Influence of natural ventilation usage on cooling energy consumption and cooling capacity of an air conditioner

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Abstract

In Japan, natural ventilation through large openings has been used for cooling in summer and medium season. However, air conditioner has become popular recently, because it is hot and humid in summer in most parts of Japan. It causes cooling energy consumption to rise continuously. Nowadays, as global warming has become a serious problem, natural ventilation has been considered as a key method for cooling energy conservation. However, there is insufficient knowledge of natural ventilation effectiveness on cooling energy conservation quantitatively. Therefore, in order to verify the effectiveness of natural ventilation through large openings, we have been conducting experiments by automatically simulating various occupants' behaviors, namely cooking, lighting, usage of electric appliances and domestic hot water, operation of air conditioners, windows and curtain opening/closing. In this paper, we have performed experiments with additional several patterns, which have different thermal conditions for on operation of air conditioners, to our previous paper. And based on the experimental results, we analyzed the heat discharge by natural ventilation and the cooling capacity of air conditioner. The result suggests that though natural ventilation sometimes brings the gain of sensible and latent heat, it is not so much as to increase the daily cooling capacity of air conditioner.

Keywords: Natural ventilation, Air conditioner, Residential house

Introduction

In Japan, natural ventilation through large openings has been used for cooling in summer and medium season. However, air conditioner has become popular recently, because it is hot and humid in summer in most parts of Japan. It causes cooling energy consumption to rise continuously. Nowadays, as global warming has become a serious problem, natural ventilation has been considered as a key method for cooling energy conservation. However, there is insufficient knowledge of natural ventilation effectiveness on cooling energy conservation quantitatively.

Therefore, in order to verify the effectiveness of natural ventilation through large openings, we have been conducting experiments by automatically simulating various occupants' behaviors, namely cooking, lighting, usage of electric appliances and domestic hot water, operation of air conditioners, windows and curtain opening/closing. In this paper, we have performed experiments with additional several patterns, which have different thermal conditions for on operation of air conditioners, to our previous paper (H. Habara, 2009). And based on the experimental results, we analyzed the heat discharge by natural ventilation and the cooling capacity of air conditioner.

Experimental Dowelling

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, for holiday that the family stays home and for holiday that the family stays out (T. Sawachi, 2007). In this paper, we analyzed data which was measured in the experiments which were performed with schedule for weekday.

Experimental Condition

Experiments have been conducted with three patterns of thermal control shown in Table 2 during July – October in 2007-2009. The name of pattern is formed from thermal control pattern (CV, AC), Ta and Tb. CV is the pattern that occupants control their thermal environment with 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. On the other hand, AC is the pattern that occupants control their thermal environment with only air conditioner. Ta is the upper limit of room temperature without using air conditioner, and Tb is the preset temperature of air conditioner.

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. Table 3 shows the outline of occupants' behavior and decision of operation. First, occupants' thermal control behavior is decided with Table 4. And then, according to the behavior, openings and air conditioners are operated by Table 5. Fig. 4 shows the occupation of each room which is scheduled at 5 minute intervals.

In CV pattern, thermal control behavior is decided by Table 4-(a). According to thermal control behavior decided by Table 4-(a), openings and air conditioners are operated by Table 5-(a), Table 5-(b), Table 5-(c) and Table 5-(d).

In AC pattern, thermal control behavior was decided by Table 4-(b). According to thermal control behavior decided by Table 5-(b), openings and air conditioners are operated by Table 5-(d)

Measurement Method

The measurement items relate with outdoor environment, indoor environment, neighborhood environment, air conditioner 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 cooling capacity is measured with temperature and humidity of discharge and intake airflow and rotation frequency of fun. The discharge airflow is estimated on the relationships between rotation frequency of fun and discharge airflow which is obtained in the pre-experiment. And then, the cooling capacity is calculated by multiplying the discharge airflow by the enthalpy difference between discharge and intake air.

The airflow rate is calculated by the product of average air flow velocity though window and area of window.

Results and Discussion

Fig. 6 and Fig. 7 describe the daily variation of heat capacity of air conditioner and heat discharge by natural ventilation with average data in 5 minutes, which was measured in CV 26_26 pattern. During daytime, when cross ventilation was used, the airflow rate was 6 – 15 ACH (300 – 800 m^3/h) and the sensible heat discharge by cross ventilation was 200 – 400 W. This is enough to discharge almost inner heat generation. On the other hand, though the latent heat was gained by around 200 W at the beginning of cross ventilation, it was almost always discharged. During evening and night time, when air conditioner was used, the sensible heat capacity of air conditioner was 400 – 1200 W and the latent heat capacity of air conditioner was 200 – 400 W, which exceeded the inner heat and moisture generation.

Fig. 8, Fig. 9 and Fig. 10 show the relationship of daily average temperature and daily heat capacity / discharge. Fig. 11 shows the relationship of daily average temperature and daily cooling hour. Fig. 12 shows the relationship of daily average temperature and daily electric power consumption. In CV 28_26 pattern, both sensible and latent heat discharge by natural ventilation increased as outside temperature got lower. When outside temperature was below 24 ^{o}C, total heat discharge was around 10 – 20 MJ, which was as much as the heat capacity of air conditioner. As the sum of heat discharge by natural ventilation and heat capacity of air conditioner in CV 26_26 pattern is almost equal to heat capacity of air conditioner in AC

28_26 pattern, natural ventilation took charge of heat and moisture removal in CV 28_26 pattern. Meanwhile, when outside temperature was above 24 ^{o}C, though natural ventilation didn't contribute to removal of heat and moisture generation, the heat capacity of air conditioner in CV 28_26 pattern was higher than that in CA 26_26 pattern. It is because the daily total cooling hour was reduced, as the upper limit of room temperature without using air conditioner (Ta) in CV 28_26 pattern is 2 degree lower than that in AC 26_26 pattern. According to the decrease of cooling hour, the daily total electric power consumption declined in CV 28_26 pattern.

Through the experiment period, natural ventilation sometimes brought the gain of sensible and latent heat. It was at most 5 MJ, which didn't increase the cooling heat capacity of air conditioner.

Conclusions

In this paper, we discussed the influence of natural ventilation on cooling energy consumption and cooling capacity of air conditioner, based on the experimental result which was performed with three pattern of thermal control behavior. The results suggest that though natural ventilation sometimes brings the gain of sensible and latent heat, it is not so much as to increase the daily total cooling capacity of air conditioner. The heat discharge by natural ventilation can be effective on cooling energy conservation in hot and humid areas. In the future study, in order to apply the technique of cooling energy conservation with heat discharge by natural ventilation, we will research the effects of natural ventilation on cooling capacity of air conditioner in hot and humid condition.

References

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

Table 1 Volume of rooms and size of opening

	Volume of room [m^3]	Window size [m^2]	Inner opening size [m^2]
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

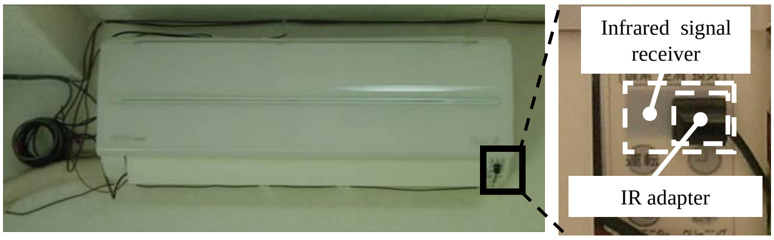

Fig. 2 Devise for operation of air conditioner

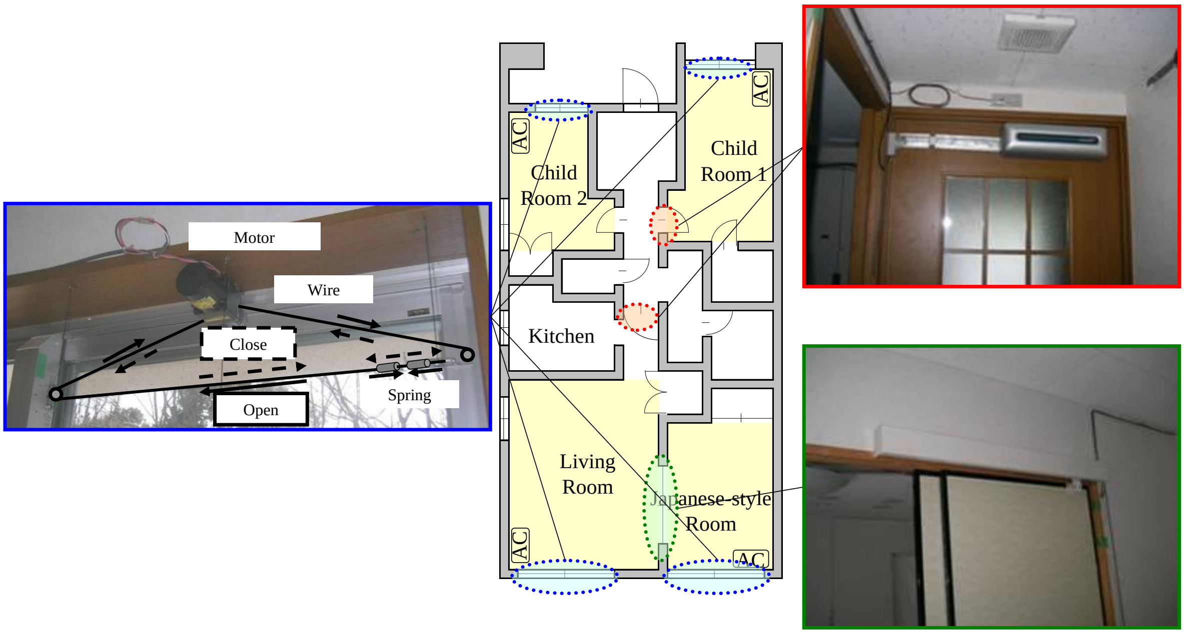

Fig. 3 Devise for operation of opening

Table 2 Experimental pattern

Thermal control pattern	Upper limit of room temperature without air conditioner (Ta)	Preset temperature of air conditioner (Tb)
CV28_26	28 °C	26 °C
AC26_26	26 °C	26 °C
AC28_26	28 °C	26 °C

Fig.3 Outline of operation logic

Thermal control pattern	Thermal control behavior	Operatin of air conditioner, window and indoor opening			
	Each room	Living room	Japanese-style room	Child room 1	Child room 2
CV	Table 4-(a)	Table 5-(a)	Table 5-(b)	Table 5-(C)	Table 5-(d)
AC	Table 4-(b)	Table 5-(d)			

Table 4 Decision of thermal control behavior

(a) CV

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

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

(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	Ta ^{o}C ≤	A
		< Ta ^{o}C	C
	A	-	A
Nn occupancy	-	-	N

Table 5 Decision of operation for openings and air conditioners

(a) Living room in CV

Now thremal control behavior		Operation		
Living room	Japanese-style room	Living room: Air conditioner	Living room: Window	Living room: 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

(b) Japanese-style 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

(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 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

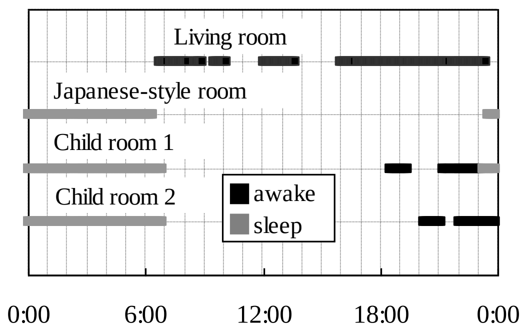

Fig.4 Schedule of occupation in each room

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
Coolin capacity of air conditioner	Electric power consumption	Clump sensor	1 per appliance	1 min
	Discharge air temperature	Thermal couple	1 per appliance	5 sec
	Discharge air humidity	Electric hygrometer	1 per appliance	5 sec
	Intake air temperature	Thermal couple	1 per appliance	5 sec
	Intake air humidity	Electric hygrometer	1 per appliance	5 sec
	Rotation frequency of fan	Rotation frequency meter	1 per appliance	5 sec
Air flow rate	Air flow velocity	Ultrasonic anemometer	5 per room	0.1 sec

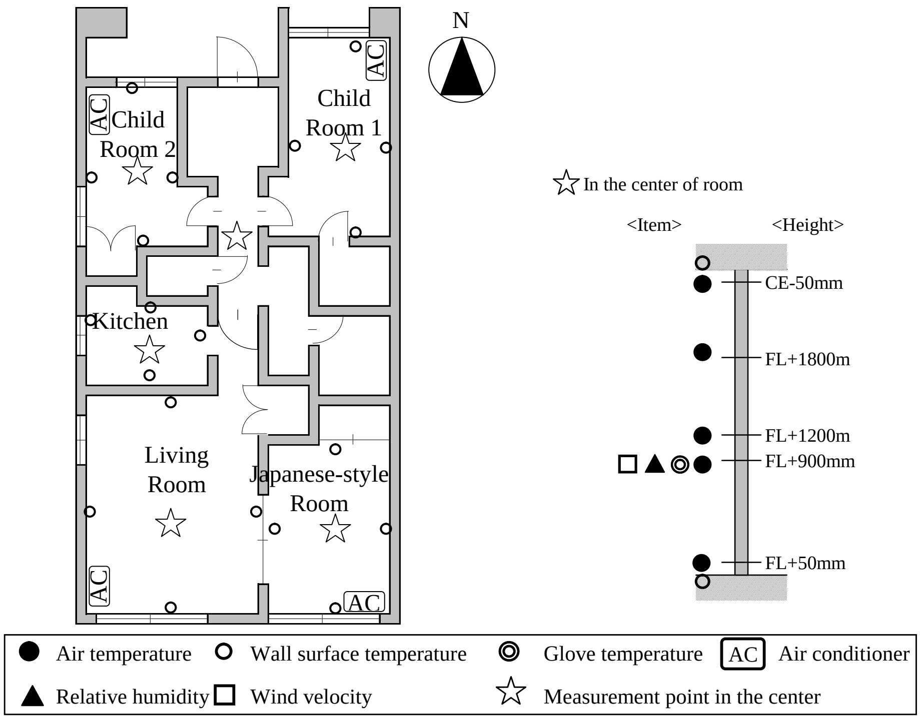

Fig. 5 Measurement points of indoor environment

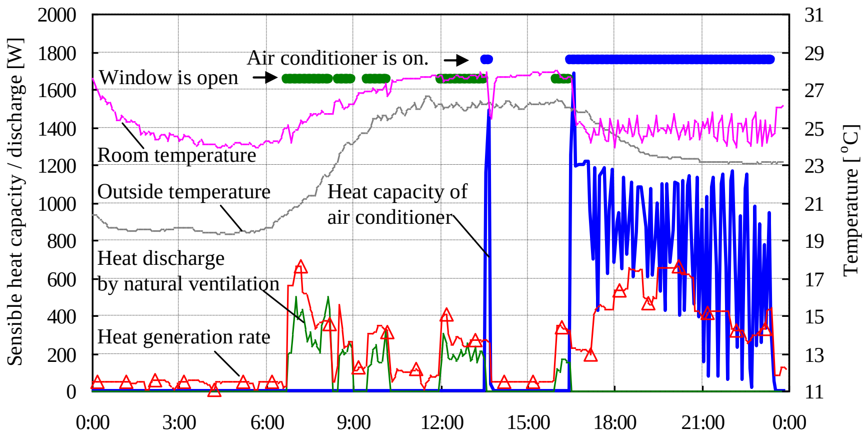

Fig. 6 Daily variation of sensible heat capacity / discharge (19 Sep. 2007)

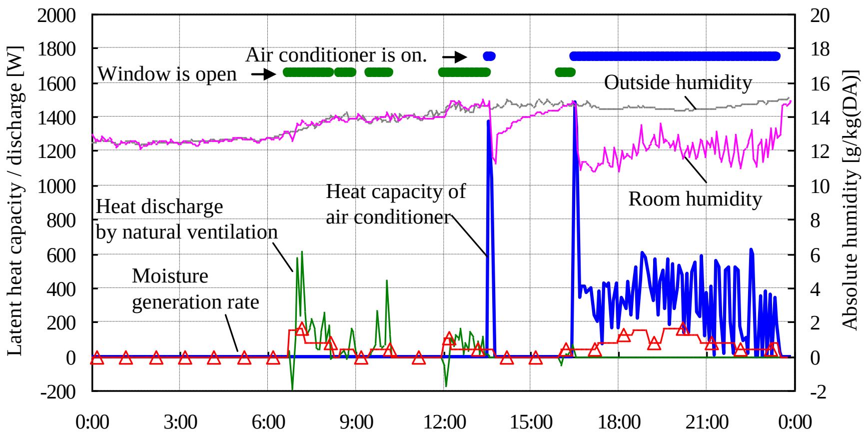

Fig. 7 Daily variation of latent heat capacity / discharge (19 Sep. 2007)

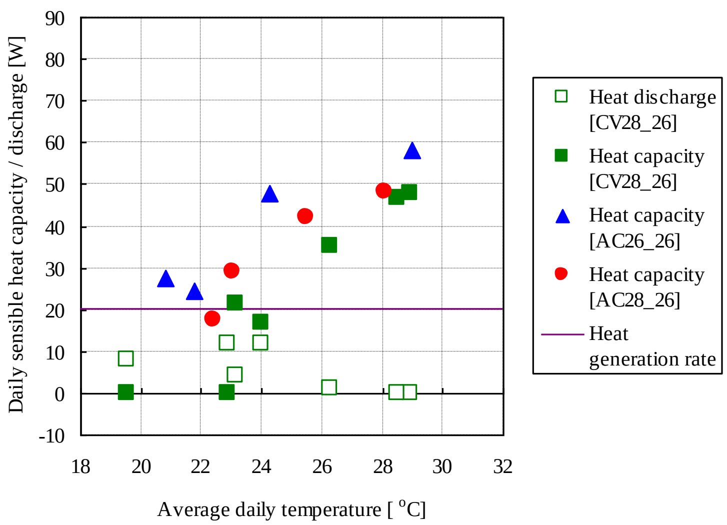

Fig. 8 Daily sensible heat capacity / discharge

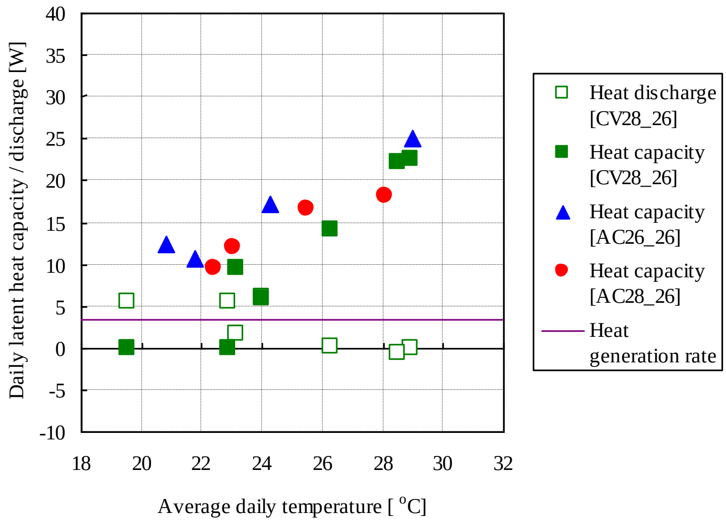

Fig. 9 Daily latent heat capacity / discharge

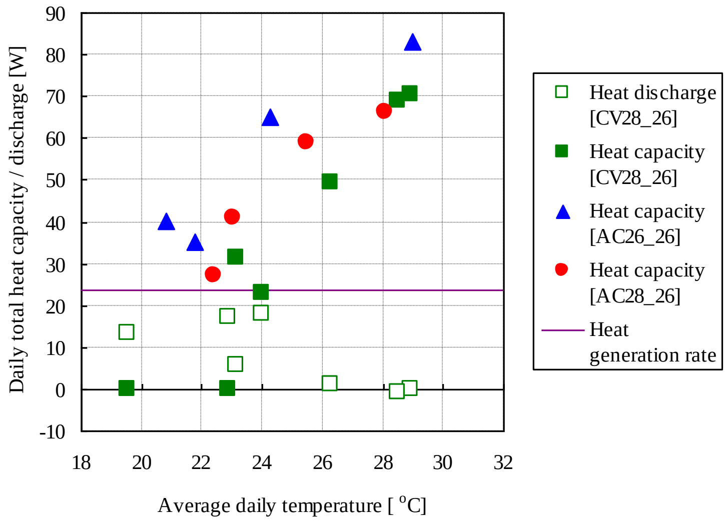

Fig. 10 Daily total heat capacity / discharge

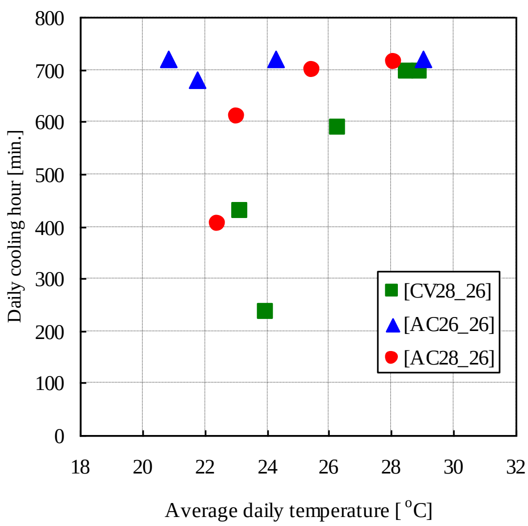

Fig. 11 Daily cooling hour

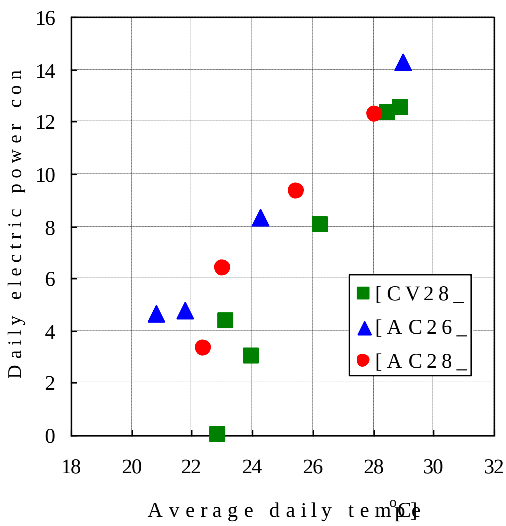

Fig. 12 Daily electric power consumption