Analysis of electricity usage habits based on electricity and hot water supply demand detail measurement of 10 houses

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Abstract. In recent years, energy-generating devices such as residential use fuel cell cogeneration systems (FCCGS) have been spreading. A solid polymer electrolyte fuel cell (PEFC), which is a type of FCCGS, determines the amount of power generation and power generation time according to the demand for electricity and hot water supply in houses. Therefore, residents' lifestyle influences a PEFC's load following speed and efficiency. However, there are few actual surveys of household electricity and hot water supply demand, and we haven’t fully grasped factors that affect them. Therefore, we aim to acquire home electricity and hot water usage habits that affect PEFC operation by measuring detailed electricity and hot water supply demand in 10 houses in Japan. In addition, we also conducted a questionnaire survey for the households and analysed the influence of resident’s behaviour on demand for electricity and hot water supply. We can’t see instantaneous changes in the amount of PEFC generated based on hourly data, so we measured the electricity consumption of the entire house and the electricity consumption and hot water consumption of each household appliance every 2 seconds. In this report, we analysed the usage habits of home appliances.

1. Introduction

In recent years, energy-generating devices such as residential use fuel cell cogeneration system (FCCGS) have been spreading. The effect of installing energy creation equipment will be examined using the data of housing electricity and hot water supply demand. However, we don’t know the usage habits of electricity and hot water supply of housing load because there are few detailed cases of survey on that subject. Conventionally, many people simulate a fuel cell using load data averaged every 15 minutes, but the result of the simulation may be different from the actual operation of the fuel cell.([1] Amatatsu K. et al, 2018) In addition, it is insufficient to examine the influence of household attributes and lifestyle on the power generation amount and efficiency of FCCGS such as solid polymer electrolyte fuel cells (PEFC) etc. ([3] Yamamoto T. et al, 2017) Therefore, the first objective of this survey is to
clarify the actual fluctuation of electric power and hot water supply demand by conducting detailed measurements of electricity and hot water supply demand. The second objective is to examine the influence of energy generation equipment such as PEFC due to the time interval of power demand and detailed fluctuation of electricity and hot water supply demand.

In this study, we report the usage habits of home appliances based on the actual values obtained by the power and hot water supply demand detailed measurement survey and the questionnaire survey for the households to be measured.

2. Overview of the survey

2.1 Overview of detailed measurement survey

In this survey, we measured the total power consumption of the house and the power consumption of each household appliance and hot water supply demand at 2-second intervals. The first objective of this survey is to clarify the actual fluctuation of electric power and hot water supply demand by conducting detailed measurement of electricity and hot water supply demand. The second objective is to examine the influence of energy generation equipment such as PEFC due to the time interval of power demand and detailed fluctuation of electricity and hot water supply demand. Table 1 shows measurement overview. As a power measurement item, we selected devices considered to contribute to changes in the total power demand of each household, and devices that may not be able to follow the power generation of the FCCGS with respect to the electricity demand among the devices owned by each household. The equipment selection conditions are (1) the power consumption may fluctuate depending on the season, (2) the rated power consumption is large, or (3) the power consumption fluctuates instantaneously, or (4) it is used frequently in each household. Since we have a limited number of measurement machines, we selected 3 to 6 household electric appliances to measure in each household.

The targets of detailed measurement are 10 houses in the Kyushu region of Japan. The measurement period was from October 2017 to January 2019. Also, we will describe the measurement method. In order to measure the total power consumption of the house, we installed a clamp type wattmeter on the distribution board. We installed a clamp type sensor in consumer electronics to measure their power consumption while connected to outlets. In addition, we measured the flow rate and temperature of hot water and unheated water using an ultrasonic flow meter and a temperature sensor in order to analyze the amount of hot water used.
Table 1. Measurement overview

| House number | Location | Resident type | Number of people | Power by distribution board | Power by the outlet | Hot water supply equipment | Remarks |
|--------------|----------|---------------|------------------|----------------------------|---------------------|---------------------------|---------|
| Housing 1    | Fukuoka city | Apartment | 5                | Master breaker, Air conditioner, Refrigerator | Microwave, Rice cooker, Washing machine | Gas-fueled water heaters |         |
| Housing 2    | Fukuoka city | Apartment | 4                | Master breaker, Air conditioner, Refrigerator | Microwave, Washing machine, Coffee maker, TV | Gas-fueled water heaters |         |
| Housing 3    | Fukuoka city | Apartment | 3                | Master breaker, Air conditioner, Washing machine | Microwave, Refrigerator, Kerosene fan heater, Dishwasher | Gas-fueled water heaters |         |
| Housing 4    | Fukuoka city | Apartment | 2                | Master breaker, Air conditioner, Electric stove | Refrigerator, Rice cooker, TV | Electric water heater | All electric house |
| Housing 5    | Fukuoka city | Apartment | 2                | Master breaker, Air conditioner, Washing machine | Microwave, Rice cooker, Hot water toilet seat | Gas-fueled water heaters |         |
| Housing 6    | Fukutsu city | Detached house | 3                | Master breaker, PV, Natural refrigerant heat pump water heater | Microwave, Electric stove, Dishwasher | Natural refrigerant heat pump water heater | All electric house |
| Housing 7    | Kama city | Detached house | 4                | Master breaker, Air conditioner, Natural refrigerant heat pump water heater | Microwave, Electric stove, Rice cooker | Natural refrigerant heat pump water heater | All electric house |
| Housing 8    | Kitakyushu city | Apartment | 3                | Master breaker, Air conditioner, Dishwasher | Microwave, Rice cooker, Coffee maker | Gas-fueled water heaters |         |
| Housing 9    | Kagoshima city | Detached house | 3                | Master breaker, Dining air conditioner, Electric stove | Living air conditioner, Microwave, Dishwasher | Electric water heater | All electric house |
| Housing 10   | Kagoshima city | Detached house | 4                | Master breaker | Microwave, TV, Hairdryer | Gas-fueled water heaters |         |

2.2 Overview of questionnaire survey on electricity and hot water usage habit

In order to grasp the basic information, lifestyle habits and living schedule of the 10 target households to be measured, we conducted a questionnaire survey on the usage of electricity and hot water for each house through interviews. The survey period is June to July 2018.

3. Analysis on power usage habits

3.1 Outline of analysis

Based on the questionnaire survey and measured values by the power and hot water supply demand detailed measurement survey, we analyzed the equipment characteristics of home appliances and the usage habits of each household. In this section we analyzed the usage habits of rice cooker, washing machine and microwave, which has fluctuating power consumption based on user's behavior.
3.2 Analysis results of rice cooker

Figures 1 and 2 show the transition of the power consumption of the rice cooker for 2 days on weekdays in housing 1 and housing 4. Housing 1 is a household which includes three young children, and housing 4 is an only adult household. Table 2 shows the specifications of the rice cooker. Figures 1 and 2 show that there are two types of rice cooker: a mode in which power consumption is instantaneously 1kW and a mode in which power consumption of 0.5 kW or less is sustained. Table 2 shows that the mode of about 1 kW is the cooking mode and the mode of 0.5 kW or less is the warming mode. Figure 1 shows that in house 1 cooking is carried out twice a day and the heat keeping time in one cooking session is 3 hours or less. The rice cooker usage time in housing 1 for two days on weekdays was approximately 13.7 hours and the power consumption was 1.40 kWh. Figure 2 shows that in housing 4, rice cooking is carried out at 10 o'clock on June 19, and warming is continued for about 32 hours continuously until 20 o'clock on 20th June. The power consumption of housing 4 for two days on weekdays was 1.92 kWh.

![Figure 1](image1.png)

**Figure 1.** Changes in power consumption of rice cooker for 2 days on weekdays in housing 1

![Figure 2](image2.png)

**Figure 2.** Changes in power consumption of rice cooker for 2 days on weekdays in housing 4

| Table 2. Specification of rice cooker |
|--------------------------------------|
| Year of manufacture | Cooking time | Rated power consumption | |
| | [min] | Rice cooking mode [kW] | Heat retention mode [Wh/h] | Stand-by mode [Wh/h] |
| Housing1 | 2016 | 56 | 1.2 | 14.9 | 0.83 |
| Housing4 | 2009 | 50 | 1.3 | 21.5 | 0.89 |
| Housing5a Before replacing | 2010 | 50~60 | 1.24 | 16.7 | 0.9 |
| Housing5a After replacing | 2017 | 46~53 | 1.105 | 15 | 0.86 |
| Housing8 | 2012 | 36~45 | 1.4 | 17.5 | No data |

*aThe rice cooker of housing 5 was replaced on July 1, 2018.*
Table 3 shows the results of the questionnaire survey on usage habits of the rice cooker. Figure 3 shows the ratio of the average daily power consumption of the rice cooker to the electricity consumption, and Figure 4 shows the average usage time per household for the rice cooker. The ratio of the power consumption is the power consumption of the rice cooker with respect to total household power consumption. From table 3, it can be seen that housing 1 answered that the usage frequency of the rice cooker was twice a day and the amount of rice cooking was 450g. The frequency of use of the rice cooker of housing 4 was once or twice a week, and the cooking amount per time was 450 g. In addition, housing 4 answered that there is a habit of keeping the rice warm for about 30 hours after cooking. The amount of rice cooked by housing 1 and housing 4 is the same. However, housing 1 is considered to have a high frequency of rice cooking because the age of children is low and the number of household members is large. Housing 4 is considered to have a long holding time because it is a household of two in their 50s. In addition, the insulation time was about 12 hours for housing 5 and about 15 hours for housing 8. Figures 3 and 4 show that the average power consumption per day of the rice cooker of housing 4 and housing 8 and the time of using the rice cooker per day are large. The frequency of rice cooking in housing 1 is high, but the average energy consumption per day of housing 1 is the smallest of 4 houses. It is considered that the longer the heat keeping time of the rice cooker, the greater the power consumption. When we consider energy supply, we can generally assume that the power consumption of a rice cooker per day is about 0.6 kWh and the usage time of a rice cooker per day is about 4 to 10 hours.

| Number of people | Frequency of rice cooking | Amount of rice to be cooked at one time | Heat retention time for one rice cooker |
|------------------|---------------------------|----------------------------------------|----------------------------------------|
| Housing 1        | 5                         | Twice a day                             | 450g                                   | unknown                               |
| Housing 4        | 2                         | 1 or 2 times a week                     | 450g                                   | 30 hour                               |
| Housing 5        | 2                         | Once a day                              | 300g                                   | 12 hour                               |
| Housing 8        | 3                         | Four times a week                       | 450g                                   | 15 hour                               |

Table 3. Result of the questionnaire survey on usage habit of the rice cooker

Figure 3. Average power consumption of rice cooker per day, and average ratio of power consumption per day

Figure 4. Average usage time of rice cooker per household per day

3.3 Analysis result of washing machine

Figures 5 and 6 show the transition of the power consumption of the washing machine on weekdays in housing 1 and housing 5, which is an adult only household. Table 4 shows the washing machine specifications and Table 5 shows the result of a questionnaire survey on usage habit of the washing machine. Figure 5 shows that in housing 1, the washing machine is used for approximately 10 hours from around 7 a.m. until around 5 p.m. From Table 5, we have observed that household 1 washes 3 times a day and wash and dry the third time. Therefore, it is thought that the first washing is done around 7 a.m., the second washing is around 8 a.m., and the third washing is done around 9 a.m. Also, it is considered that the dry mode is used after 10:00 a.m. The washing machine usage time per day was about 10 hours, and energy consumption was 1.57 kWh. Next, figure 6. shows that washing is carried
out once at around 7 a.m. in housing 5. The washing machine usage time of housing 5 was about 40 minutes a day, and energy consumption was 0.12 kWh per day.

**Figure 5.** Changes in power consumption of washing machine on weekdays in housing 1

**Figure 6.** Changes in power consumption of washing machine on weekdays in housing 5

| Table 4. Specification of the washing machine |
|---------------------------------------------|
| | Year of manufacture | Estimated time[min] | Rated power consumption[kW] |  |
| | | Washing | Washing and drying | Washing | Washing and drying |
| Housing 1 | 2010 | 45 | 165 | 0.14 | 1.15 |
| Housing 2*(Before replacing) | 2010 | 24~39 | 150~330 | 0.26 | 1 |
| Housing 2*(After replacing) | 2017 | 33 | 165 | 0.14 | 0.98 |
| Housing 3 | 2014 | 33 | 60~420 | 0.16 | 1.13 |
| Housing 5 | 2014 | 25~30 | 120~255 | 0.14 | 1.15 |

*The Washing machine of the housing 2 was replaced on July, 2018.

| Table 5. Result of questionnaire survey on usage habit of the washing machine |
|---------------------------------------------|
| Frequency of use | Method of use |
| Housing 1 | 3 times a day |
| | Use three times a day. 4 days a week twice a day. |
| | For the first use, washing only. On the third use, using the wash and dry mode, drying the towel for about 4 hours. Since it does not completely dry after washing, dry it for 1 hour in drying mode. |
| Housing 2 | 2 or 3 times a day |
| | The washing machine was replaced in July. |
| | Before replacement, it was used two or three times a day. |
| | After weekly replacement, it was used once a day on weekdays, and used on holidays a couple of times a day. |
| | Because the age of children is low, the sheets are washed every day. |
| Housing 3 | Once a day |
| | Use wash and dry mode on rainy days |
| Housing 5 | Once a day |
| | Sometimes washed several times a day |
Next, figure. 7 shows the transition of the power consumption of the washing machine of housing 2. Housing 2 is a household including two young children and replaced the washing machine in July. Figure. 8 shows the average daily energy consumption per day before and after the washing machine replacement in the housing 2. Figure. 9 shows the average usage time of the washing machine per day before and after the washing machine replacement in housing 2. Figure. 7 shows that there is power consumption of about 0.2 kW at 8 a.m. and 2 p.m. before replacement. The washing machine usage time per day was about 2.5 hours. In table 4, the rated power consumption of the washing machine at the time of washing before replacement in housing 2 is shown as 0.26 kW. Therefore, before replacing the washing machine, Housing 2 is considered to be using only the washing mode. Figure. 7 shows that there is a maximum power consumption of about 0.5 kW at 8 a.m. and about 0.6 kW after 9 p.m. after replacing the washing machine of housing 2. Table 4 shows that the rated power consumption of the drying mode of the washing machine after replacement in housing 2 is 0.98 kW. Therefore it is considered that after 9 p.m. it is using the drying mode. Figures 8 and 9 show that washing machine average usage frequency is about 1.5 times a day and day integrated power consumption has increased about 4 times when washing machine is compared before and after replacement. The washing machine usage habits of housing 2 changed to use the washing and drying mode from the use of only washing mode by replacement. As a result, the washing machine usage time and average power consumption per day increased.
Figure. 10 shows the average power consumption of the washing machine per day, and the average ratio of power consumption per day. Figure. 11 shows the average usage time of household washing machines per day. The power consumption rate is the power consumption of the washing machine with respect to the total household power consumption. The washing machine average usage time was 7.5 hours per day in housing 1 and 0.8 hours in housing 5. When the washing machine usage time is long, it is understood that the average power consumption per day and the average power consumption rate per day are large. In particular, the frequency of use of the washing machine in housing 1 is the highest, and since the drying mode is used every day, it is considered that the usage time and the power consumption rate ratio are large. When we consider energy supply, we can generally assume that the electric power consumption of the washing machine per day is about 0.1 to 1.3 kWh and the usage time of the washing machine per day is about 1 to 8 hours.

3.4 Analysis result of microwave oven

Figure. 12 shows the transition of the power consumption of the microwave oven on the weekday's representative day in housing 3. Housing 3 is a household including a teenager. In the microwave oven of Housing 3 on the weekday's representative day, power consumption of about 1kW is instantaneously seen about six times. Table 6 shows the percentage of microwave usage by household per hour. The percentage of microwave usage is the number of times of use per hour for the total number of microwave ovens used during the measurement period. There are many households with a high percentage of microwave usage in the morning from 6 o'clock to 7 o'clock, and in the evening from 17 o'clock to 19 o'clock in the evening, while housing 5 has a high percentage of microwave usage in the morning around 12 o'clock. The average utilization rate of all households peaked at 6 o'clock, 12 o'clock and 19 o'clock. Since this is the average of nine houses in Kyushu, it is considered to be a trend of general microwave usage habits. Figure. 13 shows the number of microwave ovens used per household per day. Figure. 13 shows that the average number of microwave ovens per household per day is about 0.1 to 1.4 times. Also, in housing 3, the microwave oven was used up to seven times a day during the measurement period. When we consider energy supply, it can be assumed that about 1 kW of power consumption occurs about once or twice around 6 o'clock or 12 o'clock or 19 o'clock a day with a microwave oven.
Figure 12. Changes in power consumption of a microwave oven on weekday on housing 3

Table 6. Percentage of microwave usage by household per hour

| Hour | Housing1 | Housing2 | Housing3 | Housing5 | Housing6 | Housing7 | Housing8 | Housing9 | Housing10 | Average for all houses |
|------|----------|----------|----------|----------|----------|----------|----------|----------|-----------|-----------------------|
| 0    | 1        | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0         | 0                     |
| 1    | 1        | 2        | 0        | 0        | 0        | 0        | 0        | 0        | 0         | 0                     |
| 2    | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0         | 0                     |
| 3    | 1        | 1        | 0        | 0        | 0        | 0        | 0        | 0        | 0         | 0                     |
| 4    | 1        | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0         | 0                     |
| 5    | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0         | 0                     |
| 6    | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0         | 0                     |
| 7    | 1        | 1        | 0        | 0        | 0        | 0        | 0        | 0        | 0         | 0                     |
| 8    | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0         | 0                     |
| 9    | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0         | 0                     |
| 10   | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0         | 0                     |
| 11   | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0         | 0                     |
| 12   | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0         | 0                     |
| 13   | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0         | 0                     |
| 14   | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0         | 0                     |
| 15   | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0         | 0                     |
| 16   | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0         | 0                     |
| 17   | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0         | 0                     |
| 18   | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0         | 0                     |
| 19   | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0         | 0                     |
| 20   | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0         | 0                     |
| 21   | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0         | 0                     |
| 22   | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0         | 0                     |
| 23   | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0        | 0         | 0                     |

Figure 13. Number of microwave oven usage per household per day
4. Conclusion
In this report, we analyzed the usage habits of home appliances based on the actual values obtained in the power and hot water supply demand detailed measurement survey and the questionnaire survey for the targeted households. We found that there is a household that keeps the rice cooker warm for about 10 to 30 hours, and that the power consumption of the rice cooker with a longer cooking time is larger than that of a household with high cooking frequency. It was discovered that there are households using the washing machine three times a day. Also, we found that the washing machine's power consumption varies greatly depending on whether or not they used the drying mode of the washing machine. There were also households that changed into the habit of using the drying mode by replacing washing machines. In addition, we found that the usage of microwave ovens was high at 6 to 7 a.m. and 17 to 19 p.m. and the peak hours of using microwave ovens were at 6 o'clock, 12 o'clock and 19 o'clock. The average number of microwave oven usage per household per day was about 0.1 to 1.4 times. From now on, we will examine the fluctuation characteristics of the electricity load, the usage habits of other household appliances, and the life schedule of the inhabitants. In addition, by simulating the operation of PEFC, we will investigate whether it is a general lifestyle habit or not.

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