AIR INFILTRATION REDUCTION IN EXISTING BUILDINGS

4th AIC Conference, September 26-28 1983, Elm, Switzerland

PAPER 15

AIR-TIGHTNESS OF RESIDENTIAL BUILDINGS IN JAPAN

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SYNOPSIS

The air-tightness of various types of 25 residential units was measured in detail by the fan pressurization technique. The residences included nine detached houses and 16 apartment units. In this study, the relationship between the pressure difference across the building envelope and the volumetric flow rate of air is shown as well as the ratio of the effective leakage area of one building element to the total leakage area. Secondly, the air-tightness of various types of houses in different countries is compared using the value of the effective leakage area per floor area when the pressure difference across the envelope is 10 Pa. This comparison gave the important information as to the air-tightness target in Japanese houses. Additionally, in the three apartment units which had different leakage areas, the decrease in indoor pressure compared to outside pressure and the extracted volumetric flow rate of air were measured in relation to the diameter of the duct for intaking outdoor air. Lastly, the important points in the design of ventilation systems for an air-tight house are considered.

LIST OF SYMBOLS

- Δp : Pressure difference between the inside and the outside of building, Pa
- Δp_o : Reference pressure difference, Pa
- Q : Volumetric air flow rate through leakage, m^3/h or m^3/s
- Q_o : Q for $\Delta p=\Delta p_o$, m^3/h or m^3/s
- Q' : Q per unit floor area, m^3/hm^2
- Q'_o : Q' for $\Delta p=\Delta p_o$, m^3/hm^2
- Q_l : Volumetric air flow rate per unit length of window crackage, m^3/hm
- Q_{lo} : Q_l for $\Delta p=\Delta p_o$, m^3/hm
- n : Flow exponent
- ρ : Air density, kg/m^3
- A : Orifice area or effective leakage area, m^2 or cm^2
- A_o : Effective leakage area for $\Delta p=\Delta p_o$, m^2 or cm^2
- A'_o : Specific leakage area, that is A_o per unit floor area, cm^2/m^2
- F : Floor area, m^2

1. SURVEY OF THE RESEARCH DONE ON AIR-TIGHTNESS OF HOUSES IN JAPAN

1.1 Abstract of research in Japan

Sixty years ago, Nomura[1](1924) and Ohtani[2](1928) measured, for the first time, the area of the crackages in the room envelope by means of a scale, and investigated the effect of the amount of such crackages on air infiltration. Watanabe[3](1951) indicated, on basis of the above results, that the leakage areas in the room envelope of conventional wooden houses constructed roughly, normally and strictly were, more than 90 cm^2, 50 to 60 cm^2 and less than 30 cm^2 per cubic metre of the room volume, respectively. Also, he showed that the leakage area in the room envelope of a concrete house was 10 to 15 cm^2 per cubic metre.

Maeda and Ishihara[4](1961) measured the air-tightness of building elements in concrete apartments using the fan pressurization technique. It was the first time the fan pressurization technique was used. This study was followed by Narasaki et al.[5](1974), Murakami, Yoshino et al.[6,7,8,9](1975-), Asano[10,11] (1979), Aratani et al.[12] (1980) and Kamata et al.[13,14] (1981-), all of whom measured the air tightness of various types of houses by the fan pressurization method.

Recently, Yoshino et al.[15,16] (1982-) and Kamata et al.[14,17] (1982-) investigated the relationship between the air-tightness of a house and air infiltration by field measurements.

1.2 Measurement techniques of air-tightness

The air-tightness of a whole house or one room was measured by fan pressurization and/or depressurization. In general, the volumetric flow rate through the fan at depressurization is a little smaller than the flow rate at pressurization, because when the room is depressed the space of crackage is forced to become narrower by the pressure exerted on the outer surface of the wall. Kato et al.[13] (1981) showed, by the investigation of a small test house, that when the pressure difference was 10 Pa, the volumetric flow rate in the case of depressurization was 60 to 80 % of that in the case of pressurization. Yoshino et al.[9] (1981) also demonstrated, by the measurement of the air-tightness of one room, that the volumetric flow rate in the case of depressurization was 80 % of that of pressurization. But, Kamata et al.[14] (1982) and Yoshino et al.[9](1981) reported that no significant different in volumetric flow rate was found between the pressurization and the depressurization methods when applied to a typical wooden house.

The air-tightness of a particular building element was estimated by Murakami, Yoshino et al.[6](1975) in terms of the volumetric flow rate difference of air pushed into the shelter before and after removing tapes and/or vinyl sheets which covered that element. Maeda and Nakazawa[18] (1965) proposed a measurement technique in which a covering sheet supported by wires was attached to window and air pushed into the space between the window and the cover by a small fan. Kamata et al.[14] (1982) measured the leakage area of building elements using Blomsterberg's technique[19], which he modified to apply to Japanese houses.

1.3 Indication of air-tightness of house

Air-tightness is indicated by the effective leakage area, which can be calculated on the basis of the relationship between the pressure difference and the volumetric flow rate of air. In the case of an orifice plate, the relationship between the pressure difference across the plate and the air flow is

$$\Delta p = \frac{\rho}{2}\left(\frac{Q}{A}\right)^2 \qquad \text{----------------} \quad (1)$$

Therefore, the effective orifice area is obtained by

$$A = \sqrt{\frac{\rho}{2}/\Delta p}\cdot Q \qquad \text{----------------} \quad (2)$$

In the case of the leakage of building envelope, the relationship between Δp and Q is expressed by

$$Q = Q_o\left(\frac{\Delta p}{\Delta p_o}\right)^{\frac{1}{n}} \qquad \text{----------------} \quad (3)$$

Q_o takes the value of the flow rate Q for $\Delta p = \Delta p_o$. n is flow exponent, which varies from 1.0(laminar flow) to 2.0(turbulent flow).

If Equation(3) is introduced into Equation(2), the effective orifice area (effective leakage area) is calculated by

$$A = \sqrt{\frac{\rho}{2}/\Delta p}\cdot Q_o\left(\frac{\Delta p}{\Delta p_o}\right)^{\frac{1}{n}} \qquad \text{-----------} \quad (4)$$

If $\Delta p = \Delta p_o$, Equation(4) is rewritten simply as

$$A_o = \sqrt{\frac{\rho}{2}}\cdot Q_o(\Delta p_o)^{-0.5} \qquad \text{-----------} \quad (5)$$

Q_o depends on the value of Δp_o. So, it is significant how the value of Δp_o is selected. In Japan, Δp_o is given as 9.8 Pa (1 mmAq). Tamura[20], Hildon[21] and Grimsrud et al.[22] gave Δp_o as 74.7 Pa(0.3 inchH_2O), 50 Pa and 4 Pa, respectively. In consideration of the pressure range exerted upon the building surface in a natural environment and ease of the measuring by the fan pressurization technique, it is better to select 10 Pa(≒1 mmAq) as the reference pressure difference.

2. MEASUREMENT OF THE AIR-TIGHTNESS OF HOUSES

2.1 Description of measured houses

Table 1 shows the description of measured houses including 8 detached houses, 4 terrace houses and 13 apartments. Some detached

Table 1 Description of measured houses

	Location	Houses			Floor area, m^2	SLA* cm^2/m^2	Date of measurement
Detached houses	Ibaraki pref.	①Wooden prefab. house(One story, 3BR+LR)			96	15.1	1975.2.1-5
	Tokyo	②Concrete prefab. house(Two stories, 4BR+LR)			101	5.8	1975.11.18-23
	Sendai-shi	Conventional wooden houses	③A-1(Two stories, 3BR+LR)	A Co.	99	10.5	1981.8.3-6
			④A-2(Two stories, 3BR+LR)	A Co.	89	10.0	
			⑤B-1(Two stories, 4BR)	B Co.	98	11.7	
			⑥C-1(Two stories, 5BR)	C Co.	88	20.8	
			⑦C-2(Two stories, 3BR+LR)	C Co.	81	21.9	
			⑧C-3(Two stories, 4BR)	C Co.	81	22.6	
Multi-family houses	Tokyo	⑨Concrete prefab. house(Semi-det. 4BR+LR)			104	11.8	1975.1.21-29
	Hachiohji-shi, Tokyo	⑩ KEP-Experimental house(Mid floor, 4BR+LR)			89.0	6.0	1976.3.28-31
		⑪ KEP-Experimental house(Mid floor, 2BR+LR)			70.0	7.5	
	Tokyo and the suburbs	Housing estat-A (apartments have acoustic insulated windows)	⑫ A-1(3rd flr. end flat. 3BR)		67.0	2.4	1980.7.14-19
			⑬ A-2(3rd flr. mid flat. 3BR)		65.8	3.0	
			⑭ A-3(3rd flr. mid flat. 3BR+LR)		63.4	2.8	
			⑮ A-4(3rd flr. mid flat. 3BR)		63.4	2.2	
			⑯ A-5(3rd flr. mid flat. 3BR)		64.3	1.7	
		Hous.Est.-B	⑰ B-1(5th flr. mid flat. 3BR)** ***		46.3	8.7	1980.7.22
		Hous.Est.-C	⑱ C-1(4th flr. mid flat. 3BR)***		54.4	3.4	1980.7.24
		Housing estate-D	⑲ D-1(1st flr. end flat. 3BR+LR)		73.6	3.8	1980.7.28-31
			⑳ D-2(2nd flr. mid flat. 3BR+LR)		73.6	3.8	
			㉑ D-3(2nd flr. mid flat. 3BR+LR)		73.6	3.8	
		Housing estate-E	㉒ E-1(End terr. 4BR+LR)		93.0	5.7	1980.8.4-9
			㉓ E-2(Mid terr. 3BR+LR)		93.0	7.8	
			㉔ E-3(End terr. 3BR+LR)		93.0	6.6	
			㉕ F-1(2nd flr. 4BR+LR)		98.2	2.2	

*Specific Leakage Area   **Steel frame windows   ***Measured after occupation

houses are constructed by the conventional method, others are prefabricated. Measurements were made before the houses were occupied, except for Houses #17 and #18 which were measured several years after occupation. Houses #12 to #16 in housing estate A had acoustic insulated windows.

2.2 Measurement techniques

The measurement of the air-tightness was made using the fan pressurization technique. The tightness of the building elements was estimated by the volumetric flow rate difference before and after removing the vinyl sheet which covered that element. Measurements were carried out under low wind speed conditions.

2.3 Results of measurements

2.3.1 Tightness of a whole house

Fig.1 and Fig.2 show the relationship between the pressure difference across the shelter and the volumetric flow rate per unit floor area. Multi-family houses are generally more air-tight than detached houses. Among detached houses, House #2, built with concrete, is significantly more air-tight than other houses. Conventional wooden houses, Houses #6 to #8, are rather leaky. Detached houses have the value Q_0' of 8 to 33 m^3/hm^2 and the value n of 1.1 to 1.9. Among multi-family houses, Houses #12 to #16 which had acoustic insulated windows are relatively air-tight. Multi-family houses have Q_0' of 2.5 to 20 m^3/hm^2 and n of 1.3 to 3.3. The value of n is 1.0 to 2.0 theoretically. But three of n values calculated by regression analysis are more than 2.0. This may be due to the fact, when the pressure difference was low, Δp and Q were not always precisely measured because of the wind effect.

2.3.2 Air-tightness of one to two rooms

Fig.3 shows the results of measuring the air-tightness of one or two rooms. No difference in air-tightness was found between detached houses and multi-family houses. The room of House #8 is leaky because the rooms are divided by "Fusuma", traditional Japanese sliding doors.

2.3.3 Air-tightness of building elements

Fig.4 shows the air-tightness of the building elements of House #9. Fig.5 shows the same information for House #2. Houses #9 and #2 are typical examples of leaky and air-tight houses.

Before the measurements were taken in a room, each element was covered over with a vinyl sheet until the whole inner surface of the room was covered over. We then confirmed that the room was almost perfectly air-tight. Then, every time a vinyl sheet was removed from a particular element, the relationship between the pressure difference across the shelter and the volumetric flow rate was measured. For a whole house, the measurements were taken, after visible openings such as crackages of windows and doors, ventilation inlets, and openings for pipes were sealed with tape and vinyl sheets.

(1) House #9

a) Main bedroom

Even when the whole inner surface of the room was covered over with vinyl sheets, a slight air flow was measured when the room was pressured, which means the room was not perfectly air-tight. Whenever a vinyl sheet was removed, the value Q increased. The data of Fig.5 indicates the followings:

i) The wall itself has no leakage, but the ceiling, the interface between the ceiling and the wall, and the interface between the floor and the wall have significant leaks. It is surprising that the volumetric flow rate Q_0 through such leaks is three times that of Q_o through the crackages of windows.

ii) Unexpectedly, Q_o through the crackage of windows is about one-fifth of Q_o through all leakages in the room.

b) The whole house

House #9 has a Q of about 600 m^3/h at Δp=5 Pa when all visible leaks are sealed. Even if the openable ventilation inlets provided in the window frame were open, the increasing fragment of Q is only 10 % of Q through the crackage of windows. It can be said that such inlets are not used for ventilation at all.

(2) House #2

a) Main bedroom

There was no leakage in the wall, ceiling, floor and the interface between them except for the crackages of windows and doors, and ventilation inlets. The value Q_o through the ventilation inlets is half that of Q_o through the crackage of windows.

b) The whole house

The value of Q for Δp=5 Pa when all visible leaks are sealed is a quarter that of House #9. Both Houses #2 and #9 are prefabricated with concrete panels. But a significant difference in tightness is found between the two houses. This differnce is most likely due to the difference in the quality of workmanship, judging from the close observation of the building and the report of builders.

2.3.4 Comparison between the catalog data and the field measurement results of the air-tightness of windows

Fig.6 shows the measurement results for Houses #1, #2 and #10 and their catalog data. The volumetric flow rate per unit length, Ql_o, obtained by the field measurement of Houses #1, #10 and #2 are, 1 to 1.5 times, 4 times and 6 times values of their catalog data. This may be due to unskilled construction. In order to realize the expected air tightness of windows, skilled construction is necessary.

2.4 Effective leakage area of building elements

The effective leakage area of a particular element, A_o, can be obtained by calculating the difference in the effective area before and after removing the vinyl sheet which covers the element. Table 2 shows the A_o of the building elements of Houses #12, #19 and #22 all of which are apartments. The background leakage areas of Houses #12, #19 and #22 are, 40.3 cm^2, 28.1 cm^2 and 126.0 cm^2, respectively. The background leakage area of House #22 is 25% of all of the leakage area of the envelope. The acoustic insulated

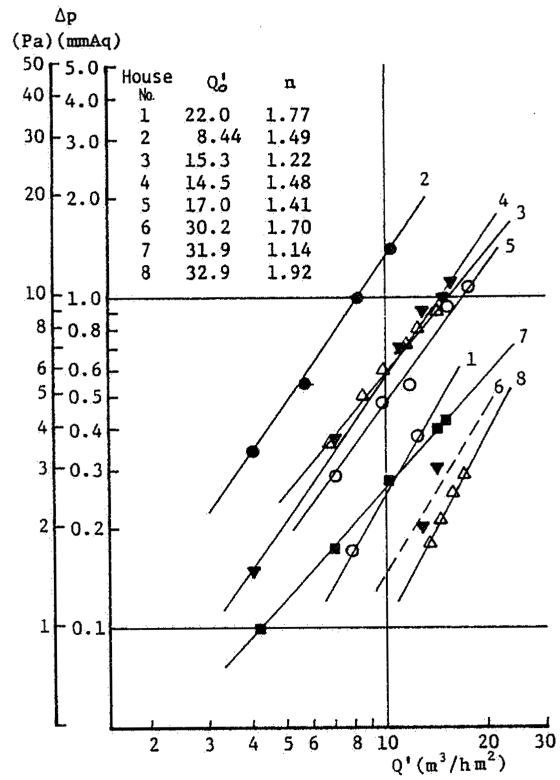


Fig. 1
Pressure difference and leakage flow rate for detached houses

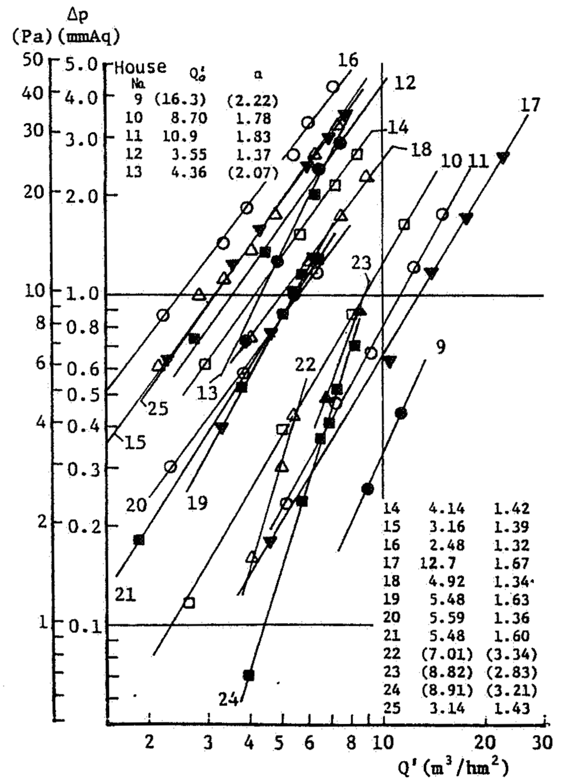


Fig. 2
Pressure difference and leakage flow rate for multi-family houses

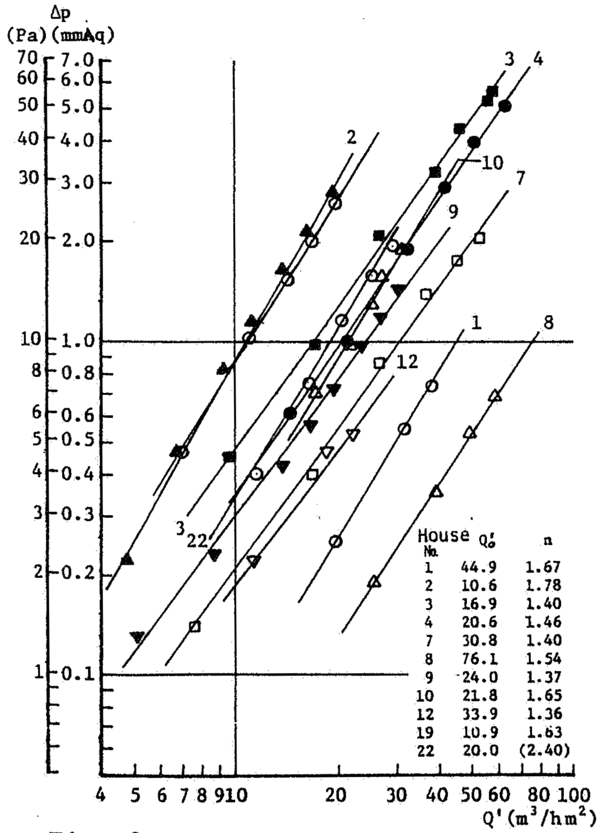


Fig. 3
Pressure difference and leakage flow rate for one or two rooms

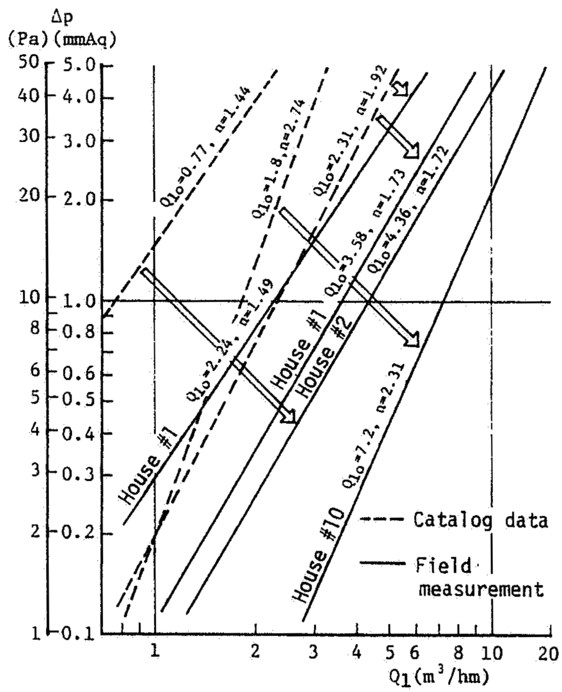


Fig.6
Measurement results and catalog data of window tightness

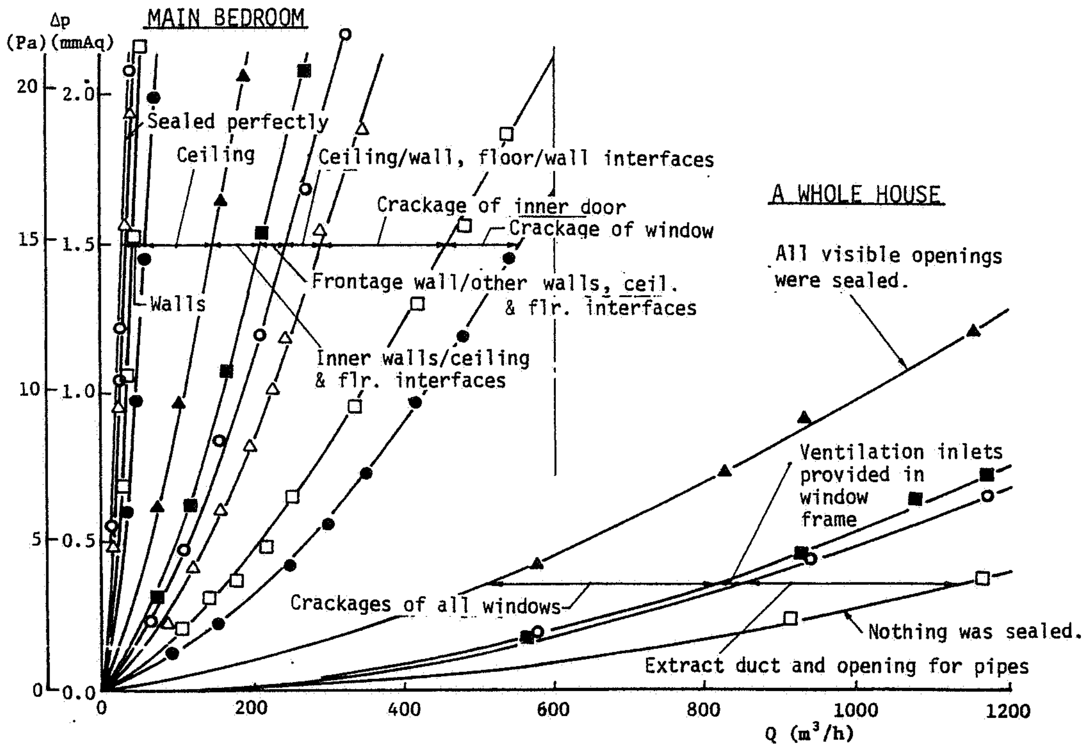


Fig. 4 Pressure difference and leakage flow rate for building elements of House #9

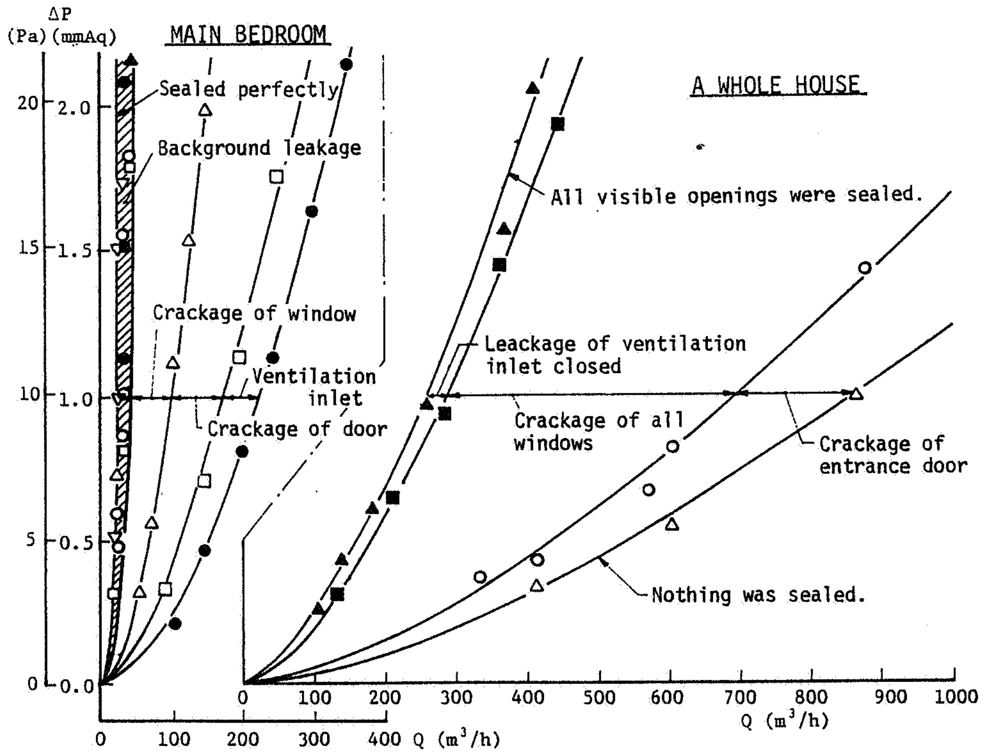


Fig. 5 Pressure difference and leakage flow rate for building elements of House #2

Table 2 Effective leakage areas of building elements

Leakages \ Houses	#12 (had acoustic window)		#19		#22 (Seme-detached)	
Bachground leakage area	40.3 cm^2	(24.6%)	28.1 cm^2	(10.1%)	126.0 cm^2	(25.9%)
Electric outlets	4.7	(2.9)	0.9	(0.3)	9.2	(1.9)
Leakage of venti. inlet closed	-	-	-	-	11.5	(2.4)
Cover in ceiling of closet for inspection	-	-	-	-	21.7	(4.5)
Ventilation inlet in kitchen	4.7*1	(2.9)	0*2	(0.0)	0*2	(0.0)
Window crackage	18.4*4	(11.3)	92.0	(33.2)	123.4	(25.4)
Closed venti. inlet in bath	13.9	(8.5)	-	-	-	-
Entrance door	37.9*3	(23.2)	106.2	(38.3)	0	(0.0)
Venti. inlet in entrance door	-	-	-	-	194.1	(39.9)
Leakage of kitchen fan	34.0	(20.8)	36.2	(13.0)	0	(0.0)
Vent. outlet in bathroom	9.6	(5.9)	14.1	(5.1)	-	-
Total	163.5	(100.0)	277.5	(100.0)	485.9	(100.0)

*1 The inlet was open. *2 The inlet was closed. *3 Had the post box.

windows of House #12 have an A_0 of 18.4 cm^2, which is 11 % of the entire leakage area of the envelope. That particular window is far tighter than the normal windows of other houses. The greatest leakage areas were the background leakage(24.6%) in House #12, the crackage of the entrance door(38.3%) in House #19 and the openings for ventilation provided in the entrance wall(39.9%) in House #22.

3. INTERNATIONAL COMPARISON OF THE AIR-TIGHTNESS OF VARIOUS HOUSES

It has been proposed for the purpose of international comparisons that the air-tightness of a house be given as the ratio of the effective leakage area to unit floor area for Δp=10 Pa, which Grimsrud et al.[37] called "Specific leakage area". Specific leakage are A_0' can be calculated by

$$A_0' = \frac{Q_0}{F}\sqrt{\frac{\rho}{2}}(\Delta p_0)^{-0.5} \quad \text{-----------} \quad (6)$$

Fig.7 shows the specific leakage areas of various houses in different countries. If the original data of air-tightness were not shown as Q_0 or A_0 for Δp=10 Pa, these data were conveted into Q_0 for Δp=10 Pa assuming 1/n=0.6.

a) Air-tightness of Japanese houses

Detached houses are plotted in Rank 4 to Rank 6, except for the air-tight houses in Hohhaido, which is the most northern portion of Japan. Almost all of these houses were constructed recently. The air-tightness of older houses constructed several decades ago are assumed to be plotted in the position beyond Rank 6. Multi-family houses are plotted in Rank 2 to 4 except for two houses. Apartments equipped with acoustic insulated windows in housing estate A are so tight as to take the position of Rank 2. One of apartments plotted in Rank 5 was constructed in 1956. The other

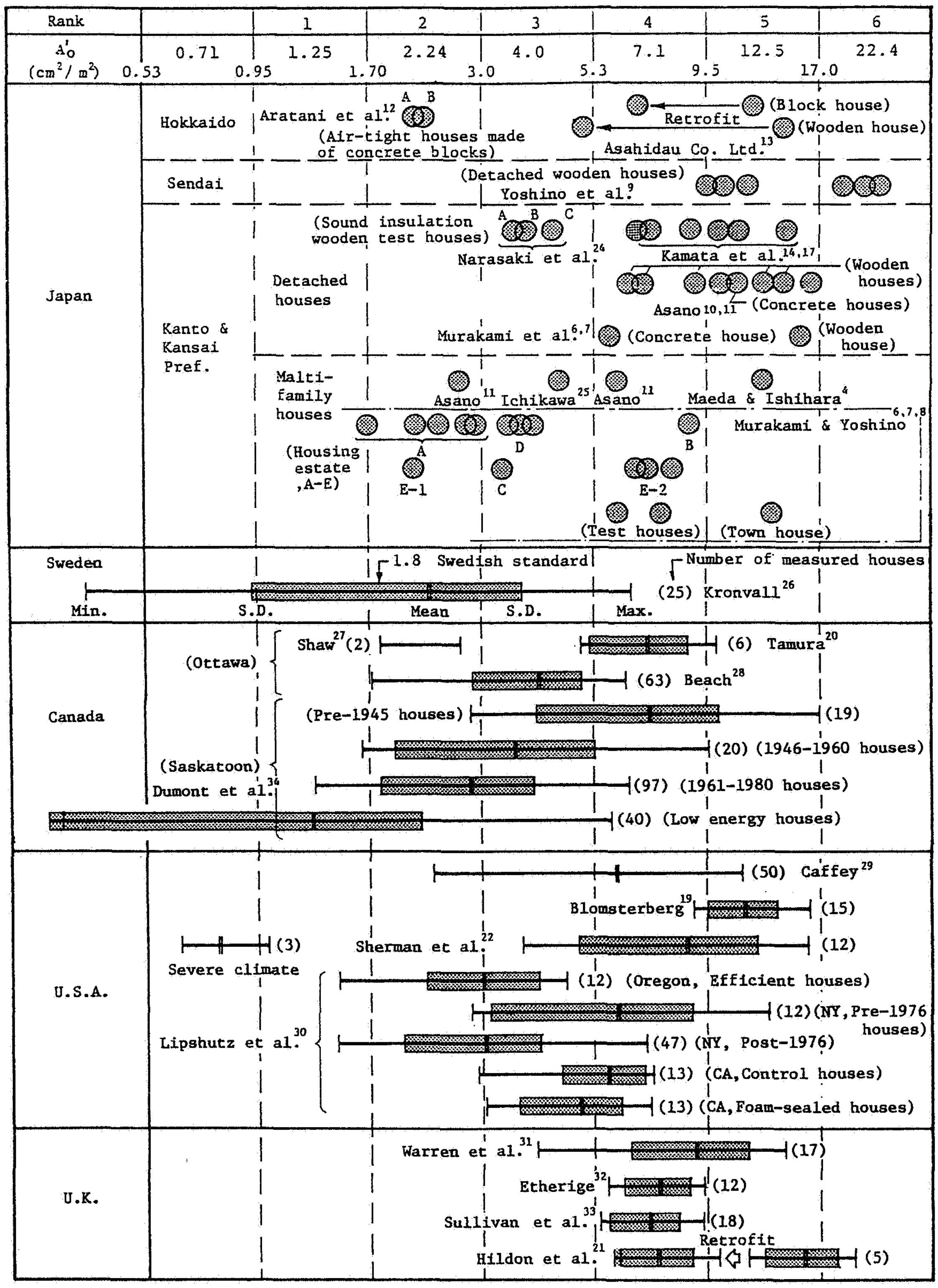


Fig. 7 International comparison of air-tightness of houses

is a terrace house built with concrete panels.

b) Sweden

70 % of Swedish houses, which are between a mean value plus a standard deviation(S.D.) and a mean value minus S.D., occupy Rank 1 to Rank 2. Swedish houses are more air-tight than those of other countries, which is due to Swedish's severe climate. The Swedish standard of air-tightness specified as the air change rate for Δp=50 Pa takes the position of Rank 2, close to Rank 1.

c) Canada

The houses in Ottawa, Canada occupy Rank 2 to Rank 4. One of houses measured by Shaw was reported to be considerably upgraded. On the other hand, it can be seen that the houses in Saskatoon have become tighter and tighter since 1945 and the houses constructed recently(1961-1980) take Rank 2 to 3. Especially, low energy houses are significantly air-tight.

d) U.S.A.

Houses in the United States are widely distributed from Rank 2 to Rank 5, except for three houses located in a severe climate region. The upgraded houses seem to be in Rank 2 to Rank 3.

e) U.K.

Houses in the U.K. are plotted from Rank 4 to Rank 5, which is nearly equal to the detached houses in Japan. It can be seen by Hildon's measurement of houses before and after retrofitting, that the air-tightness of houses are upgraded from Rank 5 to Rank 4 as a result of retrofitting. A similar change in level through retrofitting is seen in the examples of houses in Hokkaido.

As a result, Fig.7 shows not only the present levels of air-tightness of various houses in different countries, but also gives important suggestion as to the target of air-tightness in Japanese houses.

4. FIELD TEST OF THE RELATIONSHIP BETWEEN THE PERFORMANCE OF VENTILATION SYSTEMS AND THE AIR-TIGHTNESS OF A HOUSE

4.1 Introduction

It is expected that the performance of a ventilation system depends on the air-tightness of a house. In order to clarify the relationship between the performance of ventilation systems and the air-tightness of a house, the following points were investigated in three apartments which have different levels of air-tightness.

i) Relationship between the decrease in internal pressure and the extracted air flow rate when the kitchen fan was operated.

ii) Air flow pattern in the most air-tight house when the kitchen fan and the toilet fan are operated simultaneously.

iii) The relationship between internal pressure and extracted flow rate when a temporary duct for the intake of outdoor air is installed for the purpose of the experiment, and the flow rate of air passing through such a supply duct.

4.2 Description of houses and measurement techniques

(1) Houses used for the experiment

The experiment was performed in Houses #12, #19 and #22, the effective leakage areas of which are shown in Table 2. House #12 is seen to be significantly more air-tight than the others.

(2) Ventilation systems

Fig.8 shows the ventilation systems of House #12 and #22. House #19 has the same system as House #22, except that the extract duct system is divided into two series, one for kitchen and one for bathroom, and the capacity of the kitchen fan is a little smaller (300 m^3/h at Δp=100 Pa). The ventilation flow rate required for a kitchen in Japan is much greater than that of other countries, because so much smoke, vapour and combustion gas are generated by boiling, broiling and frying using a gas range.

(3) Measurement technique

The extract flow rate was measured inside the provisional duct attached to the hood using a thermister anemometer. The air flow pattern when the kitchen fan and the toilet fan are operated simultaneously was estimated by the measurement of the pressure difference scross the door dividing the two rooms by the observation of tobacco smoke.

4.3 Decrease in internal pressure and the extracted air flow rate with the kitchen fan operated

Table 3 shows the decrease in internal pressure and the extracted volumetric flow rate when the kitchen fan was operated. Without a supply duct, it is evident that House #12 which is air-tight, shows significant decrease in internal pressure,-125 Pa(-12.8 mmAq) from outdoor pressure for the extracted flow rate of 360 m^3/h when the fan is operating at high speed, and has an internal pressure of -105 Pa(-10.7 mmAq) for 310 m^3/h, even when the fan is on low.

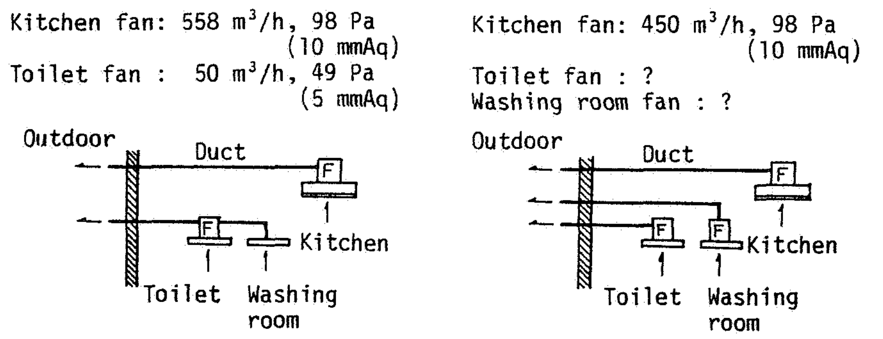
When the toilet fan was operated at the same time, air flow across internal doors was observed(Fig.9). It should be noted that the air in the toilet and the bathroom was reversely pulled into the

Table 3 Air flow rate and decrease in internal pressure under differet conditions

		Supply duct	Inlet of kitchen	Fan speed	Ratio of supply air	Internal pressure Pa (mmAq)	Air flow rate m³/h (0 – 200 – 400 – 600)
House #12	1.1	-	Closed	High	-	-125 (-12.8)	●
	1.2*	-	Open	Low	-	-105 (-10.7)	●
	1.3	125 mm	Sealed	High	48 %	-62 (-6.3)	○ ●
	1.4	150	Sealed	High	56 %	-46 (-4.7)	○ ●
House #19	2.1	-	Open	High	-	-27 (-2.8)	●
	2.2	125	Sealed	High	36 %	-16 (-1.6)	○ ●
	2.3	150	Sealed	High	47 %	-13 (-1.3)	○ ●
House #22	3.1	-	Closed	High	-	-5.4(-0.55)	●
	3.2	125	Sealed	High	24 %	-3.4(-0.35)	○ ●
	3.3	150	Sealed	High	26 %	-2.9(-0.30)	○ ●

* Ventilation inlet provided in window was open.

○ Through supply duct
● Through extract duct



(1) House #12

(2) House #22

Fig. 8 Extract duct systems of test apartments

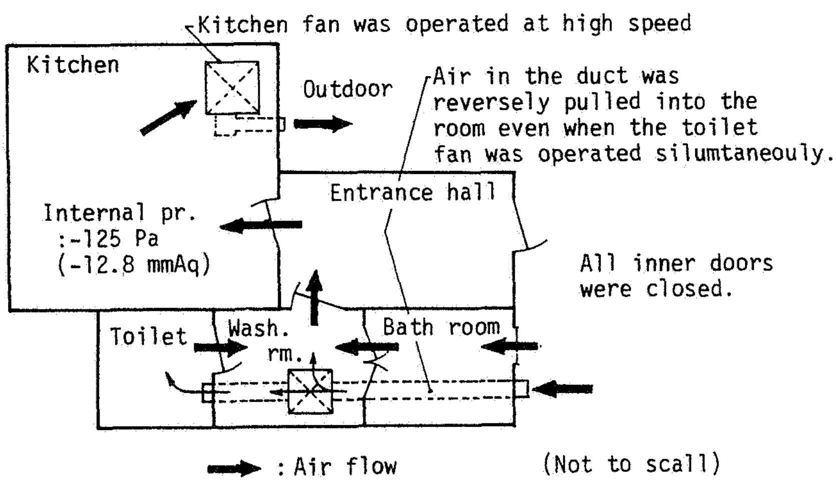


Fig. 9 Air flow pattern when the kitchen fan and the toilet fan was operated simultaneously

kitchen by way of the entrance hall due to the high pressure difference across internal doors.

The decreases in the internal pressure of House #19 and #22 were, -27 Pa(-2.9 mmAq) and -5.4 Pa(-0.55 mmAq), respectively. Reversal flow was not found in houses other than House #12. It is important to note the significant decrease in internal pressure and the reversal flow in an air-tight house.

4.4 Influence of the diameter of the supply duct on the indoor pressure and the extracted air flow rate

Table 3 also shows the decrease in internal pressure, the extracted flow rate through the fan, the flow rate of air passing through the supply duct and the ratio of the supplied flow rate to the extracted flow rate when the kitchen is installed with the temporary air supply duct for the purpose of the experiment. That duct has a diameter of 125 mm and a length of 3.6 m or a diameter of 150 mm and a length of 4 m.

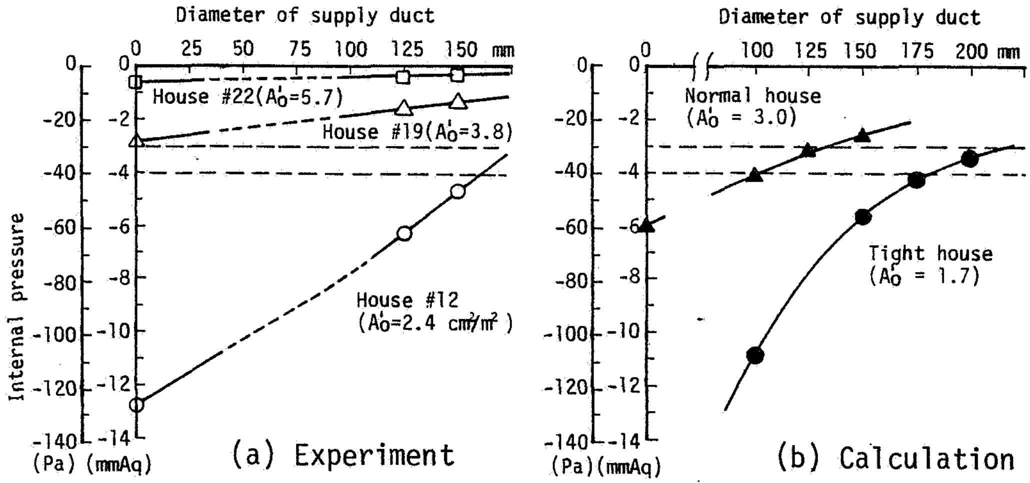
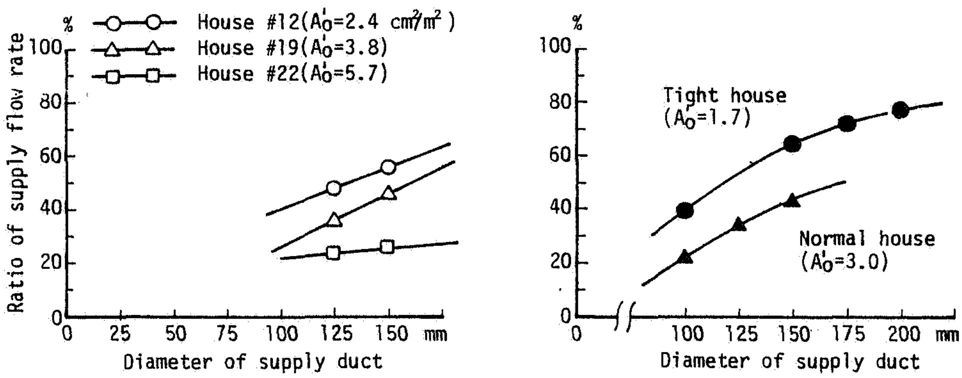


Fig.10 Change of internal pressure due to different diameter of ducts



(a) Experiment (b) Calculation

Fig.11 Ratio of air flow rate through the supply duct to that through the extract duct

Fig.10(a) shows the relationship between the diameter of the duct and a decrease in internal pressure. The wider the diameter of the duct, the more the internal pressure rises and approaches zero in two houses. But, House #12, which is tight, still has a low internal pressure(-49 Pa) when the diameter is 150 mm.

On the other hand, internal pressure was calculated[35] using the network method for the two model houses, which had 3 bedrooms and a floor area of 73.7 m^2. The house with an A_0 of 1.7 cm^2/m^2 is hereafter referred to as "Tight house", while the house with an A_0 of 3.0 cm^2/m^2 is called, "Normal house". The calculation results shown in Fig.10(b) indicate a relationship between the internal pressure and the diameter of the supply duct similar to the results obtained by measurement.

If the decrease in internal pressure is to be controlled above -29 Pa(-3.0 mmAq), it is necessary to select a supply duct with a diameter about 125 mm and 200 mm for Normal house and Tight house respectively, to prevent the reversal flow of air when the kitchen and toilet fan were operated simultaneously as well as the problems which accompany opening a door at a high pressure difference. Also, in order to control the decrease in internal pressure above -39 Pa (-4.0 mmAq), it is prefarable to select a duct with a diameter of 100 to 125 mm and 175 to 200 mm, for Normal house and Tight house.

Fig.11 shows the ratio of the air flow rate through the supply duct to the extracted flow rate, relative to the different diameters of the supply ducts. If 175 mm is selected as the diameter of the supply duct in order to control the internal pressure above -39 Pa (-4.0 mmAq), the ratio of the intaking air flow to the extracted flow rate is 70 % for Tight house. For Normal house, if the diameter is 100 mm, the ratio is only 20 %. In the latter case, it can be said that almost all of the air taken into the kitchen passes through the crackage and background leakage other than the supply duct.

4.5 Important points for designing the ventilation system of an air-tight house

a) It is important to pay attention to the capacity of a fan and the diameter of the supply duct or ventilation inlets in a tight house. In House #12, which was built with acoustic insulated windows, when the kitchen fan was operated simultaneously with the toilet fan, the air from the toilet and bathroom was pulled into the kitchen because the internal pressure in the kitchen significantly.

b) In order to control the decrease in internal pressure above -39 Pa(-4.0 mmAq) to prevent reversal flow, the diameter of the supply duct should be 100 to 125 mm for Normal house with an A_0 =3.0 cm^2/m^2(between Rank 2 and 3), and 175 to 200 mm for Tight house with an A_0=1.7 cm^2/m^2(between Rank 1 and 2).

5. CONCLUSIONS

1) The air-tightness of various types of 25 residential units was measured by the fan pressurization technique. When the pressure difference across the shelter was Δp=10 Pa, the volumetric flow rate per unit floor area of air pushed into the shelter was 8 to 33 m^3/hm^2 for the detached houses, 2.5 to 20 m^3/hm^2 for the multi-family houses and 11 to 45 m^3/hm^2 for one to two rooms.

2) It was found by measuring the air-tightness of building elements that there were many invisible leakages, that is background leakages other than the crackages of windows and doors, ventilation inlet leaks and leaks of openings for pipes. Such background leakage areas vary greatly depending on the quality of construction. For example, in one of the two houses built with concrete panels, the bedroom had no background leakage, while the bedroom of the other house had an air flow rate of 200 m^3/h through the background leakage for Δp=10 Pa at pressurization. On the other hand, between the three types of apartments, the background leakage areas varied from 28 to 186 cm^2.

3) Installed windows often have air-tightness far inferior to the performance to be originally expected. One of the windows measured this time had a Q_0 six times that of the catalog data.

4) The air-tightness of a house was specified as the effective leakage area for Δp=10 Pa per unit floor area, or specific leakage area. By plotting various types of houses along the scale of such specific leakage area and comparing the houses of different countries, important information was obtained concerning target of air-tightness in Japanese houses.

5) The internal pressure was measured when operating the kitchen fan in three apartments which had different air-tightness. In the air-tight house(A_0 of 2.4 cm^2/m^2) equipped with acoustic insulated windows, the internal pressure was -125 Pa(-12.8 mmAq) for Q=360 m^3/h. When the toilet fan and kitchen fan were operated at the same time, the air in the toilet was reversely pulled into the kitchen. Both experiment and simulation analysis clarified the fact that the diameter of the supply duct should be 175 to 200 mm for air-tight houses of Rank 2 to 3, so as to control the decrease in internal pressure above -39 Pa(-4.0 mmAq) in order to prevent reversal flow and trouble with opening doors.

6. ACKNOWLEDGEMENT

The authors wish to acknowledge the instructions and important suggestions of Honorary professor Takashi Shoda of the University of Tokyo(Professor of Nihon University), Professor Fusao Hasegawa of the Tohoku University and Chief engineer Yasuyuki Utsumi of the Fujita Technical Research Laboratory.

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