

MODELING THE OCCUPANT BEHAVIOR RELATING TO WINDOW AND AIR CONDITIONER OPERATION BASED ON SURVEY RESULTS

Rakuto Yasue¹, Hiromi Habara¹, Ayako Nakamichi¹ and Yoshiyuki Shimoda¹

¹Division of Sustainable Energy and Environmental Engineering,

Graduate School of Engineering, Osaka University

2-1 Yamadaoka, Suita, Osaka, 565-0871, Japan

ABSTRACT

The occupant behavior related to window and air conditioner operation has a large influence on the cooling energy consumption. The occupant behavior model developed in a previous work has been modified on the basis of the results of a survey conducted in 2012 to simulate the variety of occupant behaviors regarding the preferred temperature set point for cooling. The reduction in cooling energy consumption achieved upon changing the temperature set point of an air conditioner could be estimated by applying the modified model. This method is expected to influence the estimation results, especially for the intermediate season.

INTRODUCTION

A reduction in the cooling energy consumption is important when discussing energy conservation in residential buildings in summer and the intermediate season. Although there are many factors determining the cooling energy consumption, the occupant behavior related to window and air conditioner operation has a special influence. Furthermore, this behavior depends on the occupants' characteristics. Therefore, it is important to properly understand both the occupant behavior and its variety when discussing the cooling energy consumption.

In 2007, we proposed an occupant behavior model related to window and air conditioner operation that could be applied to estimate the cooling energy use through simulations (Habara et al., 2007). The model was developed based on the results of a survey on the usage of air conditioners. However, the occupants' window-opening/closing behavior was not examined completely at that time. In addition, the variety of occupant behaviors was not taken into account in the previous model. This paper discusses 1) modifications of the occupant behavior model related to window and air conditioner operation based on advanced survey results, and 2) differences in the cooling energy consumption obtained from a variety of occupant behaviors by changing the parameters of the modified model.

SURVEY AND MODELING METHOD

Survey overview

A survey on the occupant behavior related to window and air conditioner operation was conducted in 45 houses of the Kansai region in Japan. The survey overview is shown in Table 1, and the survey items are presented in Table 2. The outside temperature, indoor temperature, and humidity of the surveyed houses were recorded by data loggers containing small sensors. The open-close states of the windows were detected using magnetic proximity sensors. The on-off states of the air conditioners were determined from the fluctuating air temperatures at their outlets. The outside temperatures, on-off states of the air

Table 1 Survey Overview

Area	Kansai Region, Japan
Period	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
Room	Living Room, Master Bedroom

Table 2 Survey Items

Basic Information	Address
	House Building Style
	Construction Year
	Family Structure
Environment Data	Outside Temperature
	Indoor Temperature
	Indoor Humidity
Thermal Control Behavior	Air Conditioner On-Off
	Cooling Set Point
	Operation Mode
	Window Opening-Closing
	Reason to Open/Close Window
Occupation	Electric Fan Usage
	Staying Hours In a Room Activity

conditioners and states of the windows were recorded at one-minute intervals, whereas the indoor temperatures and humidities were recorded at 1 or 2 min intervals. Additionally, to investigate the occupant behavior in more detail, recording papers were distributed on which notes could be made regarding the operation of windows, air conditioners and electric fans, as well as the occupation of all the family members.

Survey results

First, the analyzed houses were selected by screening the houses whose occupancy status was not recorded in detail as well as those whose usage of air conditioners and natural ventilation was exceedingly high compared with the other surveyed houses. The number of analyzed houses was 12 for the living rooms and 11 for the master bedrooms. Figure 1 shows the observed frequency of occupancy in the surveyed rooms at a given time of the day. The occupants stayed in the living room from 6 am to 1 am, and in the master bedroom from 9 pm to 7 am. The data obtained during the above-mentioned times of the day was analyzed to examine the relationship between air conditioner and window operation and room temperature. The plots in Figure 2 show the cumulative relative frequencies of the air conditioner off-to-on operation and the window

close-to-open operation in the surveyed room. A sigmoid function was used to analyze the data regarding the probability that the occupants will turn on the air conditioners or open the windows at a given indoor temperature. The sigmoid function is shown in Equation (1):

$$P(t) = \frac{1}{1 + a^{-t-\theta}} \quad (1)$$

where $P(t)$ is the probability, as described above, a is the slope of the curve, θ is the indoor temperature when $P(t)$ is 50%, and t is a given indoor temperature. As shown in Figure 2, the value of a for the air conditioner off-to-on operation is larger than that for the window close-to-open operation, which suggests that the air conditioner operation could be more temperature-dependent. The value of θ for the window close-to-open operation is 3.5 °C, that is, 2.4 °C below the value for the air conditioner off-to-on operation in living rooms and master bedrooms. This result indicates that the occupants operate the windows, rather than the air conditioners, at lower temperatures. Figure 3 shows the frequency of air conditioner off-to-on operation at a given indoor temperature, which is determined by the average room temperature that is reached 30 min or more after starting the air-

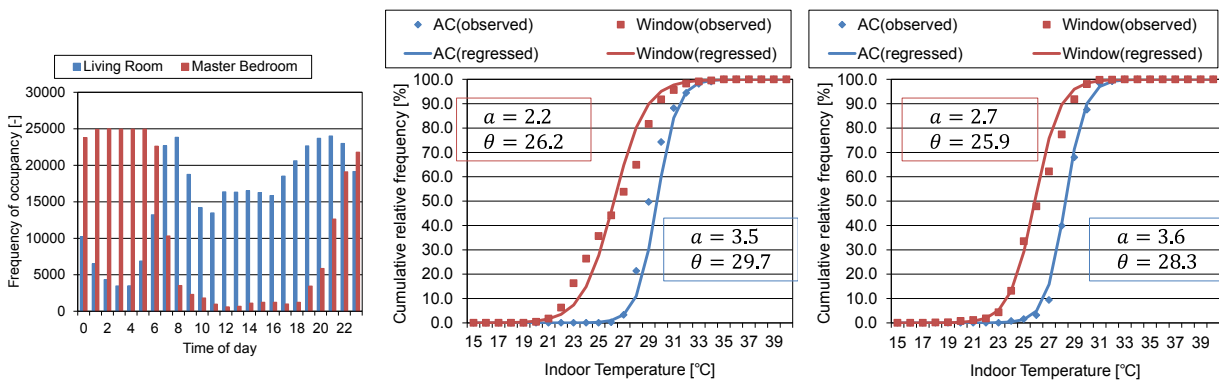
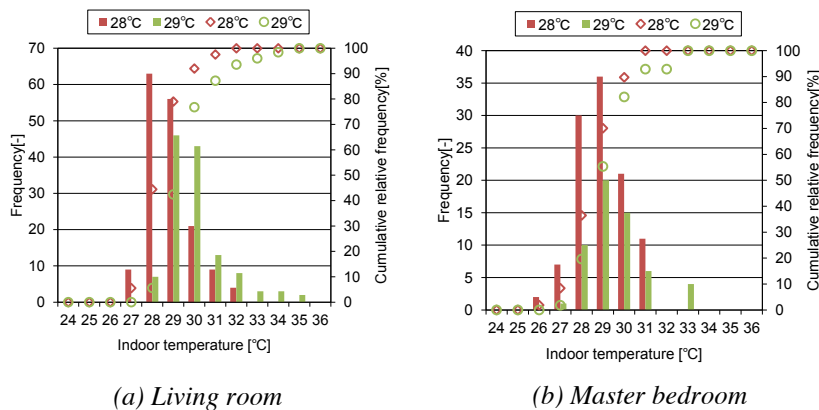


Figure 1 Hourly frequency of occupancy

(a) Living room (b) Master bedroom
Figure 2 Comparison of the frequency off air conditioner off-to-on operation with window close-to-open operation



(a) Living room (b) Master bedroom
Figure 3 Comparison of the frequency of air conditioner off-to-on operation by the average of observed temperature in air conditioning

conditioning process. At an observed room temperature (under air conditioning) of 28 °C, the most frequent air conditioner off-to-on operation occurred at 28 and 29 °C, whereas at an observed temperature of 29 °C, the most frequent air conditioner off-to-on operation took place at 29 and 30 °C. The parameters of the sigmoid function for each of the observed room temperatures (under air conditioning) are shown in Table 3. The difference in θ between the observed room temperatures of the living rooms and the master bedrooms was 1.2 and 0.8 °C, respectively. The value of a was larger at an average observed temperature of 28 °C than it was at 29 °C. These results suggest that the occupants would require a more comfortable environment as they prefer a cooler room temperature.

Modeling the occupant behavior

An occupant behavior model related to air conditioner and window operation was developed based on the assumption that the occupants will decide on the operation of air conditioners and windows according to current thermal environmental conditions. The types of thermal control behavior are: 1) using an air conditioner (hereinafter referred to as “Air conditioner”), 2) using natural ventilation through large openings (hereinafter referred to as “Ventilation”), and 3) using neither an air conditioner nor natural ventilation (hereinafter referred to as “Closed”). The flowchart of the model is shown in Figure 4. The operation is determined from the occupancy and the room temperature at every time step according to the following steps:

Step 1: If nobody stays in the room at the next time step, the air conditioners are turned off and the windows are closed.

Step 2: If the air conditioners are running and a sensible cooling load exists, the states of the air conditioners and windows are maintained.

Step 3: If the indoor temperature rises above the acceptable temperature for air conditioner off-to-on operation, the air conditioners are turned on and the windows are closed.

Step 4: If the air conditioners are not turned on in Step 3 and natural ventilation is not available, the windows are kept closed.

Step 5: If the air conditioners are not turned on in Step 3 and the windows are opened at the current time step, the windows are kept open.

Step 6: In the case in which the air conditioners are not turned on in Step 3 and the windows are closed at the current time step, if the indoor temperature is higher than the acceptable temperature for window close-to-open operation, the windows are opened. If the indoor temperature is lower than the acceptable temperature for window close-to-open operation, the windows are kept closed.

Step 7: Even if the windows are opened in Steps 5 or 6, if the wind velocity is greater than 1.0 m/s, the windows are closed.

Here, the acceptable temperature is θ , which is the parameter of sigmoidal function, as shown in Table 3.

Table 3 Parameters of the sigmoidal function

Room	Operation Mode	Parameter of sigmoidal function	
		a	θ
Living Room	28°C	4.8	28.4
	29°C	2.8	29.6
	Window	2.2	26.2
Master Bedroom	28°C	4.7	28.5
	29°C	3.7	29.3
	Window	2.7	25.9

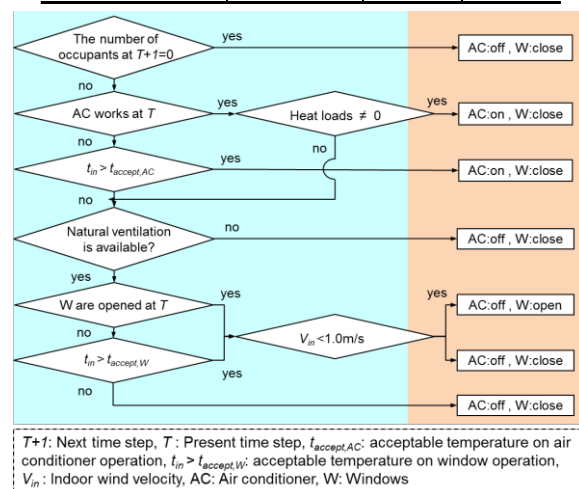


Figure 4 Flowchart of the thermal control behavior model

SIMULATION MODEL

The simulation model (Habara et al., 2007) consists of a thermal model, a radiation model, a ventilation model, an air conditioner model and a thermal control behavior model. The flowchart of the simulation model is shown in Figure 5 and the details of each component model are described below. In addition, the indoor temperature simulated by the thermal model was similar to measured value in the existing residential building.

Thermal model

The room-air temperature and the absolute humidity were calculated using a heat-balance equation assuming a perfect mixing of the air. The equation for sensible heat is as follows [Eq. (2)]:

$$C_i V_i \frac{d\theta_i}{dt} = \sum_{j=1}^M \alpha_{c,j} (\theta_{w,j} - \theta_i) A_j + \rho C_p Q_{ai} \theta_a - \rho C_p Q_{ia} \theta_i + \sum_{k=1}^n \rho C_p Q_{ki} \theta_k - \sum_{k=1}^n \rho C_p Q_{ik} \theta_i + Q_{S,i} + L_{sen,i} \quad (2)$$

where C_i is the thermal capacity of the room [J/(m³·K)], V_i is the volume of air in the room [m³], $d\theta_i/dt$ is the time derivative of the room-air

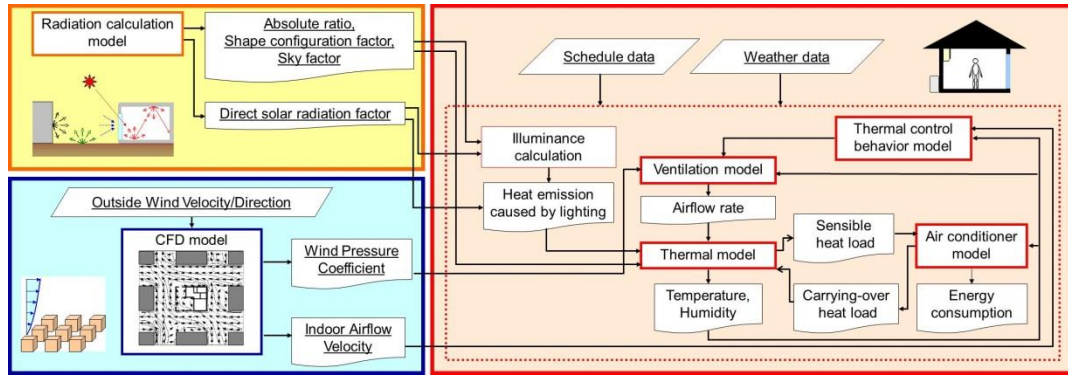


Figure 5 Flowchart of the simulation model

temperature, M is the number of wall surfaces, $\alpha_{c,j}$ is the convective heat transfer coefficient between the wall surface j [$W/(m^2 \cdot K)$] and the room air, $\theta_{w,j}$ is the surface temperature of the wall j [$^{\circ}C$], θ_i is the air temperature of a room i [$^{\circ}C$], θ_a is the outside-air temperature i [$^{\circ}C$], A_j is the area of the wall surface j [m^2], ρ is the air density [kg/m^3], C_p is the specific heat at constant pressure [$kJ/(kg \cdot K)$], Q_{ij} is the airflow from space i to space j [m^3/s], n is the number of rooms, $Q_{s,i}$ is the internal heat emission from human bodies and electric appliances [W], and $L_{sen,i}$ is the sensible cooling load [W]. The equation for latent heat is given by [Eq. (3)]:

$$G_i V_i \frac{dX_i}{dt} = \rho \gamma Q_{ai} X_a - \rho \gamma Q_{ia} X_i + \sum_{k=1}^n \rho \gamma Q_{ki} X_k - \sum_{k=1}^n \rho \gamma Q_{ik} X_i + Q_{L,i} + L_{lat,i}, \quad (3)$$

where G_i is the moisture capacity [$J/(m^3 \cdot g/kg(DA))$], dX_i/dt is the time derivative of the absolute room humidity, γ is the heat of vaporization [J/kg], X_i is the absolute humidity of the room i [$g/kg(DA)$], X_a is the absolute external humidity [$g/kg(DA)$], $Q_{L,i}$ is the internal moisture emission from human bodies and electric appliances [W], and $L_{lat,i}$ is the latent cooling load [W]. The thermal and moisture capacities of the room air were set to $12.6 \text{ kJ}/(m^3 \cdot K)$ and $25.1 \text{ kJ}/(m^3 \cdot g/kg(DA))$, respectively, including those of the furniture. The airflow Q_{ij} was calculated by the ventilation model.

Radiation model

The radiate heat transfer was calculated considering the surroundings, thereby taking shadings and other impediments into account. Direct solar radiation was assumed to diffuse perfectly, both on the building surface and on the ground. The proportion of specular-to-diffuse reflection was 1:9 on the inner surface of the window glasses and 1:1 on that of the walls. In addition, the exchange of long-wave radiation and diffusely reflected solar radiation between inner

surfaces was simulated by the Gebhart absorption coefficient method (Gebhart et al., 1959).

Ventilation model

The airflow through large openings and cracks was simulated by applying the airflow network model combined with the pressure calculation method. The characteristics of the large openings and cracks are described by Equations (4) and (5), respectively:

$$Q = 3600 \alpha A \sqrt{\frac{2}{\rho} \Delta p}, \quad (4)$$

$$Q = a \Delta p^{\frac{1}{n}}, \quad (5)$$

where Q is the airflow rate [m^3/h], α is the discharge coefficient, A is the opening area [m^2], ρ is the air density [m^3], Δp is the pressure difference [Pa], a is the air-leakage coefficient [$m/(s \cdot Pa^n)$], and n is the pressure exponent.

Air conditioner model

The energy consumption and the coefficient of performance (COP) were estimated using experimental formulas (Hosoi et al., 2010), some of which have been incorporated into the new Japanese standard, enforced in 2009. The normalized energy consumption (P_r) is represented by the energy consumption (P [W]) whereas the rated energy consumption (P_{rid} [W]) is calculated as follows [Eq. (6)]:

$$P_r = \frac{P}{P_{rid}} = f_{\theta}(qr'), \quad (6)$$

where $f_{\theta}(qr')$ is a function of the outside temperature (θ [$^{\circ}C$]) and the modified load rate (qr') [Eqs. (7)–(11)]:

$$f_{\theta}(qr') = a_3 qr'^3 + a_2 qr'^2 + a_1 qr' + a_0, \quad (7)$$

$$a_3 = 0.0148\theta + 0.0089, \quad (8)$$

$$a_2 = -0.0153\theta + 0.1429, \quad (9)$$

$$a_1 = 0.034\theta - 0.4963, \quad (10)$$

$$a_0 = -0.0012\theta + 0.288 + 0.0322, \quad (11)$$

Here, qr' is obtained by modifying the load rate (qr) to offset the differences in the measurement conditions of the exhaust airflow and the intake air humidity between the latent load (L_{lat} [W]) and the rated cooling capacity (Q_{rtd} [W]) [Eq. (12)]:

$$qr' = qr \times \frac{1}{\frac{C_{af} + C_{hm}}{2}} = \frac{L_{sen}}{Q_{rtd}} \times \frac{1}{\frac{C_{af} + C_{hm}}{2}}, \quad (12)$$

where C_{af} (=0.85) and C_{hm} (=1.15) are the correction coefficients for the exhaust airflow and the intake air humidity, respectively.

The latent load (L_{lat} [W]) is calculated using the sensible load (L_{sen} [W]) in the thermal model, and the sensible heat factor (SHF), which is estimated from Equations (13)–(16) (Hosoi et al., 2010):

$$L_{lat} = L_{sen} \times \left(\frac{1}{SHF} - 1 \right), \quad (13)$$

$$\left\{ \begin{array}{l} SHF = 1.0 \quad (R_h < 0.385), \\ SHF = 1.1774R_h^2 - 2.9042R_h + 1.9427 \\ \quad (0.385 \leq R_h \leq 0.9), \\ SHF = 0.28 \quad (0.9 < R_h), \end{array} \right. \quad (14)$$

$$\left\{ \begin{array}{l} SHF = 1.1774R_h^2 - 2.9042R_h + 1.9427 \\ \quad (0.385 \leq R_h \leq 0.9), \\ SHF = 0.28 \quad (0.9 < R_h), \end{array} \right. \quad (15)$$

where R_h is the relative humidity [%]. The cooling capacity is determined from the balance between the total cooling load ($L_{sen} + L_{lat}$ [W]) and the maximum cooling capacity of an air conditioner (Q_{max} [W]) [Eqs. (17)–(21)]:

$$Q_{all} = Q_{sen} + Q_{lat}, \quad (17)$$

$$Q_{sen} = \begin{cases} SHF \times Q_{max} & (L_{sen} + L_{lat} > Q_{max}), \\ L_{sen} & (L_{sen} + L_{lat} \leq Q_{max}), \end{cases} \quad (18)$$

$$Q_{lat} = \begin{cases} (1-SHF) \times Q_{max} & (L_{sen} + L_{lat} > Q_{max}), \\ L_{lat} & (L_{sen} + L_{lat} \leq Q_{max}), \end{cases} \quad (19)$$

If the total cooling load is greater than the maximum cooling capacity of an air conditioner, the room temperature does not reach the temperature set point of the air conditioner, and the surplus cooling load is carried over to the next time step. The maximum cooling capacity of an air conditioner is represented by Equation (22):

$$Q_{max} = qr_{max} \times q_{rtd} \times \frac{C_{af} + C_{hm}}{2} \quad (22)$$

where qr_{max} is the ratio of the maximum cooling capacity to the rated cooling capacity at a given outside temperature, which is calculated by Equation (23):

$$qr_{max} = -1 \times 10^{-5} \times r \times (\theta - 35)^3 + 2 \times 10^{-4} \times (0.5 + 0.5 \times r) \times (\theta - 35)^2 - (0.0147 + 0.014 \times (r - 1)) \times (\theta - 35) + r, \quad (23)$$

where r is the ratio between the maximum rated cooling capacity (q_{max} [W]) and the rated cooling capacity (q_{rtd} [W]), and is given in the air-conditioner catalogue [Eq. (24)]:

$$r = \frac{q_{max}}{q_{rtd}} \quad (24)$$

SIMULATION SETUP

Outside conditions

Rectangular buildings (north-south width: 7.43 m, east-west width: 8.795 m, height: 5.9 m) were spaced at intervals of 6 m. Weather data measured from July 1 to October 31 was obtained from the Automated Meteorological Data Acquisition System (AMeDAS). Figure 6 shows the daily average temperatures and humidities during the measurement period.

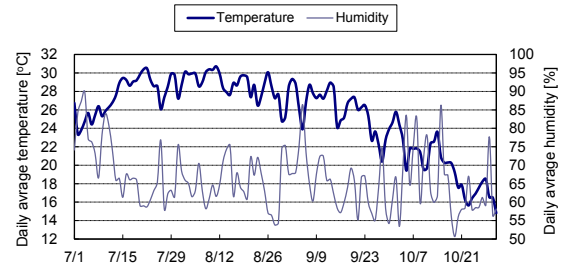


Figure 6 Daily average outside temperatures and humidities

Building and equipment

The house plan was based on the standard house model proposed by the Architectural Institute of Japan (AIJ), as shown in Figure 7. The house was a wooden construction with 0.65 m deep overhangs above each window. The thermal insulation satisfied the Japanese 1999 standards, which means that the coefficient of heat loss was about 2.7 W/(m²·K) and was calculated by Equation (25):

$$q = \frac{\sum K_l S_l + Q_{loss}}{S_o} \quad (25)$$

where q is the coefficient of heat loss [W/(m²·K)], K_l is the overall coefficient of heat-transfer of the building envelop l [W/(m²·K)], S_l is the area of the building envelop l [m²], Q_{loss} is the heat loss by ventilation [J/(K·s)] and S_o is the total floor area of the building [m²].

The sizes of the opening areas and the ventilation parameters are given in Table 4. The airtightness of the air-intake openings and the inner doors was obtained from available experimental results (Shimizu et al., 1995), whereas that of the exterior doors was set in proportion to the opening areas. The airtightness of the whole house was assumed to be 5.0 cm²/m², which satisfies the Japanese 1999 standards. Air-intake and

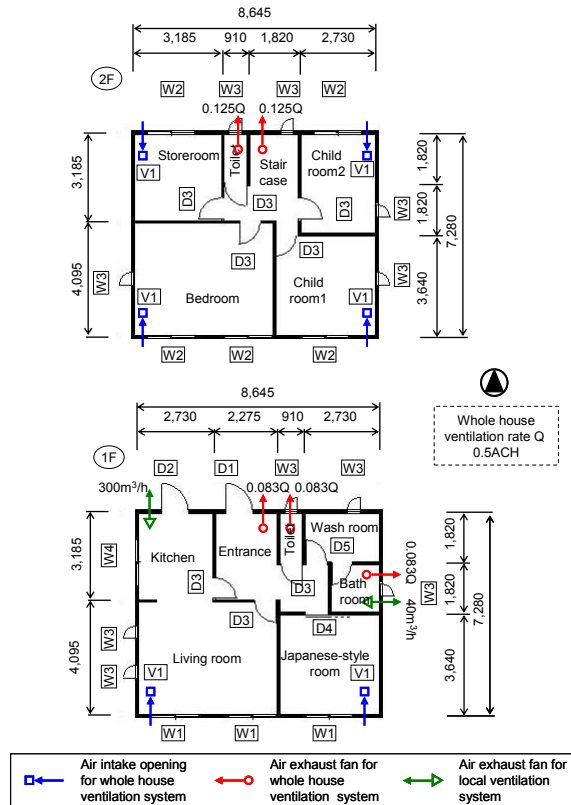


Figure 7 Ventilation system setup

Table 4 Sizes of the opening areas and ventilation parameters

Type	Size [m ²]	Air leakage coefficient [m/(s·Pa ^{0.5})]	Pressure expon [-]	Discharge coefficient [-]	
Exterior openings	W1	3.40	19.30	1.50	0.54
	W2	2.04	11.58		
	W3	0.60	3.41		
	W4	0.77	4.34		
	D1	2.00	11.35		
	D2	1.60	9.08		
Interior openings	D3	1.60	56.04	1.83	(always closed)
	D4	1.60	110.71	2.13	
	D5	1.60	36.08	1.90	
	D5	1.60	36.08	1.90	
Other	V1	4.65	2.04	2.04	-
Opening	Stair case	11.00	-	-	0.20

exhaust openings for mechanical ventilation were placed as shown in Figure 7, with the air-exhaust rate for the whole house ventilation set to 0.5 ACH (air changes per hour), according to the Japanese law. The local ventilation system worked at 300 m³/h in the kitchen while cooking and at 40 m³/h in the bathroom for 1 h after bathing. The wind pressure coefficient, which is required to calculate the natural ventilation rate, was simulated by a computational fluid dynamics model.

The specifications for lighting and air conditioning were set according to the area of the rooms, as shown in Tables 5 and 6, in agreement with the guidelines.

Lifestyle

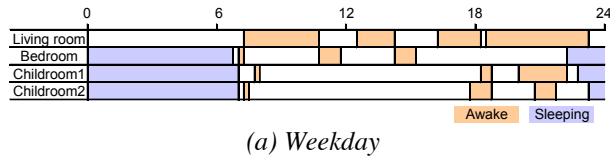
The family considered in this paper consisted of four members, namely, a couple (a male office worker and a housewife) and two children (a female high-school student and a male junior-high-school student). The

Table 5 Specifications for air conditioners and lighting

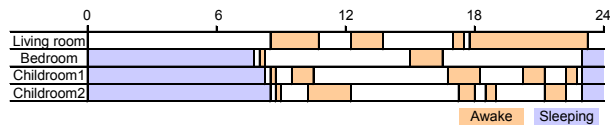
Room name	Area [m ²]	Volume [m ³]	Spec of air conditioner	Lamp wattage [W]
Kitchen	7.97	19.13	-	64
Living room	19.37	46.5	c	155
Japanese-style room	12.36	29.65	-	108
Bathroom	2.92	7	-	45
Wash room	4.42	10.6	-	45
Toilet	1.37	3.3	-	45
Entrance	6.66	15.97	-	45
Corridor	2.96	7.1	-	45
Storeroom	9.42	22.62	-	80
Bedroom	19.37	46.5	c	155
Child room 1	12.36	29.65	b	108
Child room 2	9.16	21.98	a	80
Toilet	1.34	3.21	-	45
Corridor	3.55	8.5	-	45
Stair case	3.09	7.41	-	45

Table 6 Details of the air conditioner specification

Spec of air conditioner	Rated cooling capacity [kW]	Maximum cooling capacity [kW]	COP [-]
a	2.2	3.4	4.9
b	2.5	3.5	5.0
c	3.6	4.0	3.3

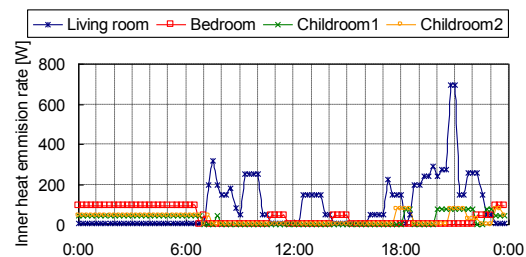


(a) Weekday

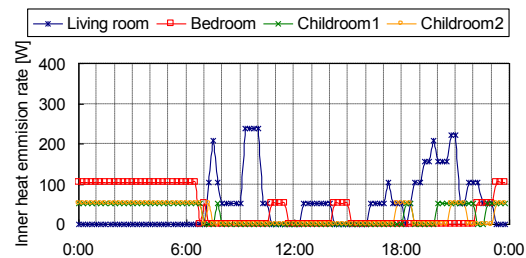


(b) Holiday

Figure 8 Occupation schedule



(a) Sensible heat-emission rate



(b) Latent heat-emission rate

Figure 9 Inner heat-emission pattern for a weekday

occupation schedule and the use of domestic appliances (excluding air conditioners and lighting equipment) were determined from survey results (Broadcasting Culture Research Institute, 2001). Figure 8 shows the occupation schedule for a weekday

and a holiday, and **Figure 9** describes the heat-emission pattern for a typical weekday.

The lighting system was turned on when the room illuminance was below 75lx without lighting. The lace curtain (rate of airflow decline: 0.35) was always closed whereas the shade curtain (rate of airflow decline: 0.58) was only closed during sleeping hours.

The use of air conditioners and natural ventilation in each room was determined by the thermal control behavior model. During the cooling hours, all the openings were closed, whereas during the natural ventilation hours, the windows and exterior doors facing the target rooms were opened while all the inner doors remained closed.

Four cases were set up to determine the influence of the modeling method of occupant behavior related to window and air conditioner operation on the cooling energy consumption: In Cases 1 and 2, the occupants only used air conditioners for cooling. The temperature set points of the air conditioners were 28 and 29 °C for Cases 1 and 2, respectively, and the instruments were turned on if the calculated room temperatures were above those set points. In Cases 3 and 4, the occupants selected between air conditioning and natural ventilation for cooling, according to the room temperature. The room-temperature ranges for the air conditioner off-to-on and the window-opening behaviors were determined from the survey results, as shown in **Table 3**. The parameters for each case are summarized in **Table 7**. The cooling energy consumption was simulated every 15 min.

RESULTS AND DISCUSSION

Table 8 shows the results of a periodic evaluation of the air conditioners. The cooling electric power consumption decreased by 29.2% in Case 3 compared to Case 1 because the occupants selected “Ventilation” instead of “Air conditioner” at outside temperatures

Table 7 Setup for each of the four cases studied

Case	Temperature of turning on air conditioner		Temperature of opening window		Temperature set point of air conditioners
	Living Room	Master Bedroom	Living Room	Master Bedroom	
Case 1	28.0°C	28.0°C	-	-	28°C
Case 2	29.0°C	29.0°C	-	-	29°C
Case 3	28.4°C	28.5°C	24.4°C	24.5°C	28°C
Case 4	29.6°C	29.3°C	24.4°C	24.5°C	29°C

between 17 and 29 °C, as shown in **Figure 10**. By changing the temperature set point of the air conditioners, the electric power consumption could be reduced by 15.1% when comparing Cases 1 and 2, and even by 23.4% when comparing Cases 3 and 4. **Figure 11** shows the monthly electric power consumption of an air conditioner in the living room. The differences in the reduction rates between Cases 1 and 2 and Cases 3 and 4 were small in August but large in July and September. As described in **Figure 12**, the reduction was almost the same between Cases 1 and 2 and Cases 3 and 4 at temperatures above 29 °C (which are mostly experienced in August) whereas differences could be observed at temperatures between 24 and 29 °C (usually experienced in July and September).

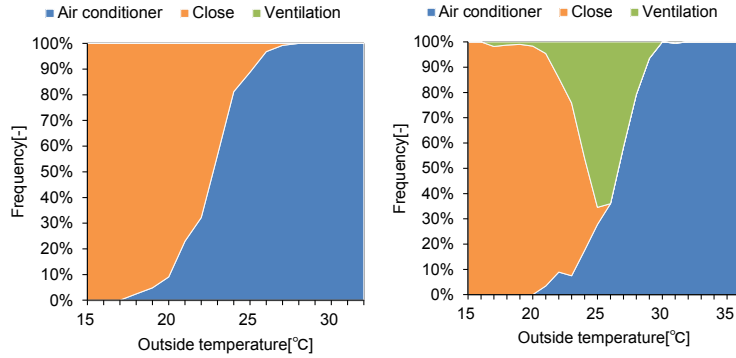
These results suggest that the occupant behavior modeling method may greatly influence the estimation of the reduction rate of cooling energy consumption by changing the temperature set point of an air conditioner. Especially during the intermediate season, for example, in July and September, the occupant behavior model related to air conditioner and window operation could play an important role in simulating the energy use in a residential house.

CONCLUSION

The occupant behavior model related to window and air conditioner operation was modified, based on survey results, to simulate the variety of occupant

Table 8 Periodic evaluation of air conditioners

Room name	Calculation case	Periodic total cooling capacity of air conditioner	Periodic electric power consumption	Periodic ventilating hours	Periodic cooling hours
		[MJ]	[MJ]	[h]	[h]
Living room	Case 1	5133	1919	0.00	1111.50
	Case 2	4293	1725	0.00	1041.50
	Case 3	4159	1463	269.75	787.50
	Case 4	3051	1124	428.75	619.50
Bedroom	Case 1	974	944	0.00	787.00
	Case 2	672	752	0.00	652.50
	Case 3	804	669	417.25	501.00
	Case 4	537	541	498.25	427.50
Total	Case 1	7570	3805	0.00	3825.25
	Case 2	6004	3232	0.00	3400.00
	Case 3	6067	2693	1788.50	2240.00
	Case 4	4234	2062	2303.50	1753.25
Difference (Total)	Case1 VS Case3	-19.9%	-29.2%	-	-41.4%
	Case1 VS Case2	-20.7%	-15.1%	-	-11.1%
	Case3 VS Case4	-30.2%	-23.4%	28.8%	-21.7%



(a) Case1

(b) Case3

Figure 10 Frequency of thermal control behavior in the living room at a given outside temperature

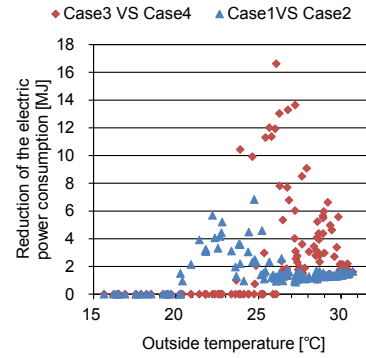


Figure 12 Daily reduction of the electric power consumption by changing the temperature set point of an air conditioner in the living room

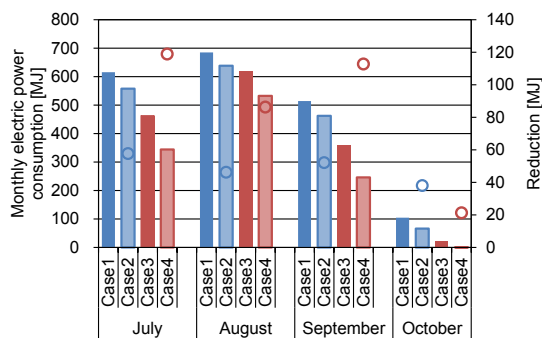


Figure 11 Monthly electric power consumption and its reduction in the living room

behaviors regarding the preferred temperature set point for cooling. The reduction in cooling energy consumption achieved by changing the temperature set point of an air conditioner could be estimated by applying the modified behavior model. The most remarkable results of this study are:

- The lower room-temperature limit for the use of natural ventilation was 24.5°C in living rooms and master bedrooms.
- The room temperature at which the occupants started using their air conditioners differed from the observed room temperature under air conditioning. It was 27.5 and 27.6°C in the living rooms and master bedrooms, respectively, when the observed room temperature was 28 °C, and 28.3 and 28.2 °C in the living rooms and master bedrooms, respectively, when the observed room temperature was 29 °C.
- The simulation results suggest that this modeling method of occupant behavior could have a great influence on estimating the reduction rate of cooling energy consumption by changing the temperature set point of an air conditioner.

This study reveals that the occupants' preference for a particular room temperature for cooling could be one of the factors determining the variety of occupant behaviors as well as the energy consumption. The next step is to analyze other possible factors that may affect

the occupant behavior related to air conditioner and window operation.

REFERENCES

- Gebhart B. et al. 1959, A New Method for Calculating Radiant Exchanges, ASHRAE Trans, No.59, pp.321-332
- Broadcasting Culture Research Institute, 2001, Japan Broadcasting Corporation. NHK data book 2000 national time use survey, National Prefectural. Tokyo: Japan Broadcast Publishing [in Japanese]
- Habara H. et al. 2005, An Occupant Indoor Thermal Environment Control behavior Model to Estimate Residential Cooling Energy Consumption, Proceedings of The 10th International Conference on Indoor Air Quality and Climate, pp.1179-1183
- Habara H. et al. 2007, Influence of Temperature, Radiation and Airflow Varied by Buildings on Cross Ventilation and Cooling Energy Consumption in a Residential House, Journal of Environmental Engineering, AIJ, No.613, pp.103-110 [In Japanese]
- Habara H. et al. 2009, Verification of the Effect of Cross Ventilation on Energy Conservation by Simulating Occupant Behavior, The International Journal of Ventilation, Vol.8, No.3 pp.263-274
- Hosoi A. et al. 2010, Calculation method of COP of residential air conditioner based on measurement: heating/cooling COP and energy consumption of residential air conditioner (part 2), Journal of Environmental Engineering, AIJ, No.654, pp.741-747 [In Japanese]
- Shimizu N. et al. 1995, Pressure drop for air of each parts for building, Proceedings of The Annual Meeting of SHASE, pp.609-612 [In Japanese]