quality of air and to provide the right degree of comfort. In houses, the domestic ventilation systems are commonly placed in the pollutant source zones such as kitchen, lavatory and bathroom. In 1950, the Japanese Building Standard announced that domestic ventilation systems must be installed in kitchen, bathroom and other rooms where
facilities (e.g., gas ring) and equipments (e.g., heater) are all obvious sources of fire. The required ventilation rate was calculated based on the fuel consumption rate and the theoretical exhaust gas rate per fuel consumption rate of an hour. For example, three gas rings and a gas hot water heater are used simultaneously, the required ventilation rate is about 450 m$^3$/h, which is a rather high value.

On the other hand, passive cooling by natural ventilation via opening windows and other openings is one of the promising and common methods to achieve thermal comfort. Japanese Building Standard prescribed that the effective areas should exceed one twentieth of the room floor area. The common type of domestic ventilation system has an axial flow fan without duct system involved, however, some of the multi-family type houses have the ventilation system connected to bathroom and toilet outlets with ducts and ventilation is operating simultaneously with sirocco fans.

The number of houses with high thermal insulation and high air-tightness has been increased recently, and the mechanical ventilation system for the entire building is commonly installed together with the domestic ventilation system mentioned above. The required ventilation rate is about 0.5 ACH, which is calculated based on the assumption of CO$_2$ emission rate of four residents in a regular residential house. This ventilation rate value also corresponds to the value for controlling CO$_2$ concentration (that is the indicator for indoor air pollutant) less than standard value, 1000 ppm.

### 3.2 Revised Japanese Building Standard for Ventilation

From the viewpoints of global warming and greenhouse gas, the thermal insulation and air-tightness of houses have been improved. However, insufficient supply airflow rate through cracks on building envelopes and increased usage of building materials that consist of various chemicals are the causes of the sick house problem. In Japan, the sick house problem has been a big social topic and has been surveyed variously. The Ministry of Land, Infrastructure, Transport and Tourism of Japan carried out a nationwide survey on sick house problem of ten thousand residential houses (Osawa et al., 2007). The results clearly showed that the concentration of formaldehyde of 27.3% of the investigated houses exceeded the guideline (100 μg/m$^3$) established by the Ministry of Health, Labour and Welfare of Japan. Thus, the Japanese Building Standard was revised in 2002 aiming to reduce the indoor Formaldehyde concentration. Then restriction on the usage of interior materials depending on the emission rate of formaldehyde, installation of mechanical ventilation system and as a general rule secure of ventilation rate in rooms with more than 0.5 ACH were established (Web page of Ministry of Land, Infrastructure and Transport).

The results of the survey on foreign countries’ standards are shown in Figure 3-1. The standard of each country was calculated based on building capacity, floor space, numbers of occupants and ventilation systems (See note

![Figure 3-1 Results of foreign countries’ standards](image-url)
[1]). Although the content of each country is different, the calculated results of required ventilation rate targeting on Standard House show clearly that the ventilation rate is 0.5 ACH or slightly more than 0.5 ACH in many countries (Yoshino et al, 2004).

3.3 Measurement results of ventilation rate

The ventilation rate of 75 houses in the Tohoku region of Japan was investigated (Mihara et al., 2005). These houses were all suspected having sick house problem. The obtained ventilation rates of those houses with mechanical ventilation systems were 0.2 – 0.9 ACH, which is suggested that only 23% of the total houses could meet the required ventilation rate of 0.5 ACH. It was believed that one of the causes of insufficient ventilation rate was due to the problem related to the maintenance of ventilation system, for examples: choking of inlet and outlet grills, insect screen and air filters covered with dust.

In 2005 and 2006, another surveys of 18 houses located in the Tohoku region were carried out (Takaki et al, 2006) (Yoshino et al, 2007). Figure 3-2 shows that the results of exhaust airflow rates before and after the filters were cleaned. Among these investigated buildings, 11 of them (Houses A–G, I, J, M and N) were built after the Japanese Building Standard was revised in 2002. It can be seen that there are some differences showed in the results, and the differences are influenced by the level of accumulated dust. However, there are many houses with increased exhaust airflow rate after the filters were cleaned. The airflow rate of House N has least value (0.1 ACH) and biggest value (0.45 ACH), before and after the filter was cleaned respectively. This increment of airflow rate is rather dramatic. There were some cases that the airflow rates at inlets and outlets were not observed. Therefore, the construction of ventilation system was examined. It was found that some ducts were either broken or fallen off from the heat exchange unit or chamber. This problem can be attributed to the careless construction process. As shown from the results of measurement and survey, it indicated that the ventilation performance of many houses does not meet the designed airflow rate criterion of 0.5 ACH. And hence it is a very important issue how the ventilation performance of houses can be improved.

3.4 Necessity of Commissioning Procedures

In order to ameliorate the problem of insufficient ventilation in houses, it is essential to have verification on primary performance of the ventilation system in the stage of completion. In the stage of operation, it is necessary to inspect the ventilation system periodically because the decrease of ventilation rate is caused by fine dust constantly choking the filter screens. And immediately after the completion, there are cases that ventilation rate is insufficient, which is probably due mainly to the inappropriate planning of ventilation system. Therefore, it is essential to have synthetic test and commissioning procedures on the performance verification of the ventilation system in the stages of designing, completion and operation of buildings.

In regard to the method of measuring ventilation rate, it is important to develop a measurement method with simple operation system and high accuracy as well as performance criteria for ventilation system evaluation.

About the measurement method, a Standard entitled “Thermal performance of buildings – Determination of air change in buildings: Figure 3-2 Exhaust airflow rates before and after cleaning the filters.
Tracer Gas dilution method” (ISO12569) was established in 2000. The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan (SHASE of Japan) proposed the measurement method of ventilation rate in single zone using tracer gas in 1998. And ISO12569 has been under revision by referring to these standards. SHASE of Japan has been surveying many Standards of other foreign countries and organizing the scheme of Standard for field measurement of ventilation rate. Additionally, standardization of ISO is considered.

3.5 Subjects in future

Ventilation is the intentional movement of air from outside a building to the inside. Good ventilation is performed aiming to remove indoor pollutant concentrations or to reduce their concentrations as well as to control indoor temperature and humidity. It is thus indispensable to maintain a balanced level of air pressure inside the home that provides the proper amount of air exchange for both its occupants and its combustion appliances.

In Japan, the required ventilation rate of houses is based on the revised Japan Building Standard 2002 which is designated to reduce the concentration of Formaldehyde. The results obtained from the nationwide survey done by the Ministry of Land, Infrastructure, Transport and Tourism of Japan show that the level of Formaldehyde concentration has indeed fallen below the set limit specified by the revised Japanese Building Standard 2002. In 1997, the Ministry of Health, Labour and Welfare of Japan established the first guideline of Formaldehyde and further formulated 12 more between the years 2000 and 2002 because the problem of health disorder caused by more chemical substances besides Formaldehyde, was noticed. In addition, there are many other pollutants, except chemical substances, existing in buildings, such as mould, fungus, bacteria, house dust, virus, bacterium, smoke of cigarette etc. Therefore, it is necessary to consider the required ventilation rate by referring to them. In recent years, various studies on mould, fungus and house dust, which are suspected as the causes of allergy and asthma, have been carried out in Japan.

In foreign countries, the relation between ventilation issues and occupants’ health conditions has been examined variously, but the study related to houses is lacking. According to those studies related to office space, the results showed that the ventilation rates below 10 L/s per person are associated with a significantly higher prevalence of one or more health outcomes or with worse perceived air quality. On the other hand, increases in ventilation rates above 10 L/s per person, up to approximately 20 - 25 L/s per person, are associated with a significant decrease in the prevalence of SBS symptoms or with improvements in perceived air quality. Discussions on whether ventilation rate should be increased or not have been seen in international conference (Seppanen, 2008). It is necessary to consider the required ventilation rate of houses from much kind of view points.

4. CONCLUSION

This paper outlines of the current trend of air-tightness and ventilation system in houses of Japan. The summary of this paper is given as follows,

1) In Japan, studies of building air-tightness were initially commenced 30 years ago. The development of indicator for air-tightness evaluation using corresponded crack area was proposed by Murakami and Yoshino.

2) Soon after the Energy-saving Standard of houses was amended in 1992, the activities of evaluation system for air-tight house had started. To date, the total number of acknowledged residential systems is about 170 and the total number of engineers related to air-tightness measurement has reached about 3,800.

3) Subjects in the future related to air-tightness are that the method of building elements is developed, and that accumulate data related to deterioration from passage and influence from humidity.

4) The Japanese Building Standard was revised in 2002 to solve sick house problem. In this standard, the restriction on the usage of interior materials depending on the emission rate of formaldehyde, installation of mechanical ventilation system and as a general rule secure of ventilation rate in rooms with more than 0.5 ACH were established.
5) According to the field survey carried out by the current authors from 2005 to 2006, there are many houses where ventilation performance does not meet the designed goal of 0.5 ACH. This is because the air filters are choked by dust and some ducts are either broken or fallen off from the heat exchange unit or chamber.

6) It is essential to have synthetic commissioning procedures for performance verification of residential ventilation system in the stages of designing, completion and operation of buildings. And also, it is important to develop a measurement method with simple operation system and high accuracy as well as performance criteria for ventilation system evaluation.

7) Subjects in the future related to ventilation system should include the consideration of required ventilation rate for houses from the viewpoint of actual conditions of indoor pollutants and health risk of occupants.

NOTE

[1] Trial calculations of required ventilation rate in Japanese standard house (two-storey independent house with 126m² floor space and 302m³ house volume) is provided by Architectural Institute of Japan were carried out. (Udagawa, 1985) The occupants are a family of two adults and two children.

REFERENCES


