Experiment on the effect of natural ventilation on cooling energy conservation

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ABSTRACT

Recently, natural ventilation, which is traditional cooling method in Japan, has become considered as the key method for cooling energy conservation. We have carried out experiments to measure indoor thermal environment and cooling electric energy consumption in experimental RC construction apartment house by simulating occupants' life-style including thermal control with natural ventilation and air conditioner. And based on the experimental results, we estimated cooling electric power consumption from July to September. The results suggest that cross ventilation could reduce cooling electric power consumption of the experimental dwelling by 56% while single-sided ventilation could reduce it by 41%.

1. INTRODUCTION

In Japan, natural ventilation has been used for cooling in summer and medium season. However, because it is hot and humid in summer in most parts of Japan, air conditioner has become popular recently. This causes cooling energy consumption to rise continuously. In these days, as global warming has become a serious problem, natural ventilation has been considered as a key method for cooling energy conservation. However, there is little sufficient knowledge to evaluate the effect of natural ventilation on cooling energy consumption quantitatively. That is one of the problems in popularizing the technique for utilization of natural ventilation.

Therefore, we have developed an experimental facility where occupants' life-style including thermal control with natural ventilation and air conditioner is simulated automatically. And we validated the effect of natural ventilation on cooling energy consumption. In this paper, we will introduce the experimental facility and report some experimental results.

2. EXPERIMENTAL DWELLING

The experimental dwelling is a west unit on the third floor of RC construction multi-family house building (T. Sawachi, 2007). Fig. 1 shows the external view of the house building and the internal view of living room. The house building has been built on an open site, and the surroundings have little influence to obstruct the outside wind. The dwelling has 4 occupied rooms (e.g. Living room, Japanese-style room, Child room 1 and Child room 2). Each occupied room has one air conditioner, one inner opening and one window. Table 1 shows the volume of room and the size of opening. These air conditioners and openings except the inner opening of child room 2 are operated automatically by the devises shown in Fig. 2 and Fig. 3. Air conditioners are operated by the infrared signal from the IR adapter which is put on the receiver directly. On the other hand, windows are operated by taking out or up wire with motor on the topside of them. Inner openings are operated by applying the device on the market.

On the assumption that the family is consisted of a couple and their 2 children, we set the 3 patterns of occupants' life-style; for weekday (W), for holiday that the family stays home (HH) and for holiday that the family stays out (HO) (T. Sawachi, 2007).

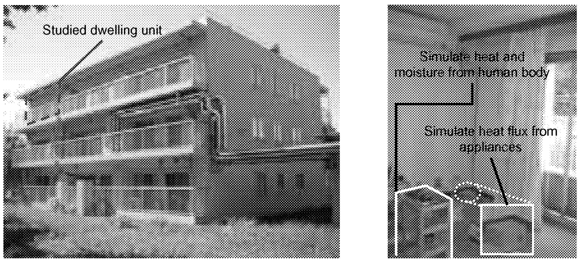


Fig. 1: External view of the house building and internal view of the living room

Table 1: Volume of room and the size of opening

	Volume of room [m3]	Window size [m2]	Inner opening size [m2]
Living room	54.0	1.1	1.7
Japanease-style room	22.3	1.1	2.4
Child room 1	23.2	0.5	1.6
Child room 2	18.0	0.4	1.6

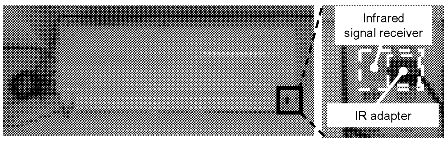


Fig. 2: Devise for operation of air conditioner

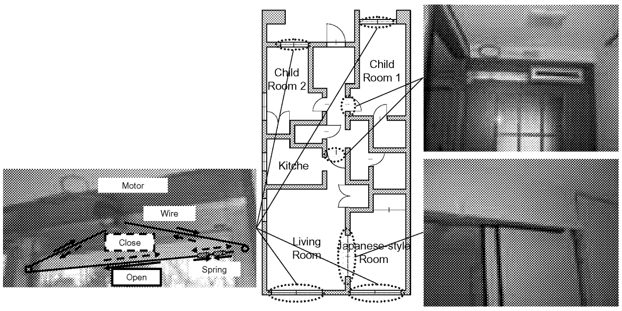


Fig. 3: Devise for operation of opening

3. EXPERIMENTAL CONDITION

In order to validate the effects of thermal control with natural ventilation and air conditioner on indoor thermal environment and cooling electric power consumption, experiments with three patterns of thermal control have been conducted during July – October in 2007. The schedule of experiment is shown in Table 2. CV and SV are the pattern that occupants control their thermal environment with natural ventilation and air conditioner. CV is the pattern of cross ventilation between living room and child room 1 in the day time and between Japanese-style room and child room 1 in the night time. SV is the pattern of single-sided ventilation. On the other hand, AC is the pattern that occupants control their thermal environment with only air conditioner. In all patterns, the set point of temperature for air conditioner is 26 ^{o}C. Besides, in order to validate the effects of heat and moisture generation on indoor thermal environment, experiments have been conducted during 10 October – 15 October in 2007. CL is the pattern that occupants stay in the room without air conditioner and natural ventilation.

Table 2: Schedule of experiment

Thermal control pattern	Experimental term			
CV	7/4 - 7/9 10/3 - 10/8	7/25 - 7/30 10/17 - 10/22	8/29 - 9/3	9/19 - 9/24
SV	7/11 - 7/16	8/8 - 8/13	9/5 - 9/10	9/26 - 10/1
AC	7/18 - 7/23	8/15 - 8/20	8/22 - 8/27	9/12 - 9/17
CL	10/10 - 10/15			

Occupants' thermal control in each room is judged from occupation and room temperature at 900 mm height above the floor every one hour while sleeping and every five minutes while awaking. First, occupants' thermal control behavior is decided with Table 3. And then, according to the behavior, openings and air conditioners are operated by Table 4. Fig. 4 shows the occupation of each room which is scheduled at 5 minute intervals.

In CV pattern and CS pattern, thermal control behavior is decided by Table 3-(a). In these 2 patterns, occupants absolutely use cross ventilation or single-sided ventilation for 5 minutes after the beginning of occupation. Except first 5 minutes after the beginning of occupation, occupants continue to use cross ventilation or single-sided ventilation if room temperature is between 20 ^{o}C and 28 ^{o}C. Otherwise, if room temperature is under 20 ^{o}C, openings turn close. If room temperature is above 28 ^{o}C, air conditioner turns on. In order to protect experimental facilities from typhoon, if outside wind velocity is above 10 m/s as openings are open, all openings turn close. According to thermal control behavior decided by Table 3-(a), openings and air conditioners are operated by Table 4-(a), Table 4-(b), Table 4-(c) and Table 4-(d) in CV pattern and by Table 4-(d) in CS pattern.

In AC pattern, thermal control behavior was decided by Table 3-(b). In this pattern, air conditioners turn on if room temperature is above 26 °C. According to thermal control behavior decided by Table 3-(b), openings and air conditioners are operated by Table 4-(d)

In CL pattern, occupants always stay in the room without air conditioner and natural ventilation.

Table 3: Decision of thermal control behavior

(a) CV and SV

Requirement				Now thremal control behavior	Notes
Now schedule of occupation	Precious thermal control behavior	Now environment: Outside velocity	Now environment: Room temperature	Each room	
Awake or Sleep	N	10m/s ≤	26 °C <	A	Decide the behavior at the beginning of occupation
			< 26 °C	C	
		< 10m/s	-	V	
	V	10m/s ≤	26 °C <	A	Decide the behavior except first 5 minites after the beginning of occupation
			< 26 °C	C	
		< 10m/s	28 °C ≤	A	
			20 °C ≤ and < 28 °C	V	
			< 20 °C	C	
	C	-	26 °C ≤	A	
			< 26 °C	C	
	A	-	-	A	
On occupancy	-	-	-	N	

A: Air conditioner, C: Close window without air conditioner, V: Cross ventilation or single-sided ventilation, N: No occupancy

(b) AC

Requirement			Now thremal control behaviour
Now schedule of occupation	Precious thermal control behaviour	Now environment: Room temperature	Each room
Awake or Sleep	C or N	26 °C <	A
		< 26 °C	C
	A	-	A
Nn occupancy	-	-	N

Table 4: Decision of operation for openings and air conditioners

(a) Living room in CV

Now thremal control behavior		Operation		
Japanese-style room	Living room	Japanese-style room: Air conditioner	Window	Inner opening
A	-	on	close	close
V	Except A	off	open	open
V	A	off	open	close
C or N	-	off	close	close

(b) Japanese-style room in CV

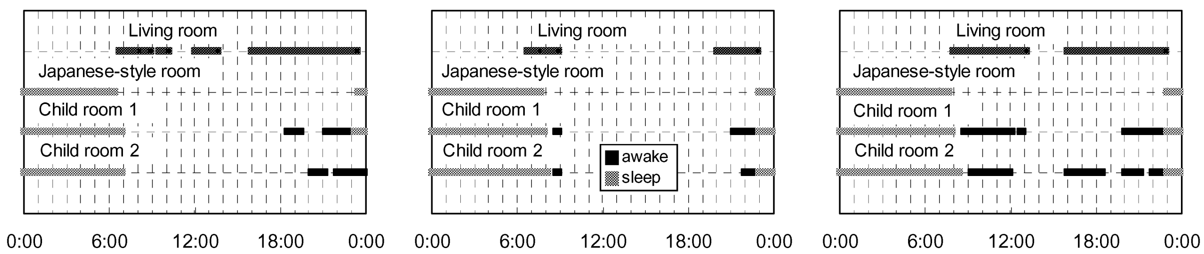
Now thremal control behavior		Operation		
Living room	Japanese-style room	Living room: Air conditioner	Window	Inner opening
A	-	on	close	close
V	-	off	open	open
C or N	C	off	close	open
C or N	Except V	off	close	close

(c) Child room 1 in CV

Now thremal control behavior			Operation		
Child room 1	Living room	Japanese-style room	Child room 1: Air conditioner	Window	Inner opening
A	-	-	on	close	close
V	-	-	off	open	open
C	-	-	off	close	close
N	A	-	off	close	close
N	V	-	off	open	open
N	C or N	V	off	open	open
N	C or N	Except V	off	close	close

(d) Child room 2 in CV and each room in SV and AC

Now thremal control behavior	Operation		
Each room	Each room: Air conditioner	Window	Inner opening
A	on	close	close
V	off	open	close
C or N	off	close	close



(a) Life-style: W (b) Life-style: HO (c) Life-style: HH

Fig 4: Schedule of occupation in each room

4. MEASUREMENT METHODS

The measurement items include outdoor environment, indoor environment, neighborhood environment, electric power consumption and air flow rate. Table 5 shows the summary of measurement items. Fig. 5 shows the measurement points of indoor environment. The items on outdoor environment are temperature, relative humidity, solar radiation, wind velocity, wind direction and rain fall. The items on indoor environment are air temperature, relative humidity, glove temperature, wall surface temperature, and wind velocity. The electric power consumption is measured about each home electrical appliance and lighting. The air flow rate is calculated by the product of average air flow velocity though window and area of window.

Table 5: Measurement items

Item		Instrument	Number of point	Interval
Indoor environment	Air temperature	Thermal couple	5 per room	5 min
	Relative humidity	Electric hygrometer	1 per room	5 min
	Glove temperature	Thermal couple	1 per room	5 min
	Wall surface temperature	Thermal couple	6 per room	5 min
	Wind velocity	Hot wire anemometer	1 per room	5 min
Outdoor environment	Temperature	Thermister	1 per room	5 min
	Relative humidity	Resistance hygrometer	1 per room	5 min
	Solar radiation	Pyranometer	1 per room	5 sec
	Wind direction	Ultrasonic anemometer	1 per room	5 sec
	Wind velocity	Ultrasonic anemometer	1 per room	5 sec
	Rain fall	Pluviometer	1 per room	5 min
Energy consumption	Electric power consumption	Clump sensor	1 per appliance	1 min
Air flow rate	Air flow velocity	Ultrasonic anemometer	5 per room	0.1 sec

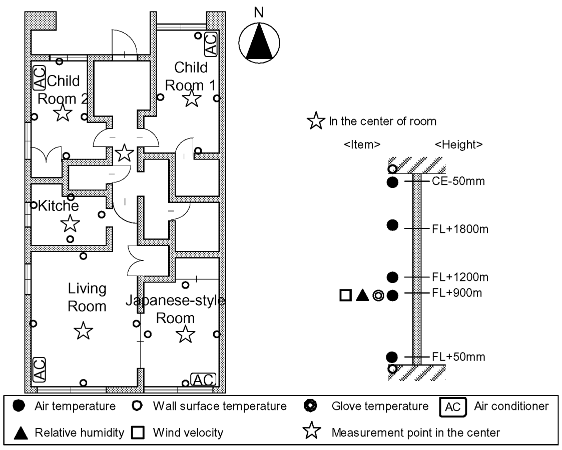


Fig 5: Measurement points of indoor environment

5. EXPERIMENTAL RESULTS

5.1 Influence of heat and moisture generation on indoor environment

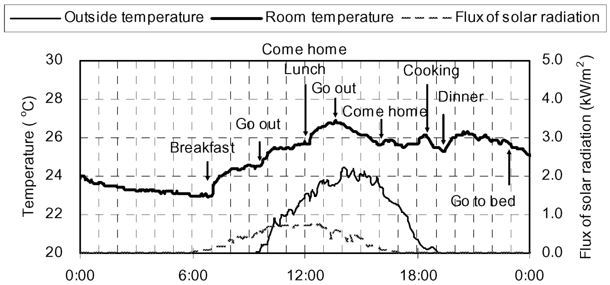


Fig. 6: Daily variation of room temperature in the living room (Thermal control: CL, Life-style: W)

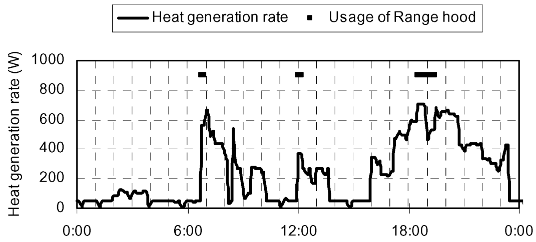


Fig. 7: Daily variation of heat generation rate in the living room (Life-style: W)

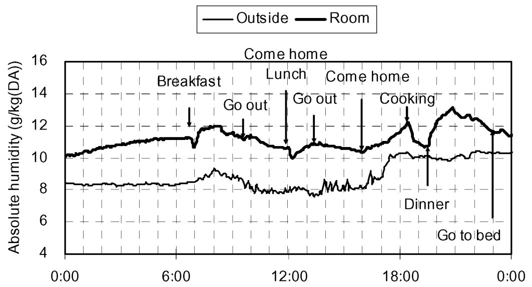


Fig. 8: Daily variation of room absolute humidity in the living room (Thermal control: CL, Life-style: W)

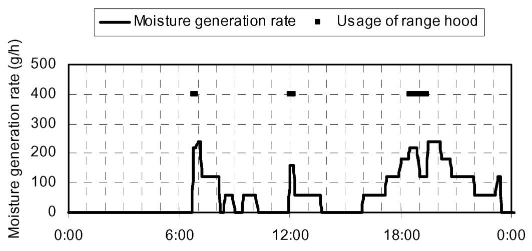


Fig. 9: Daily variation of moisture generation rate in the living room (Life-style: W)

Fig. 6 - Fig. 9 describe the daily variation of temperature, heat generation rate, absolute

humidity and moisture generation rate in the living room by CL pattern. As these figures show, room temperature and absolute humidity were varied according to heat and moisture generated by occupants' life-style. Especially at meal and in going out, coming home and cooking, there was remarked difference.

5.2 Indoor environment and air flow rate

The relation between air flow rate of living room and outdoor wind velocity in CV pattern and SC pattern is shown in Fig. 10. The relation of temperature between living room and outside is shows in Fig. 11. The relation of absolute humidity between living room and outside is shows in Fig. 12.The air flow rate of living room was 2-20 ACH in CV pattern while 2-3 ACH in SV pattern. When occupants used cross ventilation or single-sided ventilation, the temperature in the living room was 2-3 ^{o}C higher than outside and the absolute humidity in the living room was 1-2 g/kg(DA) higher than outside. Thought there was difference in air flow rate between CV pattern and SV pattern, CV pattern and SV pattern was close in the room temperature and the absolute humidity. It is suggested that even SV pattern had sufficient effect of heat and moisture discharge. On the other hand, when occupants used air conditioner, the temperature in the living room was about 1 ^{o}C lower than cooling set point for air conditioner. And the absolute humidity was lower than outside, which represents dehumidification by air conditioner.

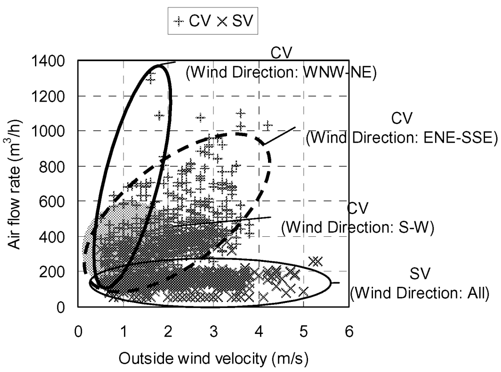


Fig. 10: Relation between air flow rate of living room and outside wind velocity

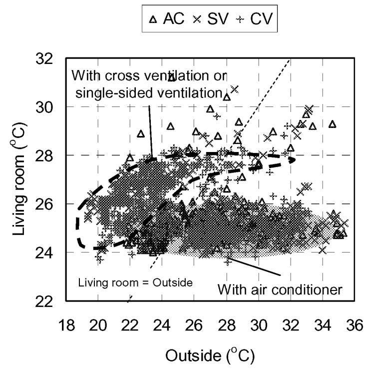


Fig. 11: Relation of air temperature between living room and outside

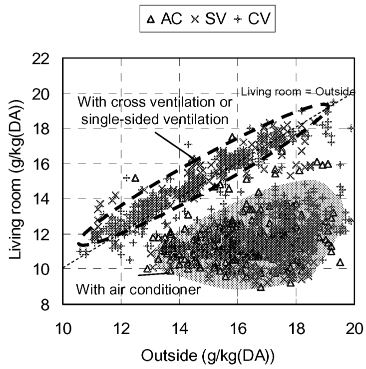


Fig. 12: Relation of absolute humidity between living room and outside

5.3 Air conditioning hours and electric power consumption

The relation between daily total of air conditioning hours in the living room and daily average outside temperature is shown in Fig. 13. The relation between daily total cooling electric power consumption in the living room and daily average outside temperature is shown in Fig. 14. Cross ventilation and single-sided ventilation reduced cooling electric power consumption when the outside temperature was relatively low. However, when outside temperature was above around 28 ^{o}C, cross ventilation and single-sided ventilation had little effect. It is because occupants used air conditioner almost all day in CV pattern and SV pattern as cross ventilation and single-sided did not work well for cooling in the hot day.

Fig 15 shows the total cooling electric power consumption from July to September which was estimated with a linear approximate formula based on the experimental results. The sample of the formula for the estimation in CV pattern is lined in Fig. 14. Outside temperature which substitutes for formula was measured on the roof of experimental apartment house. Compared to AC pattern, the cooling electric power consumption was reduced by 56 % in CV pattern while by 41 % SV pattern.

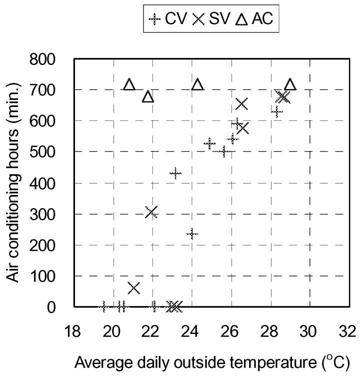


Fig. 13: Relation between daily total of air conditioning hours in the living room and daily average outside temperature

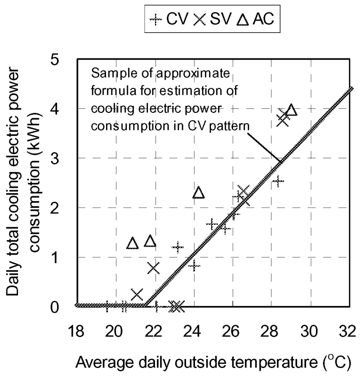


Fig. 14: Relation between daily total cooling electric power consumption in the living room and daily average outside temperature

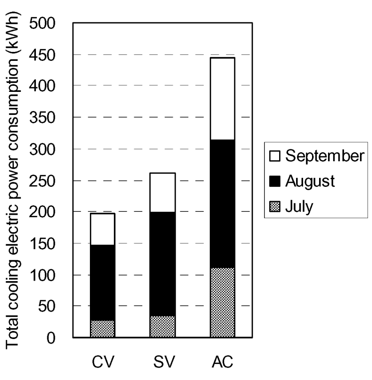


Fig. 15: Estimation of total cooling electric power consumption from July to September

6. DISCUSSION

As the experimental results demonstrated, single-sided ventilation had equivalent potential to cross ventilation for discharge of heat and moisture and cooling energy conservation in the living room of experimental unit, though there was obvious difference of air flow rate among them. In the future work, in order to investigate this reason, we will measure distribution of air temperature and air flow velocity in the living room of experimental unit to study on the process of heat discharge by cross ventilation and single-sided ventilation.

7. CONCLUSIONS

We have developed devices for operating air conditioner and openings to simulate occupants' thermal control with air conditioner and natural ventilation. By applying these devices, the experiment has been carried out to measure indoor thermal environment and cooling electric power consumption in RC construction apartment house. Based on the experimental results, the total cooling electric power consumption from July to September was estimated. The results suggested that cross ventilation could reduce by 56 % while single-sided ventilation could reduce by 41 %.

REFERENCES

T. Sawachi et al, 2007. Proposal of the experimental method with lifestyle simulating method aimed at validating energy performance of promising measures: Study on the experimental validation of energy conservation measures for residential buildings Part 1, Journal of environmental engineering, AIJ, 621, pp. 69-76