Evaluation of Energy Performance of Smart Community Considering Occupant's Behaviour

Yuki Kitagawa¹, Monica I. C. Gondokusuma¹,
Yoshiyuki Shimoda¹

¹Division of Sustainable Energy and Environmental Engineering,
Graduate School of Engineering, Osaka University, Japan

Abstract

In Japan, the recent development of “smart communities”—low-carbon residential areas consisting of hundreds of detached homes—has received a great deal of attention. However, the energy performance of such communities has yet to be measured effectively. In this study, the energy demand and photovoltaics (PV) generation of a simulated smart community are estimated using a bottom-up model. Energy performance is shown quantitatively using various evaluation indicators. Results suggest that, under Osaka-like climate conditions, it is possible to build a zero-energy community by installing a 5.0 kW PV unit in each house and orienting the houses to the south. The model also shows a 16% increase in energy demand 30 years after initial construction due to the aging of residents and corresponding changes in household size and resident characteristics.

Introduction

In recent years, increasing attention has been given to the development of Japan's so-called “smart communities.” These are low-carbon residential areas in which new energy saving/creation technologies and other environmental measures are applied at the community level. Such communities may well provide a model for low-carbon cities in the near future. To this end, the Japanese government has established the goal of developing Zero-Energy Houses (ZEH)—houses in which net annual energy consumption is reduced to 0 or below through energy savings and the use of efficient means of energy generation (Ministry of Economy, Trade and Industry, 2015). In pursuit of this goal, the houses in Japan's smart communities utilize some combination of PV, fuel cells, batteries, energy efficient appliances, enhanced insulation, Information and Communication Technology (ICT), energy management systems, and so on. As self-sufficiency in electric power generation is of particular importance in Japan given the many natural disasters that occur there, some smart community developers have been granted subsidies in order to form a micro grid (MG) that offers independence from regional electric power systems.

Complicating an effective evaluation of these developments is the fact that the adopted technologies and the extent of the efforts made in the various communities vary rather widely. This makes it difficult to judge their impact and project their future direction. To promote the

development of smart communities, it is crucial that we be able to quantitatively evaluate the relationship between technology patterns and energy performance (to determine, for example, the amount of PV and energy savings that are needed to achieve Zero-Energy Communities (ZEC)) and measure the degree of energy-related resilience that is provided against potential disasters. Moreover, in communities where a massive utilization of PV is expected, there are concerns regarding the instability of the electric power supply and demand. Thus, it is important to understand the influence of technology and the various measures taken on energy performance across an entire community. In this research, a household energy demand estimation model is used to evaluate energy performance in a virtual Japanese smart community consisting of hundreds of detached houses.

To effectively evaluate the community's energy performance, our simulation has the following characteristics:

1. It uses a bottom-up model

The model can simulate energy demand on community scale by summing up the households' simulation result which consider occupants' attributions and building specifications. Evaluating the influence of various parameters such as family composition, housing specification, weather conditions, etc., on energy demand gives us the ability to understand the extent to which these elements influence energy performance.

2. It has the ability to replicate load curves

In order to evaluate the supply-demand balance for electricity, it is necessary to reproduce the PV generation and load curves of each house over a detailed time interval.

3. It has the ability to replicate a variety of load curves for the various community households

The load curve of the community is produced by integrating the load curves of the diverse households that make up the community. Thus, it is important to understand the variations among households in order to realistically reproduce actual conditions, showing such features as the sharing of electric power between houses.

4. It has the ability to use various evaluation indexes

Various evaluation indicators are needed to evaluate the energy performance of the community from a variety of aspects such as environmental friendliness, the stability of electricity supply and demand and resilience.

There already exist models that reproduce household load curves at high temporal resolution based on the behavior patterns of its residents (Flett et al, 2017; Richardson et al, 2010; Widén et al, 2010). Models have also been created to evaluate PV surplus power (Baetens et al, 2010). However, there are no studies that evaluate the energy performance of a community using multiple indicators.

The aim of this paper is to evaluate the energy performance of a smart community by simulating the energy supply and demand of the community at five-minute intervals and quantifying performance using various indicators. The target community is a new detached residential area consisting of 303 all-electric houses.

Energy Performance Evaluation Method

We examined existing smart communities in Japan and set key indicators which show energy performance of smart community. The contents of the evaluation conducted in this paper are as follows. : (1) Evaluation of low energy community design alternatives, (2) Evaluation of energy management strategies such as battery storage and Demand Response (DR), and (3) Evaluation of an aging community. Three models—a Residential Energy End-Use Model, a Battery Model, and an MG model—are used to simulate and evaluate performance.

Residential Energy End-Use Model

To create an accurate evaluation of the energy performance of a smart community, it is necessary to consider the diversity of energy demand in each of the community's constituent households. To accomplish this, we use the Residential Energy End-Use Model (Taniguchi et al, 2016). Figure 1 shows the flow chart for this simulation model. First, the occupant behavior model creates a behavior schedule for every occupant of each household. The schedule is probabilistically generated according to the attributes of the resident such as gender, age, presence of occupation, presence of children, and so on. The appliance energy-use model then determines the operation of appliances as related to the behavior of each of the occupants. Finally, based on the specifications of each appliance, the model estimates the energy consumption of each individual house. Heating and

cooling energy consumption is estimated based on the building insulation level and weather conditions. The model's special characteristic is its ability to replicate energy use for five-minute intervals and to estimate the corresponding electricity load curve. The energy consumption of the community as a whole is estimated by aggregating the simulation results for each household. The model also considers weather information for a specific area, allowing the heating/cooling energy use simulation to take into account changes in such factors as outdoor air temperature and humidity. The amount of PV generation is calculated using the same weather data; thus, the power flow between the electric grid and the community can be replicated. Examples of the estimated results on a representative day using the simulation model are shown below:

Example 1: Figure 2 shows a one-day load curve for a representative household with a 4.0 kW PV capacity. In this case, the wife is at home during the day, creating daytime electricity demand for home appliances and air conditioners. The electricity demand for air conditioning increases in the evening when other family members return home. Since, in Japan, heat pump (HP) water heaters mainly operate in the early morning, when the price of electricity is relatively cheap, demand for electricity from 5:00 a.m. to 7:00 a.m., as indicated here, is significant. Figure 2 shows two kinds of curves—an energy demand curve and a PV generation curve. When PV generation exceeds energy demand in a particular five-minute time step, surplus power flows to the electric power system.

Figure 2: Simulated Load Curve for a Household.
*4 people (Single Income Couple and 2 elementary school students)

Figure 1: The system of Residential Energy End-Use Model.

Example 2: Figure 3 shows the results when adapting the model to the community scale. Not surprisingly, the aggregated load curve at the community level is smoother than the load curve of the individual households since the community load curve is formed by integrating the various individual curves.

Figure 3: Simulated Load Curve for Community.

The approach thus allows us to estimate the energy demand and supply situation for a large residential area.

Battery Model

To promote self-sufficiency in renewable energy, storage batteries are among the essentials; when the Feed-in Tariff (FIT) is low, a battery enables residents to use their PV-generated power economically. Batteries also have a leveling effect on the load curve, absorbing surplus PV power. The Battery Model used in the simulation here simulates the charge and discharge of batteries installed in each house.

Figure 4 shows the flow chart of the Battery Model. First, for each time step, the data estimated by the Residential Energy End-Use Model determine the operational status of the battery. (The four possible states are shown in the figure.) The energy flow is then calculated using the main equations described in tables 1 and 2. PV-generated power is prioritized for domestic consumption. When surplus PV power is available, it is stored in the in-home battery. Whenever the supply of electricity being currently generated is insufficient to meet domestic demand, the gap is closed by discharging electricity from the battery and by purchasing electricity from the grid.

Figure 4: Main Calculation Flow of Battery Model.

Table 1: Calculation Formula List of Battery Model.

	Charge	Selling Only	Discharge	Purchase Only
pur_t	0	0	$e_t - pv_t - Dis * Loss$	$e_t - pv_t$
sur_t	$pv_t - e_t - Char$	$pv_t - e_t$	0	0
$self_t$	e_t	e_t	$pv_t + Dis * Loss$	pv_t
$dis/char_t$	$+ Char * Loss$	0	$- Dis$	0

Table 2: Summary of Notations.

Notation	Description	Unit
t	time step	
pv_t	PV generation	
e_t	electricity demand	
pur_t	purchased electricity	
sur_t	PV power flow to the grid	
$self_t$	self-electricity consumption	
$dis/char_t$	change amount of battery (+: charge power to the battery /-: discharge power from the battery)	
$Char$	max charge power	
Dis	max discharge power	
$Loss$	loss rate of battery	%

An example of results for a representative household using the Battery Model is shown in Figure 5. The figure shows the operational status of the battery—*Max cap*, 5.6 kWh; *Char*, 0.9 kW; *Dis*, 0.5 kW; *Loss*, 95 %; *Charging Start Time*, 10:00 a.m. At midnight, since some energy is still stored in the battery, energy is discharged to meet demand. After 2:30 a.m., since the power demand of the HP water heater is relatively high, a part of its energy consumption is covered by the battery using its maximum discharge of 0.5 kW; the remainder is covered by purchasing electricity. After 5:00 a.m., PV generation increases. At 10:00 a.m., surplus PV power begins to charge the battery. The battery is fully charged at approximately 3:00 p.m., at which time the charging ends. After 6:00 p.m., PV generation decreases and power consumption exceeds PV generation; as a result, discharging begins.

Figure 5: Simulated Operational Status of Battery.

Micro Grid Model

In a smart community, since all the buildings and distribution networks are developed at the same time, it is possible to form a micro grid (MG) that allows electric power to be interchanged via private lines laid between the houses. By managing electricity within the

community, the MG allows the community to be independent of the electric power system. Importantly, in the case of a general power outage, power generation from PV within the community can be supplied to all the houses. In Japan, due to the Great Eastern Japan Earthquake in 2011, there has been a renewed focus on electricity blackouts and Life Continuity Plans (LCPs) that would serve to maintain a normal life in an emergency situation. In this context, it is important that we understand the role and influence of MG on energy performance.

In the MG model used here, the MG representing the community power interchange system is simplified. Specifically, power consumption, PV generation, and total battery storage for the community are treated as a large-scale building with PV and battery. The operating condition of the battery is thus estimated using the same calculation method as the Battery Model. Hence, the actual flow of electric power between buildings through private lines is not accurately reproduced, and, consequently, the power loss on the private lines is not taken into account.

Simulation Results

Using the models described above, the energy performance of smart communities of various types can be evaluated. In this study, the community scale and weather conditions are similar to the smart community currently being planned in Osaka. The development includes 303 new detached residential homes having two layout patterns; every house is all-electrified housing.

Estimating conditions and evaluation results are described for the following three categories:

1. Evaluation of low energy community design alternatives.
2. Evaluation of energy management strategies.
3. Evaluation of an aging community.

Evaluation of low energy community design alternatives

Here, the goal is to create a net zero energy community by introducing energy-saving methods and energy-generating technology. Typically included in the effort are high performance home insulation measures, large capacity PV, and a proper orientation of the houses. Table 3 details the various cases involving zero energy efforts that are dealt with in our simulation.

In Case 1, the base case, the thermal insulation in each of the houses meets the insulation standard established in Japan in 1999 (U_A — Exterior skin averaged heat transmission coefficient— $0.87 \text{ W}/(\text{m}^2 \cdot \text{K})$); per-home PV capacity is set to 4.0 kW. Since the 303 houses in the planned community will be built along curved streets, there is, in this base case, variation in the orientation of the houses, as described in Table 4. In Case 2, the insulation in each house is set to meet the (high) ZEH standard (U_A value $0.6 \text{ W}/(\text{m}^2 \cdot \text{K})$). In Case 3, the orientation of all the houses is changed to south; in Case 4, PV capacity is set to 5.0 kW. Four additional cases are created by using various combinations of the three primary variables. The conditions examined are based on the developer's estimation.

Table 3: Simulation Conditions.

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
	(Base)	High	South	PV5	High South	South PV5	PV5 High	High South PV5
PV Capacity	4.0kW	4.0kW	4.0kW	5.0kW	4.0kW	5.0kW	5.0kW	5.0kW
Insulation Standard	1999	ZEH	1999	1999	ZEH	1999	ZEH	ZEH
House Orientation	BASE CASE	BASE CASE	ALL SOUTH	BASE CASE	ALL SOUTH	ALL SOUTH	BASE CASE	ALL SOUTH
Family Composition	2 people (Single / Double Income Couple) & 4 people (Single / Double Income Couple, Elementary School Students)							
House Specification	All-electric House, Heat Pump Water Heater, Air Conditioning, Heat Pump Hot Water Floor Heating, LED Light, High-Efficiency Home appliances,							
PV Angle / Orientation	2/1 Slope (25.6°) / South Roof							
Weather Data	Apr. 2016 - Mar. 2017, Osaka Pref., Japan, 5-mins data							
House layout	2-story house, 2 kinds of layout							

Table 4: BASE CASE of house orientation.

	Angle from South					
	Westward			Eastward		
	30°	22.5°	7.5°	7.5°	22.5°	30°
Number of Houses (percentage)	73 (24%)	54 (18%)	54 (18%)	31 (10%)	17 (6%)	74 (24%)

Simulated results showing annual energy consumption and PV generation for four of the cases (including the base case) are presented in Figure 6. In Cases 2 and 3, energy consumption is reduced by 3-4% (versus the base case). As can be seen from the simulated monthly energy consumption results in Figure 7, this is due to a decrease in the energy needed for heating and for the hot water supply (including floor heating) in winter. At the same time, PV generation increases by 6% in Case 3 and by 25% in Case 4. These results influence the various evaluation indexes used to assess performance.

Figure 6: Annual Energy Consumption and PV Generation.

Figure 7: Monthly Energy Consumption.

Figure 8 and 9 show the evaluation results, including the percent ZEC (net Zero Energy Community), CO₂ emissions, and the percent self-consumption for the various cases. Self-consumption is defined as PV generated power consumed in a community. These measures are calculated according to equations (1) - (3). CO₂ emissions are generally calculated by multiplying power consumption by the average CO₂ emission factor for all power sources. However, since a newly constructed community is the target of this research, we assume that the increase in power consumption due to the appearance of the new smart community will be covered by an increase in thermal power generation. Therefore, we use the average CO₂ emission factor for thermal power plants,

adopting the value of 0.65 kg-CO₂/kWh (Ministry of the Environment, 2016).

$$\text{Achievement rate of ZEC} = \frac{PV}{E} \times 100 \quad (1)$$

$$CO_2 \text{ emission} = Pur \times f - Sur \times f \quad (2)$$

$$\text{Self consumption rate} = \frac{Self}{PV} \times 100 \quad (3)$$

PV: annual PV generation [kWh]

E: annual energy consumption [kWh]

Pur: annual purchased electricity [kWh]

Sur: annual PV power reverse flow to the grid [kWh]

Self: annual self-consumed PV power [kWh]

f: average CO₂ emission factor of thermal power plants [kg-CO₂/kWh]

Figure 8 shows some of the evaluation results for the eight cases. ("PV5" indicates raising PV capacity to 5.0 kW, "South" indicates changing the orientation of all houses to the south, and "High" indicates increasing the U_A value of all home insulation to 0.6 W/(m² · K).) As shown, a ZEC and minus carbon community are achieved in both Case 6 and Case 8 with the simultaneous introduction of PV5 and a uniform southern orientation. Figure 9 shows that, although the percent self-consumption (represented by the curve shown in black) tends to be declining with the introduction of our energy-saving measures, the amount of self-consumed PV power remains virtually constant across all cases. It seems that since self-consumed PV power has already approached its maximum in Case 1 (the base case), the added energy-generation and energy-saving measures do not produce an increase in self-consumed PV power; they do, however, contribute to an increase in the PV reverse power flow to the grid. The implication is that controlling the electricity supply and demand by using an energy management system is necessary in order to increase the percent self-consumption.

Figure 8: Percent ZEC and Annual CO₂ Emission.

Figure 9: Percent Self-consumption.

Evaluation of energy management strategies

We considered two approaches to energy management: changing the operating schedule of the HP water heater and utilizing storage batteries. Table 5 shows the four estimation cases that were examined. Case 1' is the base case using the same simulation conditions as the "High" case in Table 3. In Case 2', the HP water heater's main operating schedule is shifted from nighttime to daytime in order to consume more electricity during the daylight hours. In Case 3', a battery is installed in each house. In Case 4', a micro grid (MG) is formed to interchange power within the community.

Figure 10 shows the energy breakdown of our simulation results. In Case 2', energy consumption is less than in the other cases. This is because the ambient temperature is higher during the daytime, when the HP water heater is mainly operated, which improves the energy efficiency of the hot water supply. In addition, the daytime operation of the HP water heater means that it can use more PV-generated power. The introduction of a battery has several effects: Charging absorbs surplus electric power and discharging satisfies a portion of the energy demand; purchased electricity decreases and self-consumption increases. Especially in Case 4', where the sharing of electricity enhances the effect of energy management, the change (from base Case 1') is substantial. As a result of these modifications, the percent self-consumption in Cases 3' and 4' is more than double that in Case 1' (Figure 11).

An LCP evaluation was done for Cases 3' and 4'. Based on the fact that a one-week voluntary evacuation is required at the time of a major earthquake in Japan, we evaluated how much of the electricity demand of appliances that are likely to be used in an emergency could be covered solely by PV during a weeklong power outage. Since the Residential Energy End-Use Model simulates energy demand in detail for virtually all appliances, it is possible to replicate a load curve for any given set of appliances. We chose the appliances listed in Table 6 as those that would be used in an emergency. Two evaluation periods—Maximum and Minimum radiation weeks—were set in recognition of the fact that evaluation

results would depend in part on the amount of solar radiation.

Figure 10: Breakdown of Energy Consumption and PV Generation.

Figure 11: Percent Self-consumption.

Figures 12 and 13 show the energy consumption of the emergency appliances and the operational status of the in-house battery. The yellow part of the figures indicates the power shortage time; the dark yellow part shows the time during which a power shortage occurs in more than half of the community households. (This latter condition occurs only in Case 3'.) Table 7 shows the total weekly (one week = 168 hours) power shortage time. In Week 1 (winter), there is a large effect from electricity sharing. As shown in Figure 12, electricity shortages occur frequently from evening to early morning in Case 3', while in Case 4', the power shortage time decreases by more than 80% (Table 7). In Week 2 (spring), the power shortage time is substantially shorter and, in both cases, the PV supply fails only during the first 6-9 hours after the outage begins (Figure 13). This is due to the fact that no electricity had been stored in the battery at the time of the outage and no electricity can be supplied until sunrise.

Table 5: Simulation Conditions.

	Case 1'	Case 2'	Case 3'	Case 4'
	High	HP	Battery	MG
Heat Pump Water Heater Operating Schedule	Night time	Daytime	Night time	
Battery	(Absent)		Capacity 5.6kWh / Charging 0.9 kW / Discharging 0.5 kW / Loss Rate 95 % / Charging Start Time 10:00 a.m.	
Sharing Electricity	(Absent)			Present
Insulation Standard	ZEH-standard			
House Orientation	BASE CASE			
Family Composition	2 people (Single / Double Income Couple) & 4 people (Single / Double Income Couple, Elementary School Students)			
House Specification	All-electric House, Heat Pump Water Heater, Air Conditioning, Heat Pump Hot Water Floor Heating, LED Light, High-Efficiency Home appliances,			
PV Capacity/Angle / Orientation	4.0 kW / 2/1 Slope (25.6°) / South Roof			
Weather Data	Apr. 2016 - Mar. 2017, Osaka Pref., Japan, 5-mins data			
House layout	2-story house, 2 kinds of Layout			

Table 6: LCP Evaluation Contents.

Appliances in Emergency	
Light	LED Light in Living Room
Information	TV in Living Room
Meals	Kitchen appliances (Refrigerator, Electric rice-cooker, Microwave oven, Hot water pot, IH)
Evaluation Period (Power outage period)	
Week 1	Winter : Dec/22/2016-Dec/28/2016
Week 2	Spring : May/17/2016-May/23/2016
Power Outage Start Time	
0:25 a.m.

Figure 12: LCP Evaluation of Week 1 (winter)
(Upper, Case 3'; Lower, Case 4').

Figure 13: LCP Evaluation of Week 2 (spring)
(Upper, Case 3'; Lower, Case 4').

Table 7: Total Power Shortage Time [hour/week].

	Battery	MG
Week 1	109.7	16.8
Week 2	9.0	6.9

From these results, it seems clear that MG formation using batteries (5.6 kWh) lowers the risk of a power shortage in an emergency situation. Even under poor weather conditions, the power shortage amounts to only 10% of a week, which means residents can generally maintain a minimal daily life during the emergency.

Evaluation of an aging community

In Japan, residents of new housing tend to live in the same house for an extended time. Thus, even if housing and appliance specifications remain the same, it can be expected that changes in household composition due to

aging will affect the home's energy performance. Accordingly, we evaluated energy performance within the community considering a secular change in its constituent households. Defining Stage 1 as the 15 year-period immediately following completion of the community, we looked at household composition during this period (Stage 1) and the two subsequent 15-year periods (Stage 2 and Stage 3). Table 8 shows the considered household conditions at each life stage. In Stage 1, we defined four household composition patterns based on the developer's estimation. In Stage 2, the composition possibilities are more diverse. Finally, in Stage 3, we assume an aging community and set a new type of household composition that might include an elderly couple alone or two generations living in the family home.

Table 8: Family Compositions at each Stage.

Stage 1 : Initial Condition (Residents, 1038 people; Housewives & Elderly, 112 people)		
e	Single Income Couple	20%
	Double Income Couple	20%
e	Single Income Couple +Elementary school students	20%
	Double Income Couple +Elementary school students	40%
Stage 2 : 15 Years After (Residents, 1060 people ; Housewives & Elderly, 107 people)		
2 people	Single Income Couple	5%
	Double Income Couple	15%
3 people	Single Income Couple + Child	10%
	Double Income Couple + Children	30%
4 people	Single Income + High school student + Middle school student	20%
	Double Income Couple + High school student + Middle school student	20%
Stage 3 : 30 Years After (Residents, 1104 people ; Housewives & Elderly, 556 people)		
4 people	Couple	20%
	Elderly Couple	15%
	Couple + Working man	10%
	Couple + Double Income Couple	10%
	Elderly Couple +Single Income Couple + Middle school students	45%

Figure 14 shows the associated annual energy consumption. Relative to Stage 1, annual energy consumption in Stage 2 increases by 2% and in Stage 3 by 16%. In terms of specific energy usage, in Stage 3, energy consumption for Cooling, TV, Home appliances, and Kitchen increase by 10% or more relative to Stage 1. In addition, the load curves for a representative day (Figure 15) show that power consumption during the day is increasing. This is essentially due to the change in resident numbers and characteristics. For example, in Stage 3, the number of housewives and elderly who are in the house for long hours during the day is 5.0 times higher than in Stage 1 (Table 8); as a result, the energy consumption of appliances that operate during the day increases.

Figure 14: Annual Energy Consumption

Figure 15: load curve.

Figure 16 shows the percent ZEC and annual CO₂ emissions during the various stages. As shown, these evaluation measures decline in Stage 3. On the other hand, the percent self-consumption (Figure 17) improves due to the increase in power consumption during the day.

Figure 16: Percent ZEC and Annual CO₂ Emission.

Figure 17: Percent Self-consumption.

Conclusion

In this paper, the Residential Energy End-Use Model was applied at the community level, and the energy performance of a Japanese virtual smart community was evaluated. As this bottom-up model considers a number of parameters affecting energy consumption, it is possible to estimate the energy performance of a variety of communities having different characteristics by changing the parameters. The simulation here produced several important findings:

- In an evaluation of low energy community design alternatives, the impact of housing orientation on energy consumption is greater than the impact of improved heat insulation. A zero/minus energy community can be realized by building south-facing houses with PV 5.0 kW capacity without improving insulation performance above the standard level. This indicates the importance of land use. The layout of houses should also be considered from the viewpoint of outside ventilation.

- In an evaluation of energy management strategies, the percent self-consumption, which is a major index for a distribution network, greatly changes. Specifically, with the introduction of batteries, the percent self-consumption more than doubles. In addition, by changing only the schedule of the HP water heaters, self-energy consumption can be controlled. Furthermore, MG formation using batteries (5.6 kWh) enables residents to continue a minimal living routine during a power failure.
- In an evaluation of an aging community, the state of the household—i.e., the number of residents and their characteristics—affects energy performance. For example, annual CO₂ emissions may double over a period of 30 years due solely to a change in household composition related to age.

Given that household composition in a community changes with the passage of time, it is important to consider not only technology options when planning the development of a smart community but also the anticipated status of the community's residents. In future research, we plan to estimate the energy performance of various technologies and determine optimum community characteristics according to specific development conditions.:

This work was supported by JSPS KAKENHI Grant Number 17H03354

References

- Baetens, R., Coninck, C. R., Helsen, L. Saelens, D. (2010). The Impact of Load Profile on the Grid-Interaction of Building Integrated Photovoltaic (BIPV) Systems in Low-Energy Dwellings. *Journal of Green Building*5(4), 137-147.
- Flett, G., & Kelly, N. (2017). A Disaggregated, Probabilistic, High Resolution Method for Assessment of Domestic Occupancy and Electrical Demand. *Energy and Buildings* 140,171-187.
- Ministry of Economy, Trade and Industry (2015). ZEH Roadmap,http://www.meti.go.jp/english/press/2015/1217_01.html
- Ministry of the Environment (2016). Plan for Global Warming Countermeasures, <https://www.env.go.jp/press/files/jp/102816.pdf>
- Richardson, I., Thomson, M., Infield, D., & Clifford, C. (2010). Domestic Electricity Use: A High-Resolution Energy Demand Model. *Energy and Buildings* 42, 1878-1887.
- Taniguchi, A., Inoue, T., Otsuki, M., Yamaguchi, Y., Shimoda, Y., Takami, A., & Hanaoka, K. (2016). Estimation of the contribution of the residential sector to summer peak demand reduction in Japan using an energy end-use simulation model. *Energy and Buildings*12, 80-92.
- Widén, J., & Wäckelgård, E. (2010). A High-Resolution Stochastic Model of Domestic Activity Patterns and Electricity Demand. *Applied Energy* 87, 1880-1892.