Airtightness Standards for Residential Buildings in Japan

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ABSTRACT

*In consideration of energy conservation and thermal comfort, an airtightness standard was included in the revised national standard for insulation performance of the housing envelope in Japan. Also, the design manual for high-quality houses, the so-called Japanese R-2000 houses, published by the Japan 2*4 Home Builders Association in 1991, prescribes an airtightness standard. The level of this standard is higher than that of the national standard.*

This paper reviews the results of airtightness measurements of different types of houses in different countries and compares airtightness standards in different countries. The background of the airtightness standard prescribed in the revised Japanese national standard is described, as well as the factors that influence airtightness, for example, the number of years since construction. Finally, the housing appliances corresponding to the rank of airtightness are recommended.

INTRODUCTION

The Law Concerning the Rationalization of Energy Use in Japan was enacted in 1979 after the oil crisis. In 1980, the first standard for the insulation performance of the housing envelope (Criteria on Judgement of Client for Rationalization of Energy Use in Residential Buildings) was issued, which specified the minimum heat loss coefficient for each of the five different climatic regions in Japan. If a house was constructed or retrofitted according to this standard, the owner could receive a larger loan from the Housing Finance Corporation. This standard has significantly promoted the widespread use of thermal insulation in houses. Since April 1989, the insulation standard has been obligatory if the owner wishes to obtain a loan for construction from the Housing Finance Corporation.

In recent years, the degree of thermal insulation and airtightness of newly constructed houses, which has greatly increased due to the need for energy conservation and thermal comfort, has surpassed the level of the 1980 standard. That standard was revised in February 1992, and an airtightness standard was included. The "airtight house" is defined as a house with an equivalent leakage area less than 5 cm^2/m^2 of floor area, and it prescribes that houses be made airtight in the Hokkaido district and recommends that they be made airtight in the three northern prefectures of the Tohoku district. The 1992 standard also revised the value of the air change rate for calculating heat loss coefficients to be less than that of the 1980 standard.

The Japan 2*4 House Builders Association published a design manual for high-quality houses, the so-called Japanese R-2000 houses (similar to Canadian R-2000 houses), and the system authorizing those houses was started in 1991. That design manual requires an airtightness level equal to that of Canadian R-2000 houses.

This paper reviews the results of airtightness measurements of different types of houses in different countries and compares airtightness standards in different countries. The background of the airtightness standard prescribed in the revised national standard is described, as well as factors that influence airtightness, for example, the number of years since construction. Finally, the housing appliances corresponding to the rank of airtightness are recommended.

MEASUREMENT METHOD FOR AIRTIGHTNESS AND ITS EXPRESSION

Measurement of Airtightness

As is well known, airtightness performance is measured by the use of a fan or a fan connected with a duct that is installed in an opening, such as windows, doors, or air inlets, to pressurize or depressurize the house. In many cases, the results obtained with the pressurization method reveal a house to be more leaky than is shown with the depressurization method because the building cracks are compressed when the depressurization method is used. Figure 1 shows a comparison of results obtained with the two methods, for equivalent leakage area per floor area, including data measured by other researchers.[1-3] The leakage area obtained with the pressurization method is larger than that obtained with the depressurization method regardless of the airtightness level of the houses. The ratio of the difference of the leakage area between the two methods to the results obtained with the pressurization method is 13% on the average and 40% at the maximum.

In Japan, researchers use the pressurization method for the reason described above. However, in Hokkaido, a region of cold climate, many airtightness tests have been done by the depressurization method because when it is used, outside cold air enters a room directly and causes inspectors to feel cold. Therefore, the airtightness standard does not prescribe which method should be employed. It will include the modification factor when one of the methods is employed.

The airtightness measurement methods of the American Society for Testing and Materials,[4] the International

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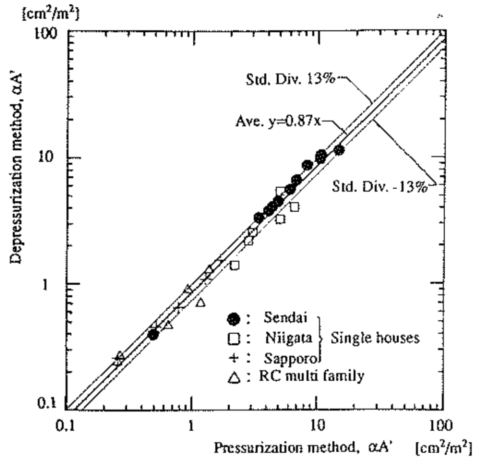

Figure 1 *Comparison between two methods.*

Standards Organization,[5] and Sweden[6] direct that the results obtained by the two methods should be averaged, as does the Japanese R-2000 manual.

Expression of Airtightness Performance

The relation between the pressure difference across the building envelope and the volumetric flow rate obtained with the pressurization method is expressed by

$$Q = Q_r(\Delta p/\Delta p_r)^{\frac{1}{n}} \qquad (1)$$

where

Q = volumetric flow rate, m^3/h;
Q_r = Q for $\Delta p = \Delta p_r$, m^3/h;
Δp = pressure difference across the building envelope, Pa;
Δp_r = reference pressure difference, Pa;
n = leakage exponent.

Therefore, airtightness performance can be expressed by Q_r and n. But using these factors, it is difficult to express the degree of airtightness, so the equivalent leakage area corresponding to the airtightness performance is adopted as its index. In the case of an orifice plate, the relationship between the pressure difference across the plate and the volumetric airflow is

$$\Delta p = \rho/2(Q/A \cdot 10{,}000Q/3{,}600A)^2 = \rho/2(2.78Q/A)^2 \qquad (2)$$

where

A = effective orifice area, cm^2;
ρ = air density, kg/m^3.

Therefore, the effective orifice area is obtained by

$$A = 2.78Q(2\Delta p/\rho)^{-0.5}. \qquad (3)$$

Substituting Equation 1 for Equation 3, the effective orifice area, which is the effective leakage area, is given by

$$A_r = 2.78Q_r(\Delta p/\Delta p_r)^{\frac{1}{n}}(2\Delta p/\rho)^{-0.5}. \qquad (4)$$

If $\Delta p = \Delta p_r$, Equation 4 is rewritten simply as

$$A_r = 2.78Q_r(2\Delta p_r/\rho)^{-0.5}. \qquad (5)$$

The value of Q_r depends on the value of Δp_r, and the value of A_r is obtained when the value of Δp_r is determined. Therefore, it is significant how the value of Δp_r is selected. In Japan, Δp_r is given the value of 9.8 Pa, which is 1 mm H_2O. This unit is normally used in Japan, considering the pressure range exerted upon the building surface in a natural environment and the easy handling of the value of 1 mm H_2O. If $\Delta p_r = 9.8$ Pa, Equation 5 is rewritten as

$$A_r = 2.78Q_r(2 \cdot 9.8/\rho)^{-0.5} = 0.7Q_r. \qquad (6)$$

The airtightness standard in Japan prescribes Equation 6 for calculation of the equivalent leakage area, A_r, and determines the value of A_r per floor area, A_r^*, as an index of the airtightness performance of houses.

As the value of Δp_r, the ASHRAE standard[7] and the Canadian building standard[8] prescribe 4 Pa and 10 Pa, respectively. According to building standards in Sweden[6] and Norway[9] and in the Canadian R-2000 design manual,[10] the value of the air change rate, which is the volumetric flow for $\Delta p = 50$ Pa divided by the air volume of the house, is used as an index of airtightness performance of houses. The Japanese R-2000 design manual[11] follows the Canadian R-2000 design manual.

COMPARISON OF AIRTIGHTNESS FOR VARIOUS HOUSES USING EFFECTIVE LEAKAGE AREA PER FLOOR AREA

Many investigators have measured the airtightness performance of houses.[1,12-32] Figure 2 shows the effective leakage area per floor area for various houses in different countries. Where the original airtightness data were not shown as A_r for $\Delta P_r = 9.8$ Pa, these data were converted, assuming $1/n = 0.6$. The originals of this figure were presented by Murakami et al.[23,33] and Yoshino,[34] which are revised in this paper.

Airtightness Performance in Japan

Figure 2 indicates that A_r^* is significantly distributed from 0.2 to 20.0 cm^2/m^2 and shows that houses are becoming more airtight year by year.

In Hokkaido, the airtightness rank of newly constructed houses was 3 to 4 in 1987 and 2 to 3 in 1988 and 1989, which is less than the value of 5 cm^2/m^2 for an airtight house. These houses have polyethylene sheets, which results in a higher degree of airtightness.

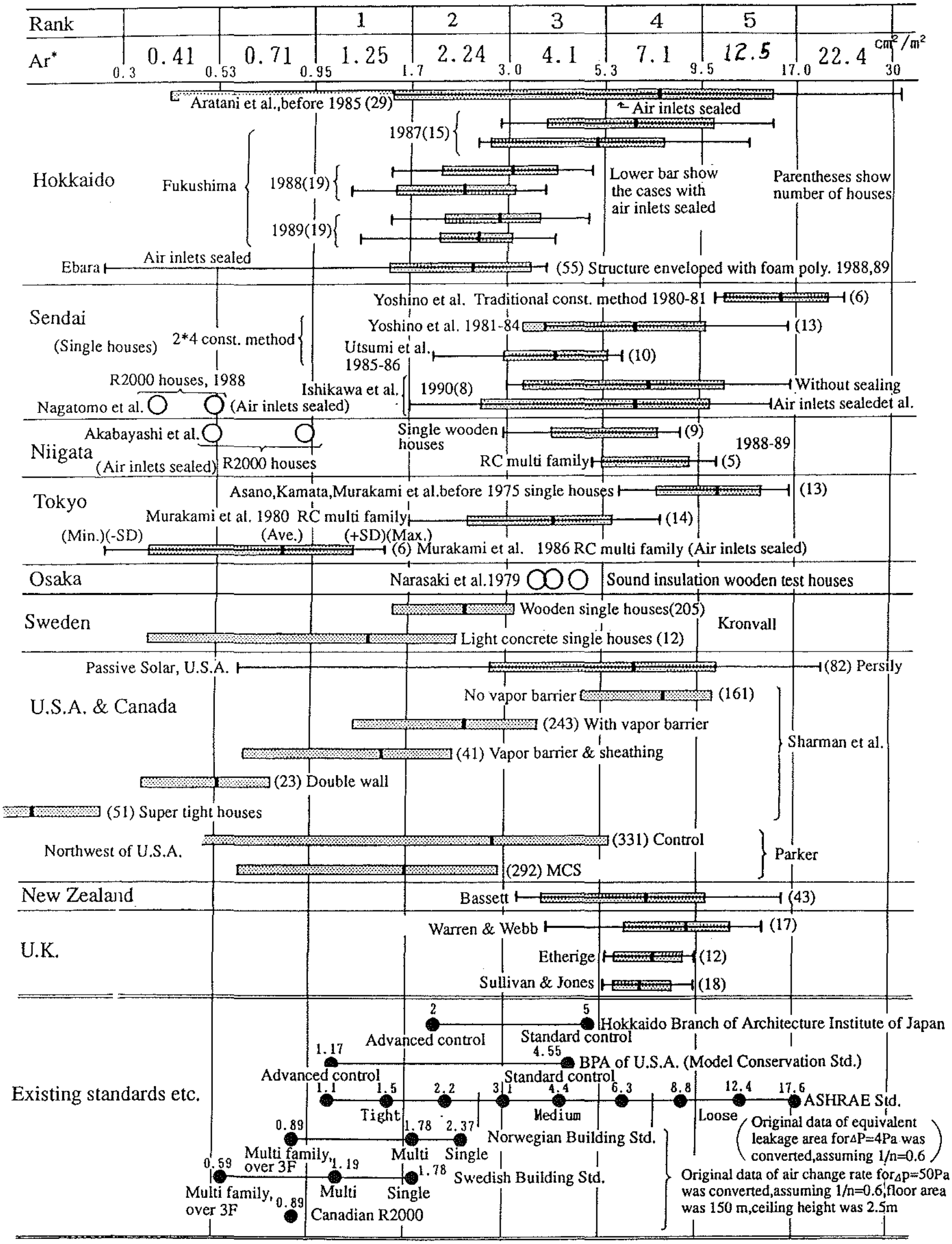

***Figure 2** Airtightness for various houses in different countries using Ar*.*

TABLE 1
Heating and Ventilating Systems and Cooker Types Corresponding to the Airtightness Rank of a House

Rank	1	2	3	4	5
Effective leakage area, Ar*(cm²/m²)	1.25 (Remarkably airtight)	2.24 (Airtight)	4.1 (Slightly airtight)	7.1 (Slightly leaky)	12.5 (Leaky)
Heating systems	Central system and passive solar heating	Central system (living room and bedrooms are heated)	Local heaters (vented heater or heat pump)	Portable local heaters (vented or semi-vented heater and electric heater "Kotatsu")	Portable local heaters (unvented heater and electric heater "Kotatsu")
Cooker types	Electricity	Electricity	Gas	Gas	Gas
Ventilation systems; Living room and bedrooms		Mechanical ventilation with heat exchanger	Mechanical ventilation only for living room	Natural ventilation by air inlets	Natural ventilation by opening windows
Kitchen	Central mechanical ventilating system with heat exchanger	Local mechanical ventilation with a heat exchanger	Local mechanical ventilation	Local mechanical ventilation	Local Mechanical ventilation
Bathroom and lavatory		Mechanical ventilation	mechanical ventilation	Natuaral ventilation by air inlets	Natural ventilation by opening windows

Note: A vented heater takes in outside air for combustion and expels the exhaust outdoors. A semi-vented heater uses indoor air for combustion and expels the exhaust outdoors. A "Kotatsu" is a Japanese device consisting of a heating element mounted under a low table covered with a quilt.

The houses constructed according to the Canadian R-2000 design manual in Sendai and Niigata are extremely airtight, their A_r^* values being less than 1 cm^2/m^2.

The multifamily houses in the area around Tokyo also have became extremely airtight in recent years.

Airtightness Performance in Foreign Countries

In Sweden, detached wooden houses and lightweight concrete houses ranged between rank 2 and below. Passive solar houses in the United States are not so airtight, ranging between rank 3 and rank 4. Sherman et al.[27] collected data of airtightness measurements and classified the data according to building construction methods. The results show that houses with a vapor barrier or a vapor barrier and sheathing are in rank 2 to rank 3 and double-wall houses and supertight houses are extremely airtight. In the case of supertight houses, the leaks that had been discovered by the pressurization test were sealed.

Not much information is available from New Zealand and the United Kingdom. Since the requirements for airtightness are not high due to the mild climates, the houses in these two countries are placed in rank 3 to 4 and in rank 4, respectively.

EXISTING STANDARDS OF AIRTIGHTNESS PERFORMANCE

Figure 2 includes the values of existing standards for airtightness performance. The Hokkaido branch of the Architectural Institute of Japan proposed 5 cm^2/m^2 as the value of A_r^* for the standard level and 2 cm^2/m^2 for the advanced control level. In accord with this proposal, the Hokkaido local government adopted an A_r^* value of 5 cm^2/cm^2 as the airtightness standard for houses in the northern region. Owners of houses meeting this standard may obtain a larger loan from the local government.

Model conservation standards[35] in the Pacific Northwest region of the United States require for standard houses an airtightness level less than 7 ach for $\Delta p = 50$ Pa, which is equivalent to an A_r^* of 4.6 cm^2/m^2. For advanced control houses, the airtightness level should be less than 2 ach for $\Delta p = 50$ Pa, which is equivalent to an A_r^* of 1.17 cm^2/m^2, and a ventilating system with a heat exchanger should be installed.

ANSI/ASHRAE Standard 119-1988[7] shows a map of regions classified by the infiltration degree-day index corresponding to the ventilation heating and cooling load and prescribes a limit of A_r^* for each region ranging from 1.1 to 17.6 cm^2/m^2. It is interesting that nine values of the limit are plotted from rank 1 to rank 5 in this map.

The A_r^* of Norwegian and Swedish building standards ranged below rank 2. The Canadian R-2000 design manual prescribes an A_r^* of almost 1 cm^2/m^2.

BACKGROUND OF THE AIRTIGHTNESS STANDARD IN JAPAN

The revised national standard for insulation performance of the housing envelope includes an airtightness standard that defines an "airtight house" as one with an A_r^* less than 5 cm^2/m^2. It directs that houses must be airtight in the Hokkaido district and recommends they be made airtight in the three northern prefectures of the Tohoku district. The reasons for these prescriptions are as follows:

1. As shown in Figure 2, newly constructed houses with vapor barriers in the Hokkaido district are plotted from rank 2 to rank 3, which means the A_r^* of these houses is less than 5 cm^2/m^2.
2. The Hokkaido local government adopted an A_r^* of 5 cm^2/m^2 for houses in the northern region. It was assumed by the government that this level could be easily reached without extra training and extra money.
3. An A_r^* level of 5 cm^2/m^2 is not so airtight from the point of view of measurement results, but this is the first time that the concept of an airtight house has been included in the national standard. This level also can be reached in the Tohoku district, where construction methods to make houses airtight are not yet popular.

FACTORS INFLUENCING AIRTIGHTNESS PERFORMANCE

It is known that airtightness decreases in the years after construction and changes with the season. Fukushima[13] reported that the equivalent leakage area of nine houses increased by about 100 cm^2 in the year after construction. Sullivan and Jones[32] showed for six houses, Elmroth[36] for five houses, and Warren and Webb[37] for one house that airtightness performance decreased by a factor of 2 one to two years after construction and did not change afterward because of the drying of timber as well as the wear and tear on door and window frames.

Kim and Shaw[38] measured the seasonal change in airtightness of two houses and reported that air leakage was smaller in the summer and larger in the winter. The difference in airtightness between the maximum and the minimum was about 20% of the mean value. Warren and Webb[37] also reported that the difference was about 30% by measuring one house. It is assumed that the reason for the seasonal change of airtightness performance is the expansion and contraction of timber due to humidity.

Figure 3 shows the seasonal change in airtightness performance of a house measured by the author and others, which has the same characteristics as reported in the literature.

HOUSING APPLIANCES CORRESPONDING TO THE RANK OF AIRTIGHTNESS

In order to minimize air infiltration, maintain clean indoor air, and avoid an extreme decrease in internal pressure, the optimum combination of heating and ventilating systems and types of cooking appliances should be designed to correspond to the airtightness rank of a house.

Table 1 shows examples of combinations of systems corresponding to the airtightness rank that the author proposes. A heating system that does not allow the exhaust to enter a room is suggested for houses in ranks 1 through 4. Electric cooking appliances are suggested for houses in ranks 1 and 2. Corresponding to these systems, the living room, bedrooms, bathroom, and toilet should be designed for mechanical ventilation in houses in ranks 1 through 3, considering the measurements that show the indoor air of some houses below rank 3 is polluted. A mechanical ventilation system including an air-to-air heat exchanger is suggested for houses in ranks 1 and 2. Since a house in rank 1 is almost airtight, passive solar heating and a central ventilating system, including a heat exchanger, are suggested. The revised standard stipulates that an open heating apparatus should not be used in an airtight house.

CONCLUSIONS

In the revised standard for the insulation performance of the housing envelope, an "airtight house" is defined as a house with an equivalent leakage area less than 5 cm^2/m^2 per floor area. The value of the equivalent leakage area was determined by consideration of the airtightness levels of newly constructed houses in Japan, the existing standard enacted by the Hokkaido local government, and the possibility of achieving it without extra money and extra training. The revised standard stipulates that an open heating apparatus should not be used in an airtight house.

ACKNOWLEDGMENTS

The standard for insulation performance of the housing envelope in Japan was revised on the basis of a report from the Committee on New Energy Conservation Standard for Residential Buildings (the chairman was S. Fujii, Honorary Professor, Shibaura Institute of Technology) located in 1991 at the Institute of Building Energy Conservation (IBEC), a public service corporation established in March 1980 with the approval of the Ministry of Construction. That report was based on discussion in the Committee on Improvement of Indoor Environmental Level for Residential Buildings (the chairman is S. Fujii) located from 1989 to 1991 at the IBEC. One of the subcommittees of this committee is Airtightness Performance, chaired by H. Yoshino. The author acknowledges the members of these committees who

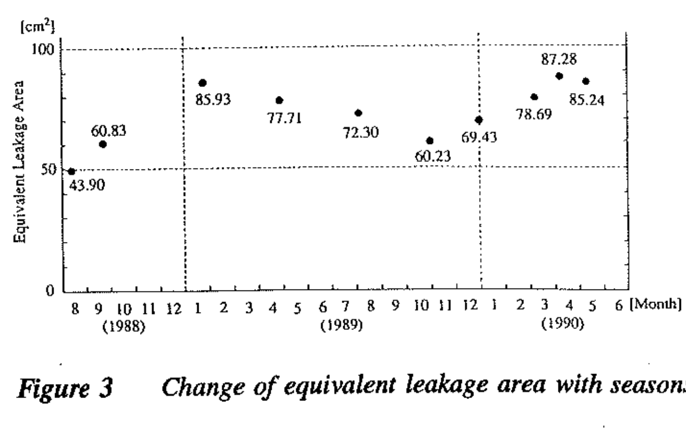

Figure 3 *Change of equivalent leakage area with seasons.*

collaborated to develop the draft of the airtightness standard for residential buildings.

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