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The effects of human behavior on natural ventilation rate and indoor air environment in summer — a field study in southern Japan

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Abstract

Residents completed a questionnaire survey assessing indoor environment and residents' behavior (i.e. when they opened windows/doors, when they operated air conditioners, and so on) during the period of ventilation measurement. The purpose of this study is to measure the ventilation rate in occupied dwellings in Kagoshima City, located in the southern part of Japan, using the tracer gas method and to investigate the relationship between the occupants' behavior in each dwelling and the energy consumption for air conditioning during the summer period. Based on the continuous measurement of the ventilation rate in eight dwellings, the proportion between the total ventilation rate (ventilation rate during occupancy of the dwellings) and the basic ventilation rate (ventilation rate during non-occupancy and with door/windows closed) is discussed. The measuring principle applied is the constant concentration tracer gas method. The main conclusion is that there is a large difference between the mean basic ventilation rate and the mean total ventilation rate. If the size of the basic ventilation rate and the user-influenced ventilation rate in the investigated dwellings are compared, it can be seen that 87% of the total air change rate is caused by the behavior of the occupants.

Keywords: User-influenced ventilation rate; Constant concentration tracer gas method; Occupants' behavior; Energy consumption for cooling

1. Introduction

Due to the hot and humid summer climate of southern Japan, the Japanese have traditionally used a passive cooling method in dwellings, for example long eaves to cast shadow, thatched roofs to allow for effective evaporative cooling and large openings to allow for natural cross ventilation. Cross ventilation, in particular, is preferred in summer not only for air exchange in dwellings but also to accelerate heat loss from the human body for thermal comfort. Therefore, many traditional Japanese dwellings are open-plan with large windows through which air moves across rooms. However, many Japanese occupants have been using heat pump air conditioning systems since sufficient cross ventilation is not expected in crowded cities where 'heat island phenomenon' may occur. In this case, traditional Japanese dwellings, being less insulated and less air tightened, are not suitable for heating/cooling the indoor air. Particularly after the Oil Crisis of 1973, thermal insulation and air tightness of building skins became popular in minimizing infiltration of outside air for energy conservation in buildings. While a reduction in the rate of fresh air intake was regarded as being very effective in minimizing energy consumption of air conditioning, indoor air pollution emitted from tobacco smoke, the human body or building materials in a room were intensified because of air tightness. Since most Japanese dwellings have heat pump air conditioning systems but no ventilation systems, occupants have obtained acceptable indoor air quality by opening windows/doors. Therefore, in a dwelling where residents open windows to allow for passive cooling and acceptable air quality, and where residents use air conditioners less frequently, energy consumption might be lower than in dwellings where residents use air conditioners frequently and do not open windows. Recently, with the increase in the quality of new buildings and the air tightening of existing buildings, the influence of climatic parameters, i.e. air temperature, wind speed, wind direction etc., has been reduced, while other parameters such as human behavior have a greater influence on the ventilation rate. Kvisgaard and Collet used the tracer gas method to investigate the user's influence on air change in 28 dwellings in Denmark [1]. They defined four types of air changes.

(i) *Basic air change*. The basic air change is the air change caused by airflows through leaks in the building. It is measured when there are no occupants and with all doors, windows and ventilation systems closed. The basic air change varies with wind velocity and indoor/outdoor temperature differences.

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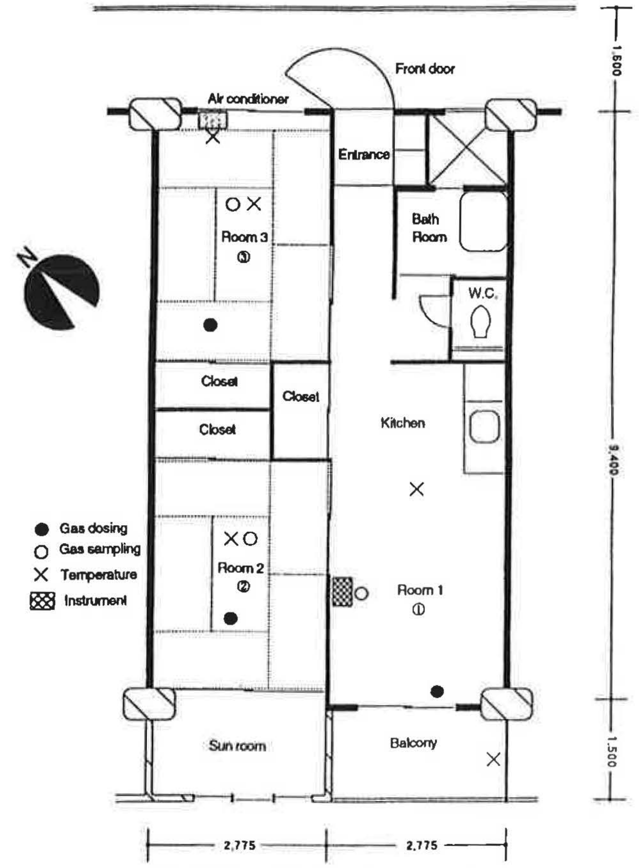


Fig. 1. Plan of the investigated dwelling.

(ii) *Air change from the ventilation system.* The air change from the ventilation system is the air change from all mechanical supply and exhaust systems.

(iii) *User-influenced air change.* The user-influenced air change is the air change caused by the opening of windows and doors.

(iv) *Total air change.* The total air change is the sum of the basic air change, the air change from the ventilation system and the user-influenced air change.

In Japan, however, there have been few studies measuring user-influenced air change rates in non-experimental, occupied dwellings. The purpose of this study is to measure the ventilation rate in occupied dwellings in Kagoshima City, located in southern Japan using the tracer gas method and to investigate the relationship between the user-influenced air change rate in each dwelling and the energy consumption of air conditioning during the summer period. Furthermore since most Japanese houses do not have a central air conditioning system, having instead a heat pump installed in every room as an intermittent air conditioner, it is also the purpose of this study to investigate the frequency of air conditioner use in real dwellings.

2. Methods

2.1. Investigated dwellings

The field study was conducted in a housing complex in the center of Kagoshima City, i.e. southern Kyushu Island, Japan (31° 41′N, 130° 33′E). During the summer, volcanic ash from Mt. Sakurajima falls broadly on Kagoshima City. As a result, some residents are reluctant to open windows. The investigated building was built in 1971 by a Kagoshima prefectural corporation. It has 16 floors made of reinforced concrete. The first floor is commercially owned. The second to fifth floors are the offices of a public company. The sixth to 16th floors are the housing complex. Fig. 1 shows the plan of a basic dwelling which includes two bedrooms, a kitchen, and a living–dining room. Since the building has no central air conditioning/heating system, most of the dwellings have one or two room air conditioner(s) in either the bedroom or the living room. When volcanic ash fell, the windows, especially those facing south, would not have been opened and the occupants might have used an air conditioner. Eight dwellings in this housing complex were investigated. The floors of every investigated dwelling and the measuring periods are listed in Table 1. The average floor area of a dwelling was 52.2 m^2, and the average number of occupants was 2.0. While no mechanical cooling system, such as an air conditioner, was installed in dwelling C, the other investigated dwellings had one ductless split-type heat pump (air conditioner) with an exterior compressor and an interior heat exchanger unit. The exterior compressor and the interior heat exchanger are connected by electrical cables and coolant pip-

Table 1
Data for investigated dwellings in a building complex located in Kagoshima City

Dwelling no.	Measuring period (year 1994)	Floor of the building	No. of occupants	No. of air conditioners (location)
A	July 17th–July 19th	14th	3 (2 adults and 1 baby)	1 (Room 1)
B	July 29th–Aug. 1st	11th	1 (elderly woman)	1 (Room 1)
C	Aug. 3rd–Aug. 6th	8th	2 (adults)	0
D	Aug. 15th–Aug. 17th	6th	1 (elderly woman)	1 (Room 1)
E	Aug. 18th–Aug. 21st	11th	1 (elderly woman)	1 (Room 1)
F	Aug. 26th–Aug. 27th	7th	3 (2 adults and 1 baby)	1 (Room 2)
G	Aug. 28th–Aug. 31st	16th	2 (teenage students)	1 (Room 1)
H	Sept. 2nd–Sept. 5th	16th		1 (Room 3)

Dwelling H was a control house where the experimenter lived during the measuring period.

ing through a small hole in the wall. The interior heat exchanger functions as a condenser when cooling and as an evaporator when heating (see Fujii and Lutzenhiser [2]).

2.2. Measuring equipment

The ventilation rates of eight dwellings were measured with an automated system employing the constant tracer gas concentration technique using sulfur hexafluoride (SF_6) as the tracer. This measuring system consists of a multi-gas monitor (Brüel and Kjær, type 1302) for measuring SF_6 concentration, a multipoint sampler and doser (Brüel and Kjær, type 1303) for dosing tracer gas into measuring points and sampling indoor air, and application software (Brüel and Kjær, type 7620). The tracer gas dosing and air sampling are controlled by a microcomputer, which also analyzes the data as they are collected, and stores the information on floppy disks. When measuring with a constant concentration of tracer gas, a constant concentration of tracer gas is maintained in the rooms where the ventilation rate is to be measured. The ventilation rates then are calculated on the basis of the quantity of tracer gas injected into the rooms necessary to maintain the constant concentration. We maintained the constant concentration of SF_6 in the room at 5 ppm. The measuring system for ventilation rate and air infiltration in the dwellings operated unattended for periods of several days.

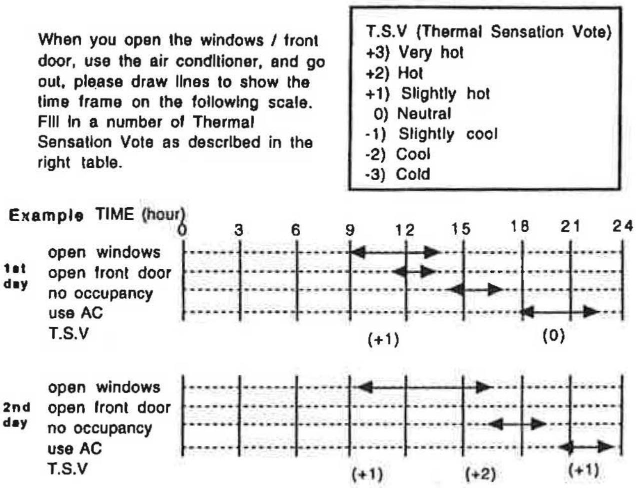
The ventilation measurement system was placed at a central location in each room of a dwelling. One 3 mm Teflon tube for tracer gas dosage and one 4 mm Teflon tube for room air collection were led from each area selected for measuring point to the multipoint sampler and doser. The tubes were connected to the dosing valve and the sampling valve on the sampler and doser. An electric fan was placed at each dosage point and the Teflon tube for gas dosage was attached to the fan to spread the tracer gas in the air.

Copper and Constantan thermocouples for measuring air temperature were installed at each tracer gas sampling point (110 cm height), the point of an air conditioner's supply diffusor, and outdoors.

2.3. Questionnaire survey for investigated dwellings

A self-report questionnaire, assessing indoor environment and resident's behavior, was completed by the residents, while the ventilation measurement was taken. The questionnaire sheet is shown in Table 2. This survey also collected data about when residents open windows/doors, when they operate air conditioners, and when the dwellings were unoccupied during the measuring period. In addition, residents completed a questionnaire of thermal comfort, which contained scales for thermal sensation, air movement sensation and comfort sensation, according to their schedules (Table 2).

Table 2
Questionnaire sheet for the residents



3. Measurement results

3.1. Indoor environment and human behavior

Fig. 2 shows the variation of the ventilation rate (upper) in the unit of CMH (m^3/h) in Room 1 and the air temperature (lower) for dwelling B where one elderly woman lives. In the lower part of Fig. 2, 'OUTDOOR', 'ROOM' and 'AC SUPPLY' represent the outdoor air temperature, the room air

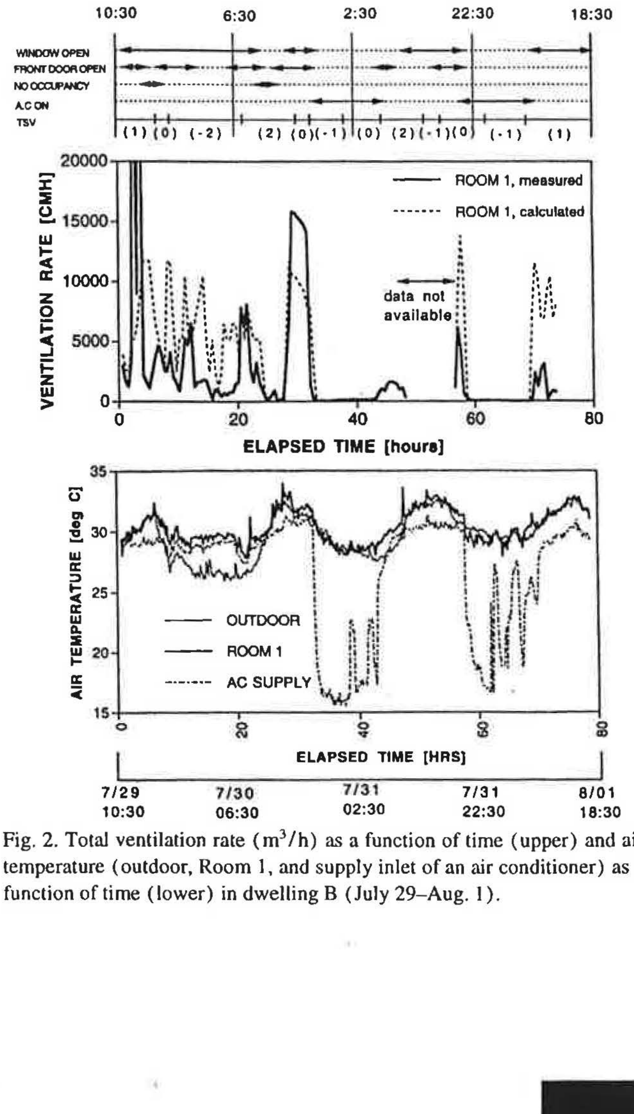


Fig. 2. Total ventilation rate (m^3/h) as a function of time (upper) and air temperature (outdoor, Room 1, and supply inlet of an air conditioner) as a function of time (lower) in dwelling B (July 29–Aug. 1).

Table 3
Mean air temperature under the cooling condition using the air conditioner (AC) in dwelling B

Period of cooling by AC	Mean outdoor temp. during cooling (°C)	Mean room temp. during cooling (°C)	Mean room r.h. during cooling (%)	Mean outdoor temp. before cooling (°C)	Mean room temp. before cooling (°C)	Mean room r.h. before cooling (%)
7/30-18:55 to 7/31-0.6:25	28.75±0.90 [a]	28.93±0.64	50.11±6.60	30.76±0.32	31.95±0.23	55.24±2.55
7/31-20:15 to 8/1-08:15	29.81±0.31	29.62±0.63	50.55±4.40	30.69±0.90	31.35±0.05	59.21±0.44

[a] Standard deviation.

temperature and the temperature of the air conditioner's supply inlet, respectively. The scales listed above the figure show the periods of opening windows/doors, operating the air conditioner (AC), and of non-occupancy reported by residents on the questionnaire sheet. The ventilation rate in dwelling B is shown in Fig. 2 (upper). Since the residents opened a papered sliding door (*fusuma*) of each room at all times, just one measuring point was placed at a central location (i.e. kitchen) in dwelling B. Namely, we regarded dwelling B as one room. The solid line shows the total ventilation rate (the total air change (1/h) × room volume (m^3)) measured by the tracer gas method, which includes the basic ventilation rate and the user-influenced ventilation rate as mentioned above. The dotted line shows the total ventilation rate calculated from a simple one-zone model of the house taking into consideration the wind velocity, the wind direction, the difference between the outdoor temperature and the indoor air temperature, and whether the windows and doors are opened or closed. The network model with the Newton–Raphson method was used for calculating ventilation rate (see Okuyama [3]). Since the calculated ventilation rate agreed fairly with the measured ventilation rate, the above calculation method can be used to simulate ventilation rate. As can be seen from the figure, there are large differences between the basic ventilation rates, i.e. the ventilation rate measured during the period of non-occupancy when windows and doors were closed, and the total ventilation rate which includes the basic ventilation rate and the user-influenced ventilation rate measured during occupancy when windows/doors were open.

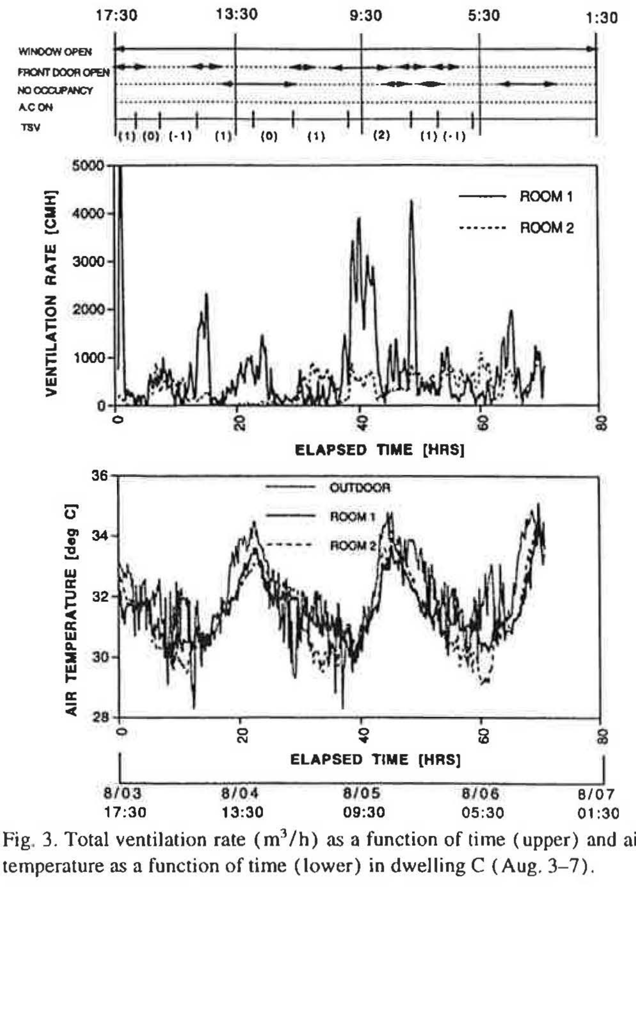


Fig. 3. Total ventilation rate (m^3/h) as a function of time (upper) and air temperature as a function of time (lower) in dwelling C (Aug. 3–7).

Table 3 shows the mean outdoor temperature and the mean room air temperature/relative humidity while an air conditioner was in operation in dwelling B. The mean outdoor temperature and the mean room air temperature/relative humidity 60 min before the air conditioner was operated are also listed in Table 3. Since the room temperature and the room relative humidity were high before operating the air conditioner and volcanic ash fell on both July 30 and 31, the air conditioner had been running through the night. However, the resident of dwelling B did not use the air conditioner during the daytime even though she voted the thermal sensation to be 'slightly hot (+1)' or 'hot (+2)'.

Fig. 3 shows the measured ventilation rate using the tracer gas method (upper) and the measured air temperature (lower) in dwelling C where two employed, elderly residents live. Since they did not have an air conditioner, the windows had been opened throughout the measuring period, as shown in the upper scale of Fig. 3. The ventilation rate in Room 1 was very large (3000–4000 m^3/h) especially when the windows and the door were both opened, because the airflow passed from the windows to the door effectively. On the other hand, when the windows were opened and the door was closed, the ventilation rate in Room 1 was approximately 500 m^3/h, the same as that in Room 2. The residents voted the thermal sensation to be between '+1 (slightly warm)' and '−1 (slightly cool)' during most of the measuring period even though they used a small electric fan and natural venti-

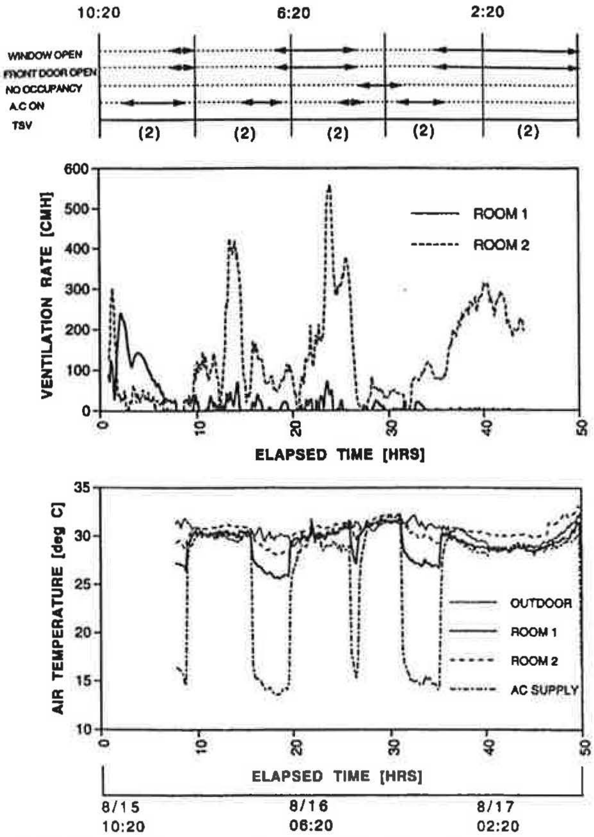


Fig. 4. Total ventilation rate as a function of time (upper) and air temperature as a function of time (lower) in dwelling D (Aug. 15-17).

lation for cooling and the room air temperature was rather high at 30–33°C.

The variation of the measured ventilation rate and the measured air temperature in dwelling D, where one elderly woman lives, is shown in Fig. 4. Since the air conditioner was installed in Room 1, the windows in Room 1 were closed when the air conditioner was running. The resident of dwelling D used the air conditioner often during the measuring period. The ventilation rate in Room 1 was then less than that in Room 2 where no air conditioners were installed and the windows had been opened for a long time. Table 4 shows the mean outdoor temperature and the mean room air temperature/relative humidity during the period of air conditioner operation in dwelling D. When the outdoor air temperature was below 30°C, the resident opened the windows and doors and did not use the air conditioner. She operated the air conditioner when the room air temperature exceeded 30°C.

The variation of the measured ventilation rate and the measured air temperature in dwelling G, where two male college students live, is shown in Fig. 5. Although the residents have an air conditioner, running time was short during the measuring period. They had opened windows during most of the measuring time resulting in a higher natural ventilation rate. Table 5 shows the mean outdoor temperature and the mean room air temperature/relative humidity during the period of air conditioner operation in dwelling G. The mean outdoor temperature and the mean room air temperature/relative humidity 60 min before operating an air conditioner are also listed in Table 5. In dwelling G, the residents used the air conditioner most often when the room air temperature exceeded 30°C. The air conditioner was in operation for only 1–2 h. This pattern of air conditioner use in dwelling G was very different from that in dwelling B where the air conditioner was in use for a long time.

3.2. Influence of the occupants' behavior

The basic ventilation rate, the user-influenced ventilation rate and the total ventilation rate (and corresponding air change rates, respectively) mentioned above for Room 1 in each dwelling are listed in Table 6. Since the windows had not been closed during the measuring period in dwelling C, the basic air change rate could not be calculated. Fig. 6 shows the user's influence on the ventilation rate in Room 1 of the eight dwellings (dwellings A–H). As can be seen in Fig. 6 and Table 6, there is a considerable difference in the total ventilation rate (and the corresponding total air change rate)

Table 4
Mean air temperature under the cooling condition using AC in dwelling D

Period of cooling by AC	Mean outdoor temp. during cooling (°C)	Mean room temp. during cooling (°C)	Mean room r.h. during cooling (%)	Mean outdoor temp. before cooling (°C)	Mean room temp. before cooling (°C)	Mean room r.h. before cooling (%)
8/16-0.2:0.4 to 8/16-0.5:54	30.11 ± 0.35 [a]	26.30 ± 0.59	56.11 ± 1.97	30.30 ± 0.21	30.35 ± 0.22	55.07 ± 0.58
8/16-12:14 to 8/16-12:54	31.13 ± 0.33	28.26 ± 0.23	56.28 ± 3.69	31.13 ± 0.32	30.92 ± 0.23	53.51 ± 0.67
8/16-17:34 to 8/16-21:34	31.30 ± 0.41	27.48 ± 0.70	53.16 ± 1.78	31.33 ± 0.10	31.63 ± 0.10	48.85 ± 0.25
8/17-12:14 to 8/17-13:04	32.25 ± 0.80	28.07 ± 1.04	[b]	31.65 ± 0.36	30.90 ± 0.48	[b]
8/17-16:44 to 8/17-17:14	32.08 ± 0.40	28.43 ± 0.15	[b]	32.43 ± 0.38	31.43 ± 0.18	[b]

[a] Standard deviation.
[b] Data not available.

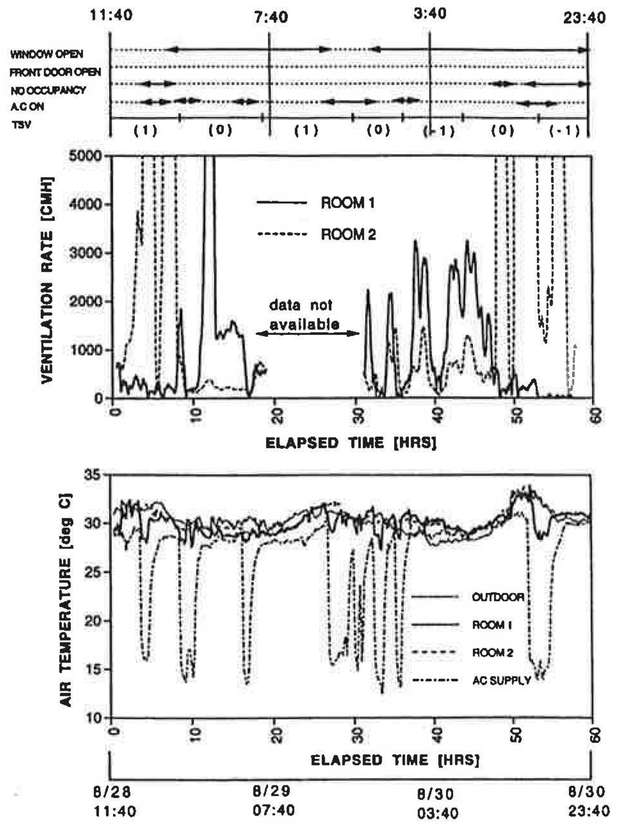


Fig. 5. Total ventilation rate as a function of time (upper) and air temperature as a function of time (lower) in dwelling G (Aug. 28—30).

among individual dwellings. As the basic air change rates are fairly similar, it was the user's behavior that caused these large differences. If the size of the basic air change rate and the user-influenced air change rate in the investigated dwellings are compared, it can be seen that 87% of the total air change rate is caused by the behavior of the occupants. Table 7 shows the time during which windows and door were open and during which the air conditioner was operated in individual dwellings during the measuring period. Although the mean outdoor air temperatures during each dwelling's measuring period were fairly similar, the ratios of operating air conditioners, i.e. the hours of operating air conditioners divided by the occupied hours during the measuring period, among the individual dwellings are rather different. The occupants of dwelling A used the air conditioner less often but opened the windows for a longer time, while other occupants, such as those in dwelling E operated the air conditioner for a longer time and opened the windows for shorter periods.

3.3. Electric power consumption for cooling

The relationship between electric power consumption for cooling (i.e. air conditioning in summer) and the measured total ventilation rate in the investigated dwelling is shown in Fig. 7. Calculations for electric power consumption for cooling in individual dwellings are based on monthly electric power consumptions from Oct. 1993 to Sept. 1994. A list of monthly electric power consumption for the investigated dwellings was obtained from an electric power company. The electric power consumption for cooling was calculated as follows:

$$ECC = \frac{EC_{summer}}{4} - \frac{EC_{is}}{2}. \qquad (1)$$

Table 5
Mean air temperature under the cooling condition using AC in dwelling G

Period of cooling by AC	Mean outdoor temp. during cooling (°C)	Mean room temp. during cooling (°C)	Mean room r.h. during cooling (%)	Mean outdoor temp. before cooling (°C)	Mean room temp. before cooling (°C)	Mean room r.h. before cooling (%)
8/28-15:28 to 8/28-16:28	31.40 ± 0.09 [a]	28.86 ± 0.85	59.836 ± 1.03	31.52 ± 0.07	31.70 ± 0.53	57.27 ± 2.33
8/28-20:18 to 8/28-22:08	30.02 ± 0.15	28.81 ± 1.07	52.73 ± 2.73	30.40 ± 0.10	29.93 ± 0.39	59.83 ± 2.23
8/29-03:58 to 8/29-04:48	30.40 ± 0.23	28.37 ± 0.28	54.28 ± 3.51	29.95 ± 0.30	28.93 ± 0.19	64.72 ± 0.61
8/29-14:38 to 8/29-17:08	31.07 ± 0.18	30.61 ± 1.34	[b]	31.35 ± 0.27	32.37 ± 0.76	[b]
8/29-17:48 to 8/29-18:48	30.49 ± 0.05	29.91 ± 0.77	[b]	30.58 ± 0.11	30.68 ± 0.22	[b]
8/29-22:58 to 8/29-23:58	29.29 ± 0.15	29.70 ± 1.02	52.90 ± 4.17	29.78 ± 0.37	31.22 ± 0.40	58.02 ± 1.20
8/30-15:48 to 8/30-18:28	32.32 ± 0.64	29.87 ± 1.66	49.40 ± 4.83	32.78 ± 0.28	32.92 ± 0.16	46.36 ± 0.16
8/30-23:58 to 8/31-00:38	30.44 ± 0.25	29.72 ± 0.91	[b]	30.40 ± 0.13	30.73 ± 0.05	[b]
8/31-04:28 to 8/31-05:48	29.35 ± 0.25	28.38 ± 0.66	[b]	29.05 ± 0.18	30.32 ± 0.66	[b]

[a] Standard deviation.
[b] Data not available.

Table 6
Basic ventilation rate, user-influenced ventilation rate, total ventilation rate and corresponding air change rate (ACH)

Dwelling no. (floor)	Basic VR (m^3/h)	Basic ACH (1/h)	User-influenced VR (m^3/h)	User-influenced ACH (1/h)	Total VR (m^3/h)	Total ACH (1/h)
A (14F)	54.65 ± 14.57 [a]	1.3	770.20 ± 695.24	18.3	587.43 ± 671.00	14.0
B (11F)	128.41 ± 164.41	3.1	1842.15 ± 1837.88	43.8	1114.63 ± 1634.76	26.5
C (8F)	[b]		716.91 ± 1061.72	17.0	716.91 ± 1061.72	17.0
D (6F)	83.23 ± 134.8	2.5	219.84 ± 149.28	5.2	130.81 ± 161.31	4.0
E (11F)	61.22 ± 44.44	1.5	546.23 ± 403.61	13.0	223.89 ± 331.16	5.3
F (7F)	33.31 ± 23.55	0.8	991.52 ± 751.38	23.6	662.49 ± 769.31	15.7
G (14F)	142.62 ± 290.67	3.4	1808.87 ± 2925.03	43.0	1063.34 ± 2302.73	25.3
H (16F)	28.11 ± 158.04	0.7	1525.77 ± 967.46	36.2	426.49 ± 844.28	10.1

VR: ventilation rate.
[a] Standard deviation.
[b] Windows were never closed in dwelling C.

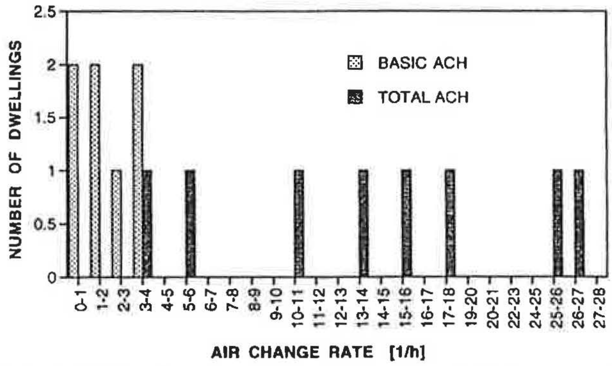


Fig. 6. Average basic air change rate and average total air change rate for investigated dwellings.

where ECC is the electric power consumption for cooling by air conditioner (kWh); EC_{summer} the average electric power consumption for four months (June, July, Aug., Sept.,) of the summer season (kWh); EC_{is} the average electric powder consumption for two months (May, Oct.) of the intermediate season (kWh).

In Fig. 7, the total ventilation rate can be seen as a function of the electric power consumption for cooling even though the correlation coefficient between the total ventilation rate and the velocity power consumption is low ($r = 0.4$). It appears from the data that other qualitative factors, such as schedules, tolerance of high temperatures and frugality, seem to have more effects on the electric power consumption.

4. Discussion

4.1. The occupant's behavior

By observing how the total ventilation varies according to time in a single dwelling, the occupants' influence on the ventilation rate can be clearly observed. An example is shown

Table 7
Time during which windows were open, closed and the air conditioner used

Dwelling no.	Measurement time (h)	Time of non-occupancy (h)	Time of opening windows (h)	Time of opening front door (h)	Time of operating AC (h)	Mean outdoor temperature (°C)
A	58	15 [0.26] [a]	27 [0.47] {0.63} [b]	27 [0.47] {0.63}	4 [0.07] {0.09}	30.5
B	76.5	9 [0.12]	48 [0.63] {0.71}	23.5 [0.31] {0.35}	22 [0.29] {0.33}	29.1
C	84	31 [0.36]	84 [1.00] {1.58}	30 [0.36] {0.57}	0 [c]	30.0
D	52.66	7.5 [0.14]	22 [0.42] {0.49}	22 [0.42] {0.49}	16 [0.30] {0.35}	28.7
E	81.5	4.5 [0.06]	15.5 [0.19] {0.20}	0 [0.00] {0.00}	23.5 [0.29] {0.31}	28.5
F	29.5	0 [0.00]	19 [0.64]	12 [0.41]	13.5 [0.46]	27.2
G	81.5	14.5 [0.18]	63.5 [0.78] {0.95}	0 [0.00] {0.00}	10 [0.12] {0.15}	29.0
H						

[a] Ratio divided by measurement time.
[b] Ratio divided by occupancy time.
[c] Dwelling C has no air conditioner.

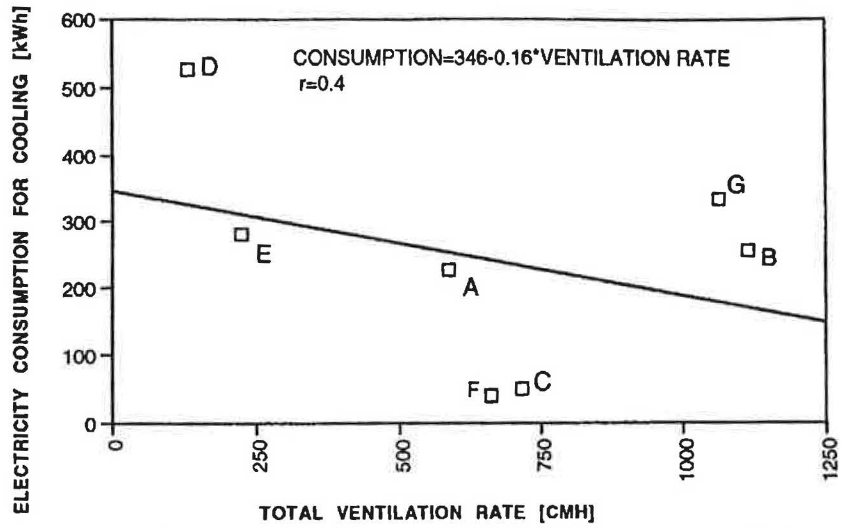


Fig. 7. Total ventilation rate as a function of electricity energy consumption for cooling (dwelling number is listed beside a plot).

of the variation of the measured total ventilation rate for a one-family dwelling without air conditioners (dwelling C) and of the calculated basic ventilation rate (infiltration rate) for that dwelling in Fig. 8. The calculated basic ventilation rate was determined based on the simple model mentioned above, taking into consideration wind velocity, wind direction, air temperature and the condition that all windows and doors were closed. As shown in Fig. 8, there is a large difference between the variation of the measured total ventilation rate (mean value: 717 m^3/h [ACH: 17 h^{-1}]) and that of the calculated basic ventilation rate (mean value: 140 m^3/h [ACH: 3.3 h^{-1}]) in the same dwelling. If occupants did not open windows/doors during the measuring period, the total ventilation rate would decrease to 140 m^3/h, which was calculated as the mean basic ventilation rate. Kammerud et al. described [4] that ventilation rate has the potential to substantially reduce cooling energy use in the residential buildings. According to their tentative calculation for the model building, the cooling load reduction increases by 35% as the air change rate increases from 3.3 to 17 h^{-1} in the warmer climate (i.e. Albuquerque, NM).

Although the occupants in dwelling C did not have an air conditioner, they did not vote the thermal sensation to be 'hot' or 'warm'. Therefore, their behavior of not using an air

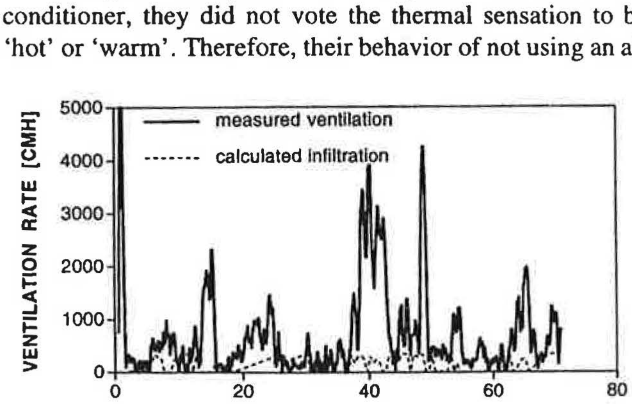


Fig. 8. Measured total ventilation rate and calculated infiltration rate as a function of time in dwelling C (Aug. 3–7).

conditioner for cooling might have an influence on their ther mal sensation, i.e. being tolerant of warmth. For example when they could induce enough cross ventilation by openin windows, their preferred temperature in summer might b higher than the comfort temperature predicted by Fanger' comfort equation [5]. Unlike in offices, occupants liv according to their preferences of indoor environment i dwellings. When occupants feel hot or warm, one occupar might turn on the air conditioner to be 'cool', while anoth might open windows to induce cross ventilation. Thus, tl occupant who prefers to use the air conditioner might co sume more electric power than the one who prefers to op windows/doors. But what causes different cooling behavio among people? Fujii and Lutzenhiser mentioned [2] that m Japanese people believe that natural ventilative cooling better for their health than an air conditioned room. Moreov 75% of the residents in that study believed natural cooling be more economical, while only 20% said that natural cooli is more comfortable than an air conditioned room. On other hand, in most of the dwellings in our study, the ratic air conditioner operation, i.e. operating hours of the air c ditioner divided by occupancy hours, was shorter than tha having windows opened (Table 7). Even in Kagoshima C where volcanic ash falls particularly in summer, it was fo that many residents in this study used cross ventilation openings windows as well as by operating air condition In order to clarify whether the financial status of indivi occupants had any effect on the occupants' behavior, an a tional questionnaire survey on the dwellings' characteri was conducted in 66 dwellings in three housing compl in Kagoshima City. The questionnaire's contents are list Table 8. The surveyed houses, including the dwellings w the ventilation rate was measured with the tracer gas met have almost the same floor area and are located in proximity. From this questionnaire survey, it was found 23% of respondents answered that they opened windows

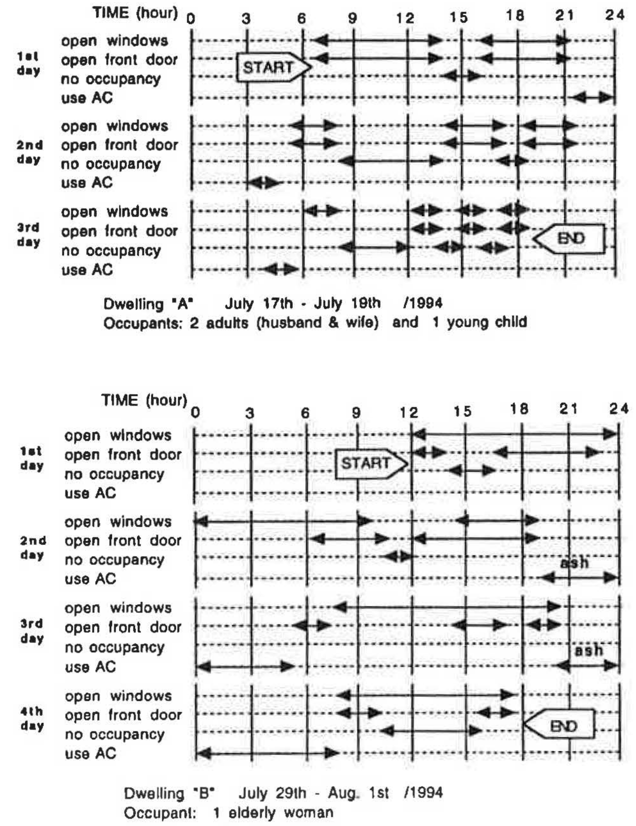


Fig. 9. Occupants' behavior in dwellings A (upper) and B (lower).

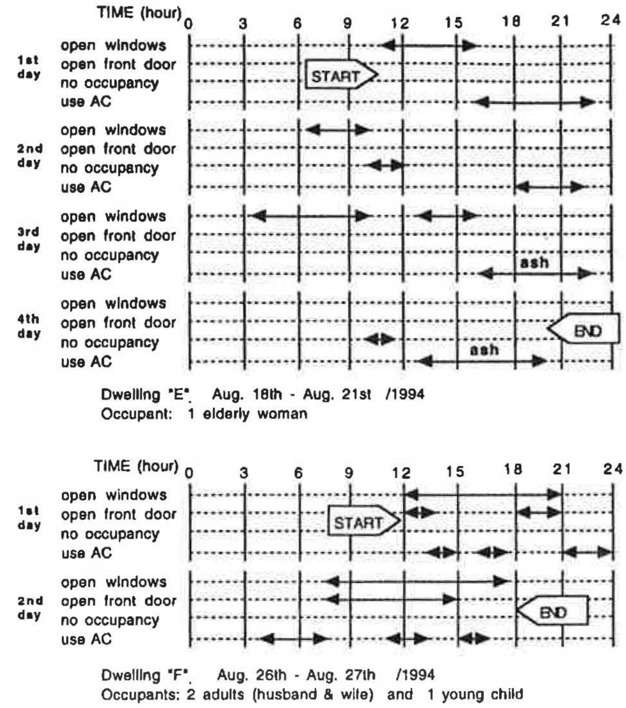


Fig. 10. Occupants' behavior in dwellings E (upper) and F (lower).

5. Conclusions

The field study on indoor air environment, i.e. ventilation rate measured with the tracer gas method, air temperature and relative humidity, was conducted in eight dwellings in a housing complex located in Kagoshima City, southern Japan. A questionnaire survey for indoor environment assessment and for residents' behavior was conducted using a self-report questionnaire sheet in the investigated dwellings. This survey also collected data about when residents opened windows/doors, when they operated air conditioners, and when the dwellings were unoccupied during the measuring period. The following conclusions were obtained.

(1) There are large differences between the *basic ventilation rate*, i.e. the ventilation rate measured during the period of non-occupancy when windows and doors were closed, and the *total ventilation rate* including the basic ventilation rate

Table 10
Hours of air conditioner operation during nighttime, daytime and evening

Dwelling no.	Time of operating AC (h)		
	Daytime (7a.m.–6p.m.)	Evening (6p.m.–9p.m.)	Nighttime (9p.m.–7a.m.)
A	1 [0.017] [a] {0.25} [b]	0 [0] {0}	3 [0.052] {0.75}
B	0 [0] {0}	3 [0.039] {0.136}	19 [0.248] {0.864}
D	8 [0.152] {0.5}	4 [0.076] {0.25}	4 [0.076] {0.25}
E	10 [0.123] {0.426}	10 [0.123] {0.426}	3.5 [0.043] {0.149}
F	7 [0.237] {0.519}	0 [0] {0}	6.5 [0.220] {0.481}
G	6 [0.074] {0.6}	4 [0.049] {0.4}	0 [0] {0}

[a] Ratio divided by measurement time.
[b] Ratio divided by air conditioning hours.