for family composition, time allocation of people, ownership and specification of home appliances. This paper first presents the simulation procedure of the model. Then, the model is validated by comparing simulation result with electricity demand collected from 227 households. We finally discuss the weaknesses in the input data and modelling approach of the model.

ENERGY DEMAND MODEL OF RESIDENTIAL BUILDINGS

Data preparation for simulation

Figure 1 shows the procedure of the simulation model. The first step of simulation is to define specification of house and family members of simulated households. The model contains databases on house specification and family composition. The family composition is defined by a combination of family members with attributes distinguished by age, gender and occupation as listed in Table 1. There are 6 and 9 house specifications for detached and apartment houses classified by the size of house. For each house specification, a house archetype is prepared. The archetypes have specific conditions on size, shape, floor plan, and other physical conditions of house like insulation performance, which is necessary to conduct a thermal simulation to estimate energy consumption for space heating and cooling.

Second, the ownership and specification of home appliances are given to simulated house. For this process, we use frequency distributions on these data. The frequency distributions were developed based on a questionnaire survey that collected information from approximately 800 households living in Osaka, Japan. By giving a random number to a frequency distribution, a condition for each appliance is randomly determined. For example, by giving a random number, a number of TV used in a house is selected. Then, the size of TV is selected by giving a random number to the corresponding frequency distribution. Finally, specification of electricity consumption of selected TV is determined using a frequency distribution on electricity consumption of TV stock with a variety of TV size.

After selecting appliances used in a house, a room is selected in which each appliance is placed. If two TV is owned in a simulated household, one TV is placed in the living room and the other TV is placed in a private room of a children.

Table 1. *Family composition and house archetype*

Family composi-tion	Single	Working male, Working female, elderly male, elderly female
	Couple	Working couple, Working male & housewife, Working mother & childe
	3 people	Working couple & a child; Working male housewife & a child; Working female & 2 children;
	4 people	Working parents & 2 children; Working male, housewife & 2 children
	5 people	Working parents & 3 children; Working male, housewife & 3 children
	6 people	Working parents, grandparents & 2 children; Working male, housewife, grandparents, & 2 children
House archetype	Detached	40 m², 50 m²,70 m², 90 m², 113 m², 146 m²
	Apartment	20 m², 30 m², 52 m², 55 m², 70 m², 73 m², 80 m², 91 m²,119 m²

characteristics if the occupants' attribute is same. Additionally, the parameters determining the ownership and the operation of home appliances were randomly given. However, these parameters could have a relationship that makes households with high and low energy demand.

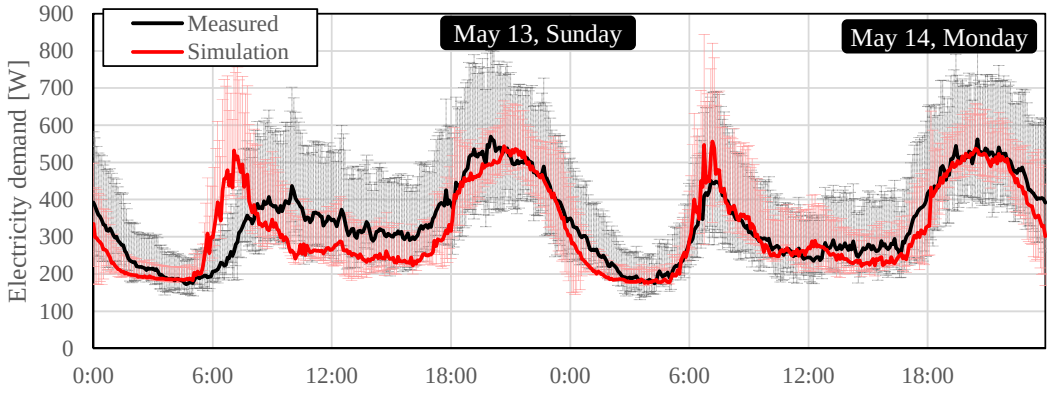


Figure 2. *Mean total electricity demand per household*

Composition of electricity demand

Figure 3 shows the mean consumption of appliances with dedicated circuit for measured consumption. As shown in the figures, the consumption of refrigerator and consumption on weekdays except microwave agreed well. The simulation result on holidays are smaller than measured. For microwave, the operation is more frequently occurred in the reality. Figure 4 shows sum of electricity consumption of appliances placed in kitchen. The black line shows the measured consumption in kitchen including plug load and lighting load. As lighting load is included in the measured consumption, we cannot directly compare the simulation result and measured consumption. However, the peak in the morning observed in the simulation result is too large compared to the measured consumption.

Finally, Figure 5 shows the sum of electricity consumption of the other appliances. The figure on the top shows the simulation result with composition by appliances. The figure on the bottom shows the measured consumption classified by rooms. As mentioned earlier, electricity demand from 6h00 to 9h00 in the simulation result is larger than the measured. The figure shows that the consumption of lighting, and hair dryer, at least, too large. This can be attributed to the setting of operation of appliances. More importantly, lighting consumption in the simulation result increased around 18h00. This is because the model calculated indoor illuminance to determine the necessity of turning on room light by using common parameters among households. This parameter must be given to reflect the realistic distribution of the parameters to replicate realistic energy demand.

Additionally, decrease in electricity consumption after night peak around 20h00 is earlier in the simulated consumption than the measured consumption. This can be mainly attributed to the discrepancy in the time use data used in the model of

time allocation of household members.

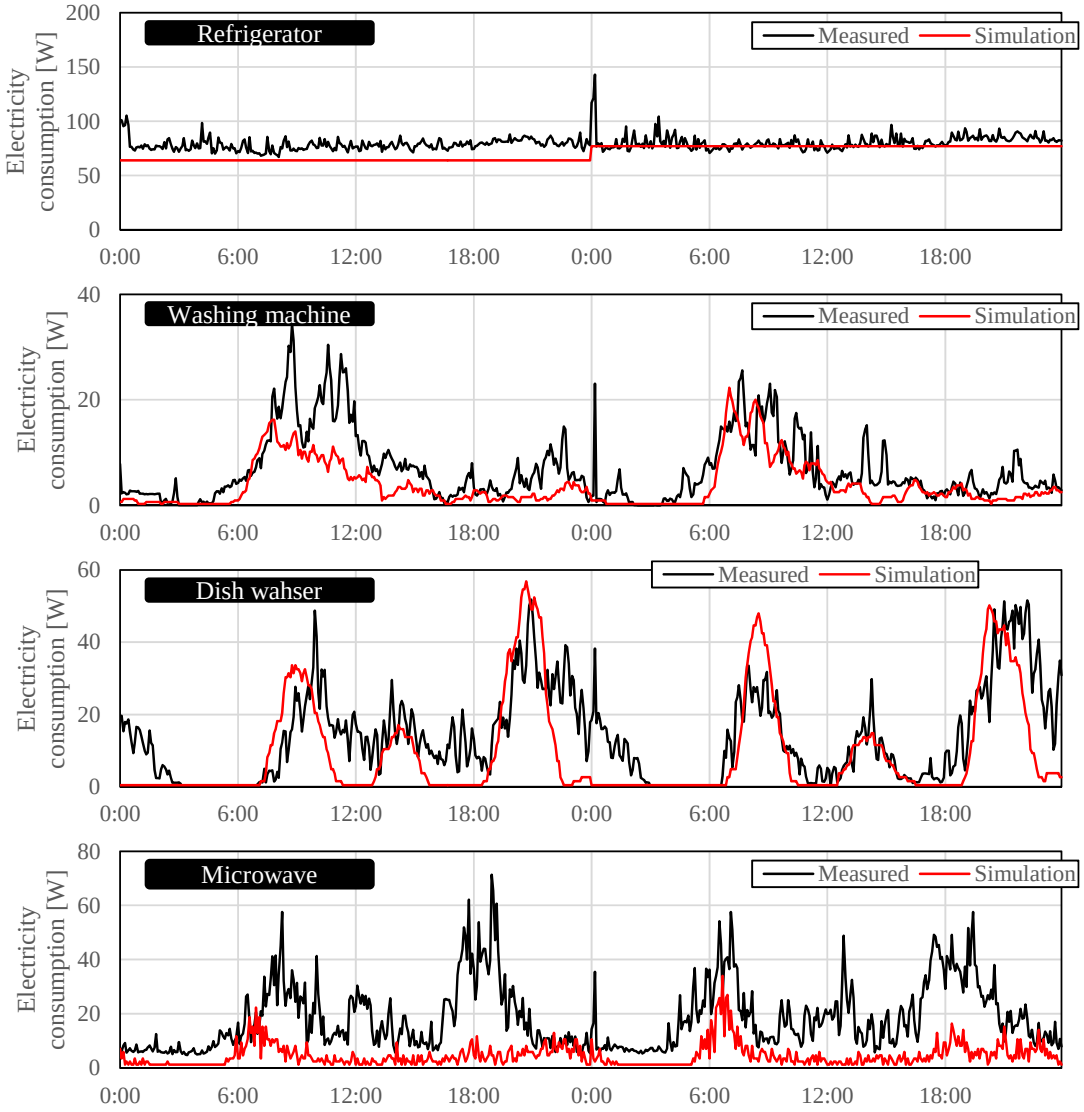
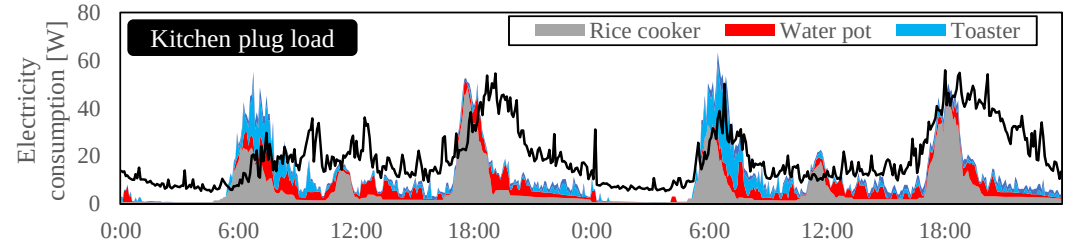


Figure 3. *Mean consumption of appliances with dedicated circuit*



The black line shows the sum of lighting and plug load in the kitchen

Figure 4. *Mean consumption of appliances used in kitchen*

CONCLUSION AND IMPLICATIONS

This paper presented an energy demand model of residential buildings. This model quantifies electricity and city gas demand of a house in the 5-min resolution as the sum of consumptions of all home appliances driven by stochastically simulated behavior of household members in the simulated house. This model was validated by comparing simulation result of electricity demand with those measured from 227 households. The

validation revealed the model has the following weaknesses; 1) The time use data, used for generating the daily behavior of household members, for holidays and for night is not appropriate, as morning peak in electricity demand on holidays occurred too early and decrease in electricity consumption after night peak around 20h00 to early morning is too fast; 2) Appliances for cooking and household maintenance as well as lighting are operated too frequently from 6h00 to 9h00 due to the conversion model from occupants daily behavior to appliances' operation; 3) Method to give parameters for households must be established to reflect realistic distribution in electricity demand among households.

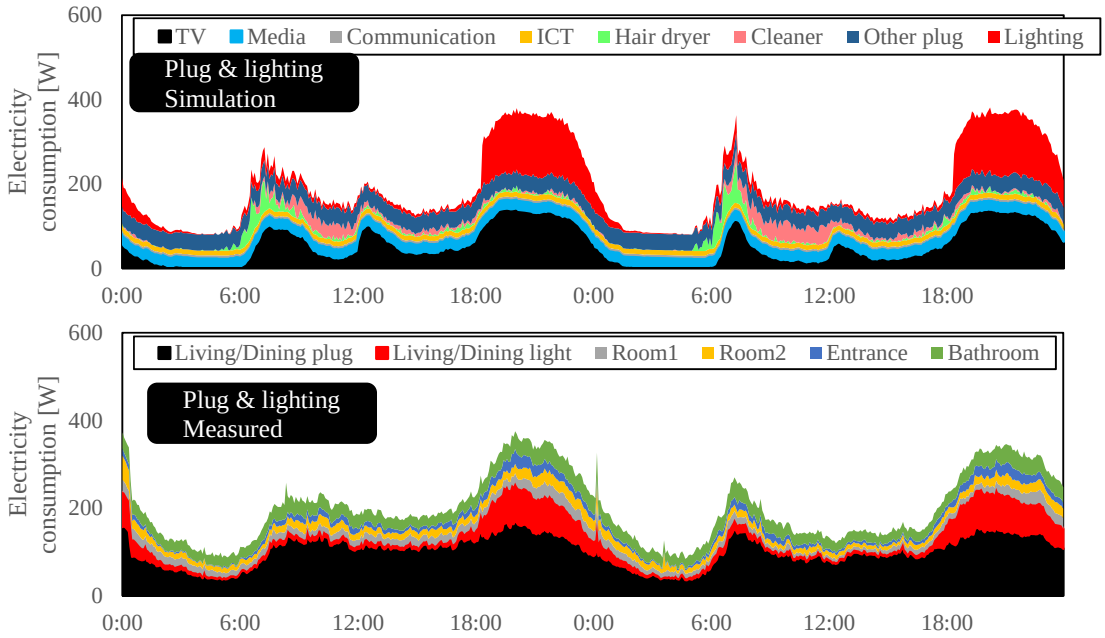


Figure 5. *Mean electricity consumption for the remaining lighting and appliances*

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