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SURVEY ON THE OCCUPANT BEHAVIOR RELATING TO WINDOW AND AIR CONDITIONER OPERATION IN THE RESIDENTIAL BUILDINGS

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ABSTRACT

Our research group has been working on modeling of occupant behavior relating to window and air conditioner usage for energy simulation of residential buildings. In order to study the determining factor of occupant behavior in more detail, a survey was carried out in 45 residential houses in the summer of 2012. The state of windows (open-closed) and air conditioners (on-off), as well as environmental data, was recorded automatically. Additionally, the room occupation of all family members was investigated by distributing recording papers. The survey results showed differences in the occupant behavior in living rooms and master bed rooms.

INTRODUCTION

Modeling of occupant behavior has recently attracted attention because it has a significant influence when estimating the energy usage and indoor environment. Several field studies have been conducted to survey occupant window opening behavior. Most of them studied on the relationships between behavior and indoor/outdoor environment which have considerable impact to determine occupant behavior. The IEA-ECECS Annex 8 project found that the type of dwelling and the orientation of rooms were important as well. Besides, Time of the day is found to determine the transition probability because it has relation to daily pattern of time use of occupants (Johnson T. et al., 2005). Therefore, the occupant lifestyle as well as environmental parameters should be taken into account as explanatory variable of the model.

Our research group has been working on modeling of occupant behavior relating to window and air conditioner usage for energy simulation of residential buildings (Habara et al., 2011). As part of modeling of occupant behavior, a survey on the usage of air conditioner in exiting residential buildings was carried out, and the relationship between air conditioner usage and room temperature was clarified (Habara et al., 2005). The survey results indicated that the frequency distribution of turning on air conditioners with respect to room temperature depended on the time of day. It suggested that the event of turning on an air conditioner could be a result of the occupant's life style as well as the thermal environment condition.

Therefore, in order to study the determining factor of occupant behavior in more detail, an advanced survey was carried out from July to October 2012. This paper presents the results of analysis regarding when occupants turned air conditioners on/off or opened/closed windows as a function of the outside/room temperature as well as time of day and room occupation.

FIELD SURVEY

Survey description

The survey was carried out in four prefectures of the Kansai region (Osaka Pref., Kyoto Pref., Hyogo Pref., and Nara Pref.) over the below five periods.

I) Jul. 17 – Jul. 26, 2012
II) Aug. 7 – Aug. 16, 2012
III) Aug. 28 – Sep. 6, 2012
IV) Sep 18 – Sep. 27, 2012
V) Oct. 9 – Oct. 18, 2012

The surveyed rooms included living rooms and master bedrooms. The surveyed households were screened through a preliminary questionnaire in order to eliminate those which could have peculiar usage of air conditioning and natural ventilation; for example, a household that does not use air conditioning or natural ventilation at all during summer or a household that uses air conditioners for pets in the absence of occupants. The total number of surveyed households in the whole period was 45, where the families were either a three-person family (a couple and a child) or four-person family (a couple and two children). After the survey was completed, 11 households were selected for analysis, on the basis of screening of households whose occupancy status was not recorded in detail and who did not have any pets. The analyzed households are summarized in Table 1.

The hourly average of the outside temperature measured at the analyzed households is shown in Figure 1. The temperature during the summer of 2012 was near or slightly above average. Though the hot days continued during Periods I, II and III, the temperature declined day by day during Periods VI and V. Period V was too cool to use air conditioners.

Table 1 Summary of the analyzed households

Household ID	Survey period					Area	Dwelling type	Construction year	Family menber			
	I	II	III	IV	V							
1	○	○		○		Urban	Detached	2000	Husband	Wife	Pre-school child	
2	○	○	○	○	○	Suburban	Apartment	1975	Husband	Wife	Pre-school child	Pre-school child
3	○	○		○		Urban	Detached	2011	Husband	Wife	School child	School child
4	○	○	○	○		Urban	Detached	1970	Husband	Wife	Pre-school child	School child
5	○		○		○	Suburban	Detached	2006	Husband	Wife	School child	Pre-school child
6	○		○		○	Urban	Apartment	2009	Husband	Wife	Adult	
7	○		○		○	Urban	Detached	2011	Husband	Wife	Pre-school child	Pre-school child
8		○	○	○	○	Suburban	Detached	1991	Husband	Wife	School child	School child
9		○		○	○	Urban	Apartment	1980	Husband	Wife	School child	School child
10		○	○	○	○	Suburban	Detached	1984	Husband	Wife	School child	
11			○	○	○	Urban	Apartment	1975	Husband	Wife	School child	School child

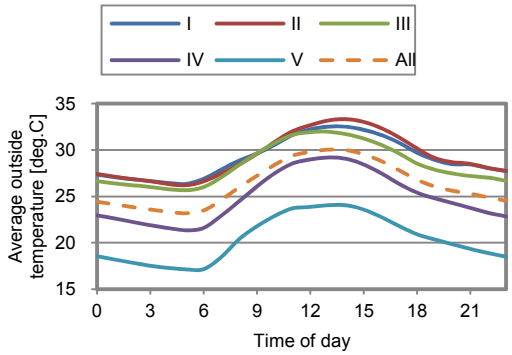


Figure 1 Hourly average of outside temperature measured in each analyzed household

Data acquisition

The open-closed state of a window was detected with a magnetic proximity sensor (Figure 2-(a)). The on/off state of an air conditioner was determined by measuring the fluctuation in air temperature at an air conditioner outlet (Figure 2-(b)). At the same time, environmental data (outside air temperature and the temperature and humidity of the surveyed room) was collected (Table 2).

Additionally, in order to investigate occupant behavior in more detail, recording papers were distributed to make notes of the usage of windows, air conditioners, and electric fans as well as the room occupation of all family members (Table 3). The recorded data relating to the state of air conditioners and windows were used to complete measurement data.

Figure 3 provides an example of the recorded data of an analyzed household.

SURVEY RESULTS

Occupant behavior pattern with regard to the usage of air conditioning and natural ventilation

The observed combination of air conditioners and window usage was divided into three patterns: running an air conditioner with closed windows

(a) Window

(b) Air conditioner

Figure 2 State detection

Table 2 Measurement instruments

Measurement Item	Sensor	Interval
On/off state of an air conditioner (Air temperature at an air conditioner outlet)	Thermocouple	1 min
Open/closed state of a window	Magnetic proximity sensor	1 min
Outside temperature	Thermistor	1 min
Room temperature	Thermistor	1 min
	or Pt 100 sensor	2 min
Room humidity	Polymer humidity sensor	1 min
	or Capacitive humidity sensor	2 min

Table 3 Survey items

Survey item		Survey method		
		Questionnaire	Recording paper	Measurement instrument
Basic information	Address	■		
	House building style	■		
	Construction year	■		
	Family structure	■		
Environmental data	Outside temperature			■
	Room temperature			■
	Room humidity			■
Thermal control behavior	Air conditioner on-off		□	■
	Cooling set point		■	
	Operation mode		■	
	Window opening-closing		□	■
	Reason to open/close windows		■	
	Electric fan Usage		■	
Room occupation	Hours in a room		■	
	Activity		■	

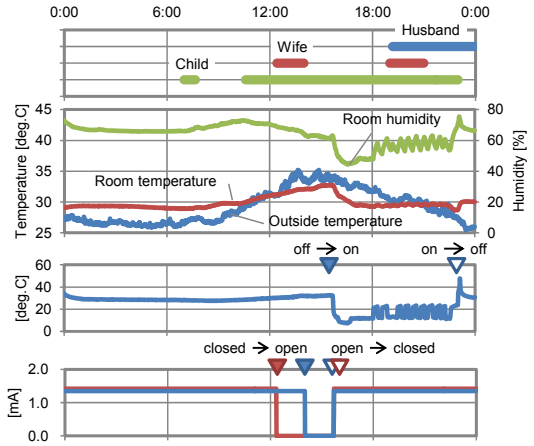


Figure 3 Example of the recorded data of an analyzed household

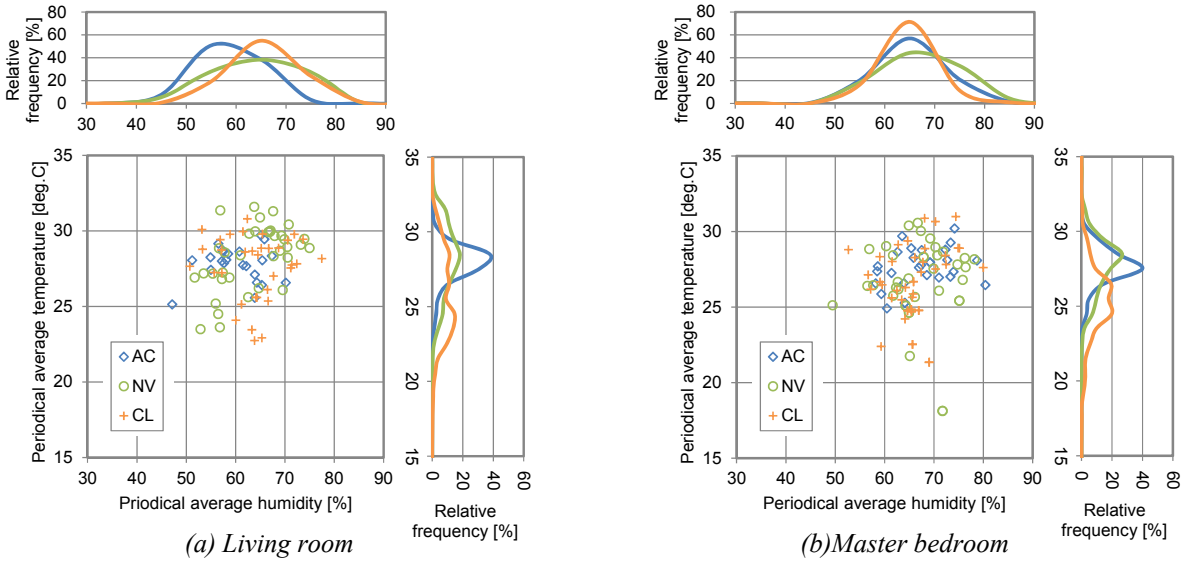
Table 4 Proportion of the number of hours to occupation hours

ID	Proportion of the number of hours to occupation hours			
	Living room		Master bedroom	
	AC	NV	AC	NV
1	0.68	0.28	0.58	0.40
2	0.43	0.41	0.58	0.13
3	0.09	0.71	0.02	0.35
4	0.12	0.60	0.38	0.35
5	0.48	0.15	0.41	0.03
6	0.05	0.88	0.00	0.62
7	0.65	0.30	0.66	0.10
8	0.44	0.12	0.36	0.19
9	0.00	0.96	0.33	0.34
10	0.27	0.23	0.19	0.35
11	0.04	0.84	0.23	0.44

(hereinafter "AC"), on air conditioning and opened windows (hereinafter "NV") and no air conditioning and closed windows (hereinafter "CL"). Here, room temperature/humidity, time of day and outside temperature observed in each state were analyzed. The used data was confined to the data that were observed when occupants' activities were anything except sleeping in living rooms and they were sleeping in master bedrooms.

Table 4 shows the proportion of the number of hours of "AC" and "NV" to occupation hours. In this survey, the features of occupant behavior have little relationships with the area and dwelling type. Air conditioners were never used in the living room of ID 1 and the master bedroom of ID 6. ID 1 and ID 7 used air conditioners in both living room and master bedroom more frequently than other households. ID 5 opened windows in both rooms infrequently.

Figure 4 and Table 5 show the air temperature and humidity of surveyed rooms after occupants resided in a particular state for more than 30 minutes. The scatter plots in Figure 4 represent the average room



(a) Living room *(b)Master bedroom*

Figure 4 Room temperature/ humidity after occupants stayed in a particular state for more than 30 minutes

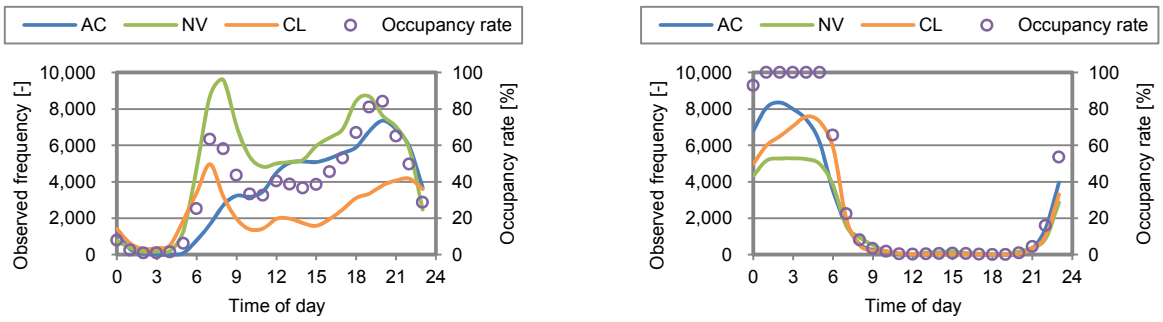
Table 5 Statistics of room temperature/ humidity

(a) Living room

	Room temperature [deg.C]			Room Humidity [%]		
	AC	NV	CL	AC	NV	CL
Ave.	27.9	28.1	25.8	58.6	64.1	65.5
SD	0.9	1.1	1.2	4.5	5.0	4.5
Min.	21.4	21.4	17.4	41.3	40.3	44.7
Max.	31.8	34.1	32.1	80.4	84.2	83.0

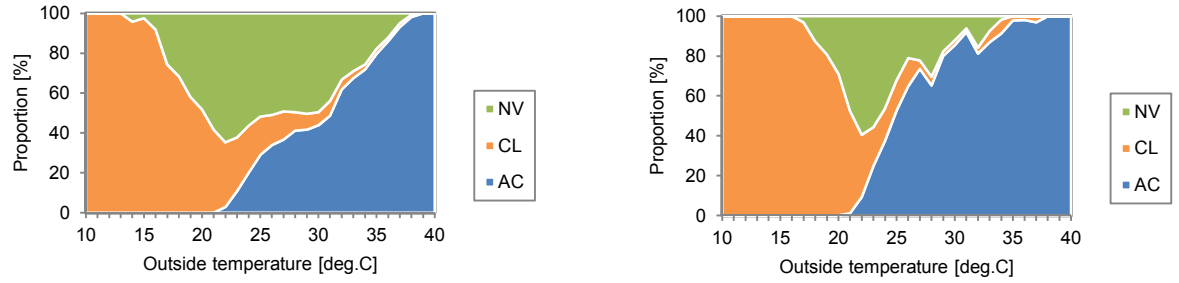
(b)Master bedroom

	Room temperature [deg.C]			Room Humidity [%]		
	AC	NV	CL	AC	NV	CL
Ave.	27.7	27.7	25.4	65.8	67.3	64.5
SD	0.5	1.1	1.0	3.2	3.9	3.1
Min.	22.5	17.5	17.0	43.2	52.4	48.7
Max.	31.5	33.8	32.0	83.5	85.8	83.8



(a) Living room *(b)Master bedroom*

Figure 5 Observed frequency of states in a given time of day



(a) Living room *(b)Master bedroom*

Figure 6 Proportion of states at a given outside temperature

temperature/humidity of a particular household in a particular survey period. The relative frequency represents the distribution of the measured room temperature/humidity. The room temperature of living rooms for the "AC" condition distributed in a higher range than that of master bedrooms, with a peak of 28 deg.C for living rooms and 27 deg.C for master bedrooms. The room humidity observed in master bedrooms was distributed in a higher range than that in living rooms.

Figure 5 shows the observed frequency of each state in a given time of day. In living rooms, "NV" increased steeply between 6 a.m. and 8 a.m. This indicates that most of the surveyed households have the habit of using natural ventilation to take fresh outside air into the room in the morning. On the other hand, "AC" increased gradually with the occupancy rate. Though the state of master bedrooms did not change significantly with the presence of occupants as compared to living rooms, "CL" state increased gradually toward the morning according to a slight decrease in the usage of air conditioning and natural ventilation as shown in Figure 5. It may be because air conditioners were turned off automatically by a timer or because occupants ceased using air conditioning or natural ventilation as room temperatures declined.

Figure 6 shows the proportion of states at a given outside temperature. The usage of natural ventilation in living rooms occurred over a wide range of outside temperature. Because this was observed at lower and higher temperature, it could include habitable usage. "AC" state in both living rooms and master bedrooms began at almost the same outside temperature, but the proportion in master bedrooms increased more steeply than in living rooms as a function of temperature. The outside temperature at which the proportion of "AC" exceeded 80 % was 36 deg.C for living rooms and 27 deg.C for master bedrooms.

Events of changing air conditioner/ window states

As Figure 5 shows, there are some relationships between occupant behavior with regard to the usage of air conditioning and natural ventilation and the occupant activities. Therefore, in order to study the result in more detail, occupant behavior at nighttime, the first entrance in the morining, daytime, and the presence of occupants in mid-summer (Periods I, II and III), late summer (Period VI) and autumn (Period V) was summaried in Table 6. The occupant behavior is different from periods and occupant activities as well as households. In mid-summer, air conditioners were mainly used in bothe living rooms and master bedrooms in the presence of occupants. Windows in master bedrooms were often left opened after occupants woke up and opened windows. In late summer, opeinng windows increased in liging rooms instead of air conditioner usage, whereas air conditioner remainded to be selectively used. In autum, some households stoped opening windows because of low outside temperature.

Figure 7 shows the percentage of room occupation action for state change behavior toward air conditioners and windows. Here, there was a time discrepancy between the room occupation and the occurrence of events because the former was manually recorded. Therefore, the events of changing

state were observed 15 minutes before and after the recorded time at which occupants entered and left the room. Moreover, the state duration was more than 30 minutes. Accordingly, there could be a difference in the frequency of events between occupants' actions on room occupation. The events of turning off air conditioner were observed in master bedrooms mostly while occupants stayed the room, because most of households use air conditioners with off timer while sleeping. Windows in master bedrooms were opened when occupants left the room, which indicates that windows would be opened habitably. On the other hand, 73% of the events of closing windows were seen in living rooms while occupants

Table 6 Occupant behavior at the time of a particular occupant activity in mid-summer, late summer and autumn

(a) Living room

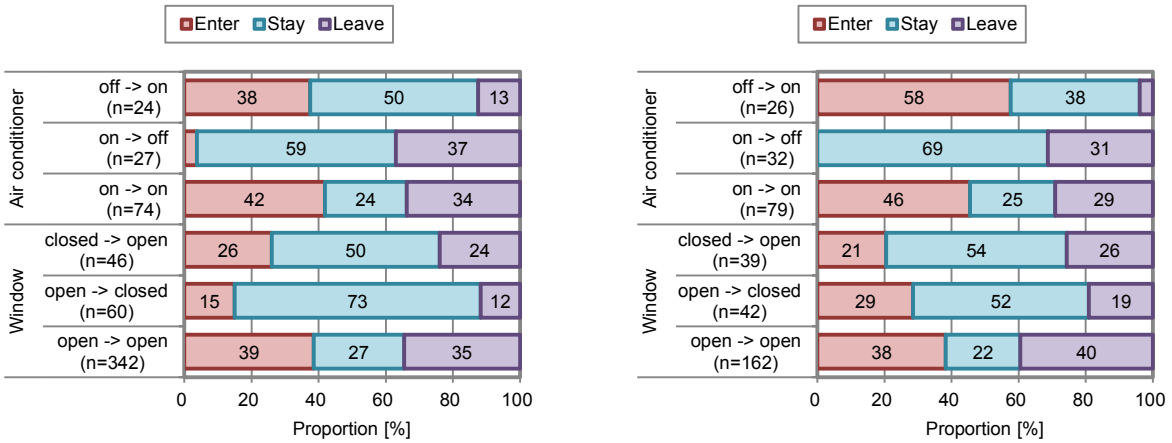
ID	Mid-summer				Late summer				Autumn			
	Unpresence in nighttime	First enterance in the morning	Unpresence in daytime	Presence (awake)	Unpresence in nighttime	First enterance in the morning	Unpresence in daytime	Presence (awake)	Unpresence in nighttime	First enterance in the morning	Unpresence in daytime	Presence (awake)
1	●	□	×	□	●	●	●	●	-	-	-	-
2	×	□	×	□	●	●	●	●	○	○	○	○
3	×	□	×	□	×	○	●	○	-	-	-	-
4	×	□	×	□	●	●	●	●	-	-	-	-
5	×	□	×	□	-	-	-	-	×	×	×	×
6	●	●	●	●	-	-	-	-	×	●	●	●
7	×	□	×	□	-	-	-	-	●	●	●	●
8	×	□	×	□	×	□	×	□	×	×	×	×
9	●	●	●	●	●	●	●	●	●	●	●	●
10	×	●	○	□	×	○	○	○	×	○	○	○
11	×	●	×	□	×	●	×	○	×	●	×	○

■: Almost always use an air conditioner, ◇: Use an air conditioner with off timer, □: Select air conditioning or natural ventilation, ●: Almost always open windows, ○: Select opening windows or not, ×: Almost always close windows, −: Unsurveyed

(b) Master bedroom

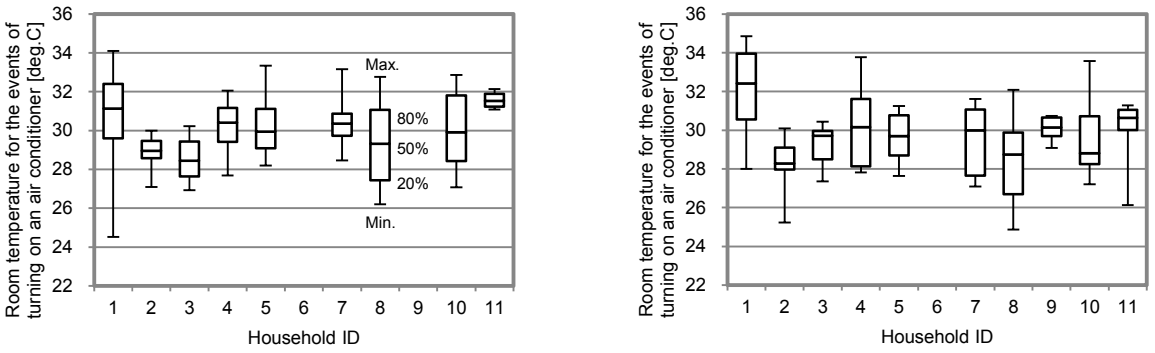
ID	Mid-summer			Late summer			Autumn		
	Presence (sleeping)	Waking up in the morning	Unpresence in daytime	Presence (sleeping)	First enterance in the morning	Unpresence in daytime	Presence (sleeping)	Waking up in the morning	Unpresence in daytime
1	■	●	●	●	○	○	-	-	-
2	■	×	×	○	●	●	×	○	○
3	■	●	●	×	○	○	-	-	-
4	◇	●	□	□	●	○	-	-	-
5	◇	×	×	-	-	-	×	×	×
6	●	●	●	-	-	-	×	○	○
7	■	●	●	□	●	●	○	●	●
8	◇	●	●	-	-	-	×	○	○
9	■	●	○	□	○	○	○	●	●
10	■	●	●	□	●	●	×	●	○
11	◇	●	●	○	●	○	○	●	○

■: Almost always use an air conditioner, ◇: Use an air conditioner with off timer, □: Select air conditioning or natural ventilation, ●: Almost always open windows, ○: Select opening windows or not, ×: Almost always close windows, −: Unsurveyed



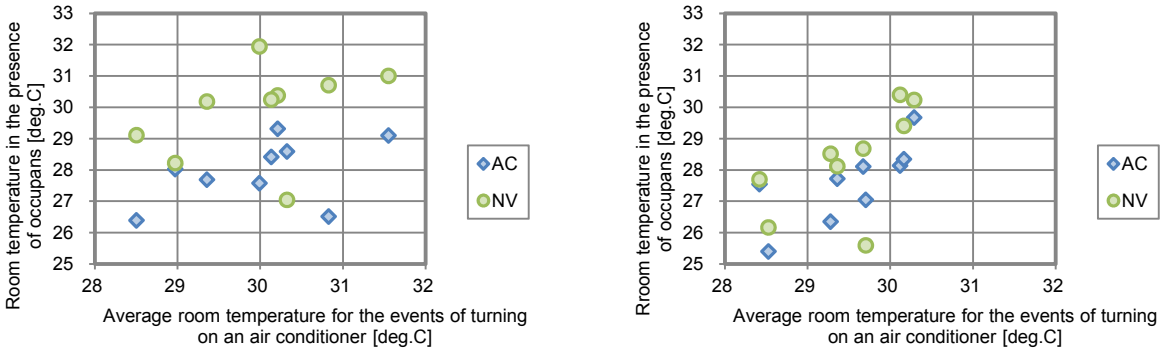
(a) Living room *(b) Master bedroom*

Figure 7 Proportion of occupant behaviour on activity accompanying changing air conditioner/window states



(a) Living room *(b) Master Bedroom*

Figure 8 Room temperature for the events of turning on an air conditioner



(a) Living room *(b) Master Bedroom*

Figure 9 Relationships between room temperature in the presence of occupants and room temperature for the events of turning on an air conditioner

stayed in the room, mostly because occupants started using an air conditioner in mid-summer and late summer.

Room temperature for the events of turning on an air conditioner

The room temperature for the events of turning on an air conditioner by households is shown in Figure 8. The behavior of turning on an air conditioner started being observed at the room temperature of about 25 deg.C and mostly occurred at the temperature between 28 deg.C and 32 deg.C. The room temperature for the events of turning on an air conditioner seems to vary widely as the proportion of the number of hours of using air conditioners is large.

Figure 9 shows the relationships between room temperature in the presence of occupants. The room temperature for the "AC" and "CV" condition is the 50th and 80th percentile of observed temperature respectively. The 80th percentile of observed temperature suggests the upper limit of the temperature for the usage of natural ventilation through windows. The room temperature for the events of turning on an air conditioner seems to have rough positive correlation with the room temperature for the "AC" and "CV" condition. The room temperature for the events of turning on an air conditioner could indicate the preference of occupants for indoor thermal environment.

CONCLUSION

The occupant behavior patterns with regard to operating of air conditioners and windows were monitored in 45 residential houses in the summer and autumn of 2012. Of these, 13 household, which used both air conditioning and natural ventilation moderately, were studied in detail. This paper provided the analysis results of relationships between occupant air conditioner and window usage behavior and outside/room temperature, as well as the time of day and the room occupation. The important results are as follows:

- The use of natural ventilation increased steeply in the living rooms between 6 a.m. and 8 a.m., which indicates that occupants would open windows habitably when entering the room in the morning.
- As compared to living rooms, the usage of air conditioners in master bedrooms grew more sharply with an increase of outside temperature. From the aspect of crime prevention, occupants would prefer air conditioning to natural ventilation.

- The events of turning off air conditioners occurred frequently when occupants left the room.
- Windows in master bedrooms were opened when occupants left the room, which indicates that windows would be opened habitably.
- The behavior of turning on an air conditioner started being observed at the room temperature of about 25 deg.C and mostly occurred at the temperature between 28 deg.C and 32 deg.C.
- The room temperature for the events of turning on an air conditioner could indicate the preference of occupants for indoor thermal environment.

The survey results revealed the differences in occupant behavior in living rooms and master bed rooms Further work will model the occupant behavior relating to air conditioner and widow usage through probit analysis.

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