EEDAL’24
12th International Conference on Energy Efficiency
in Domestic Appliances and Lighting

October 7-9.2024, Kitakyushu-city, Japan

Measurement and evaluation of the energy-efficiency effect of shifting the operation time of a heat pump water heater

Suguru Mizutani
Jyukankyo Research Institute Inc.

Background and Purpose

■ Backgrond

- After the Feed-In Tariff(FIT) period, households sell their surplus power at lower prices.
- method to utilize surplus household PV generation
  - electricity in storage batteries and electric vehicles
  - thermal storage

■ Purpose

- We evaluate measured **energy-efficiency effects** and an increase in **the ratio of PV generation consumed on-site** (PV self-consumption rate) resulting from switching the heat pump water heater(HPWH) thermal storage operation from nighttime operation to daytime operation.

Contents

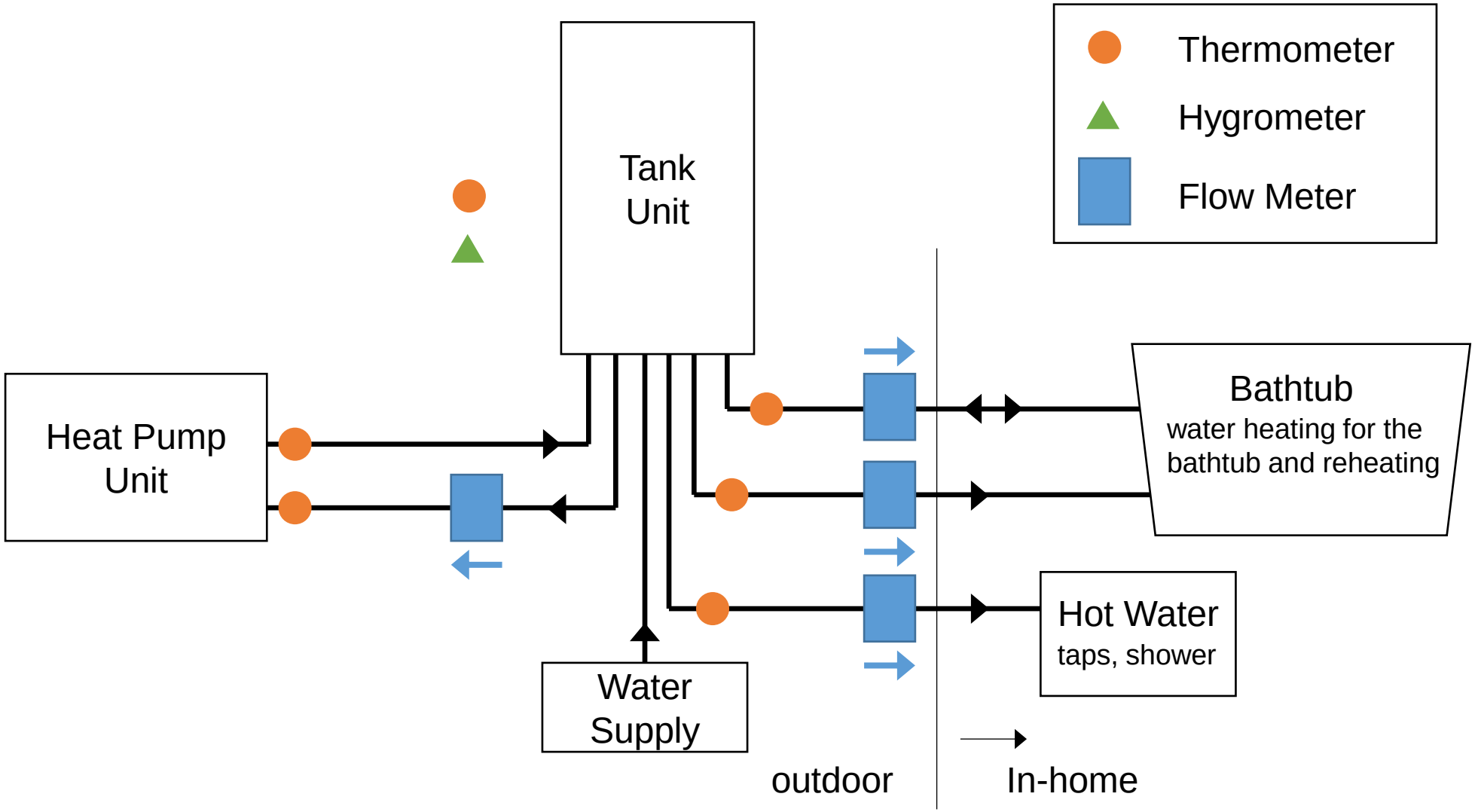
- Overview of measurements
- Measurement points
- parameters required for setting the water heating end-time
- Results of measurement
- Case study about PV self-consumption rate
- Conclusion

Overview of measurements

■ Study household

- Lived in Yokohama (near Tokyo)
- five-person household (two working parents and three children)
- Installed a PV system (3.84kW) and a HWHP (tank capacity:460L)
- Measurement periods:
  - 18 days with nighttime thermal storage
  - 19 days with daytime thermal storage

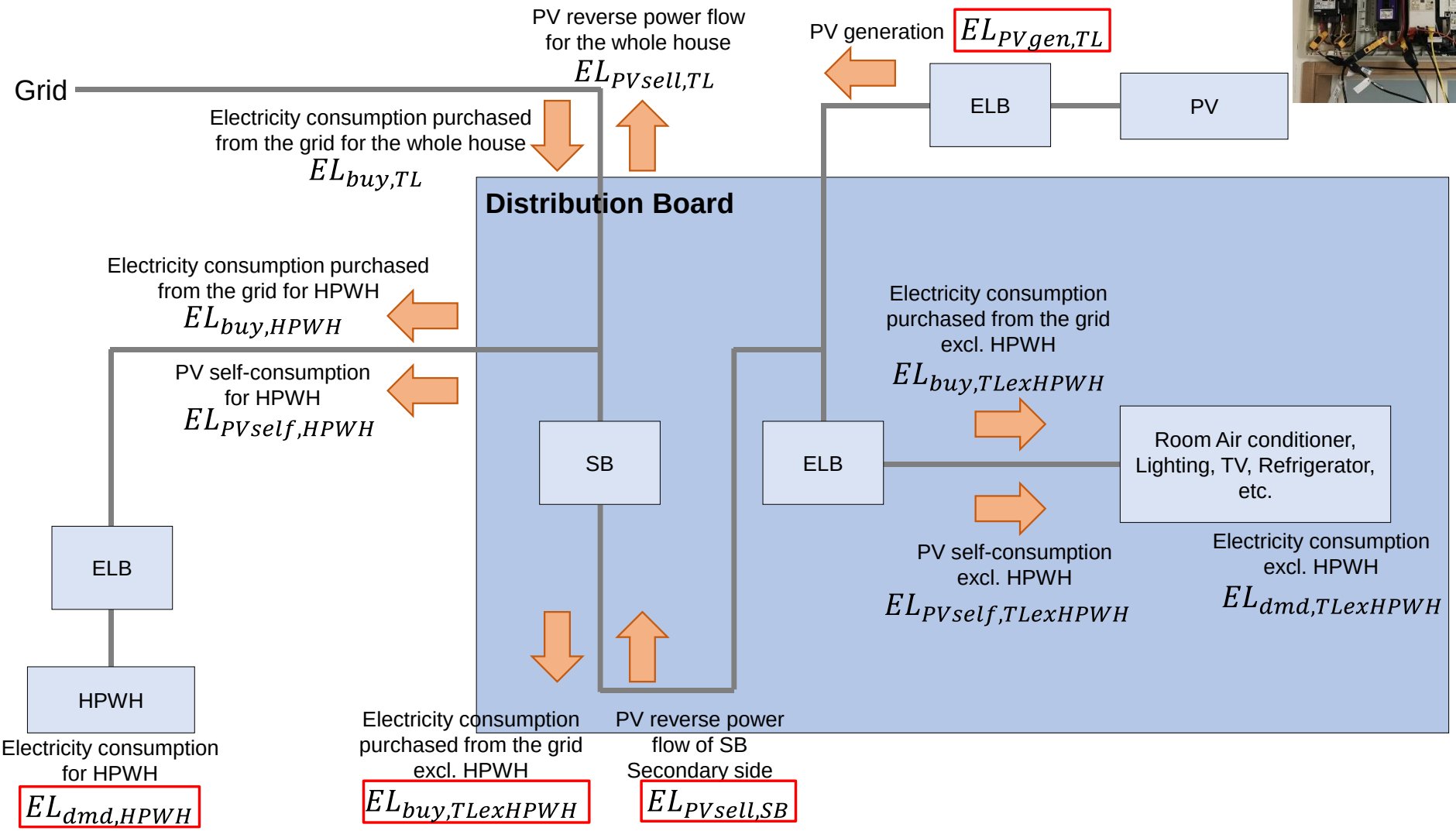
Main measurement points around the HPWH



Note: The ambient temperature and humidity sensors were located near the tank unit.

Electricity measurement points and variable names

Variables in red boxes are subject to measurement

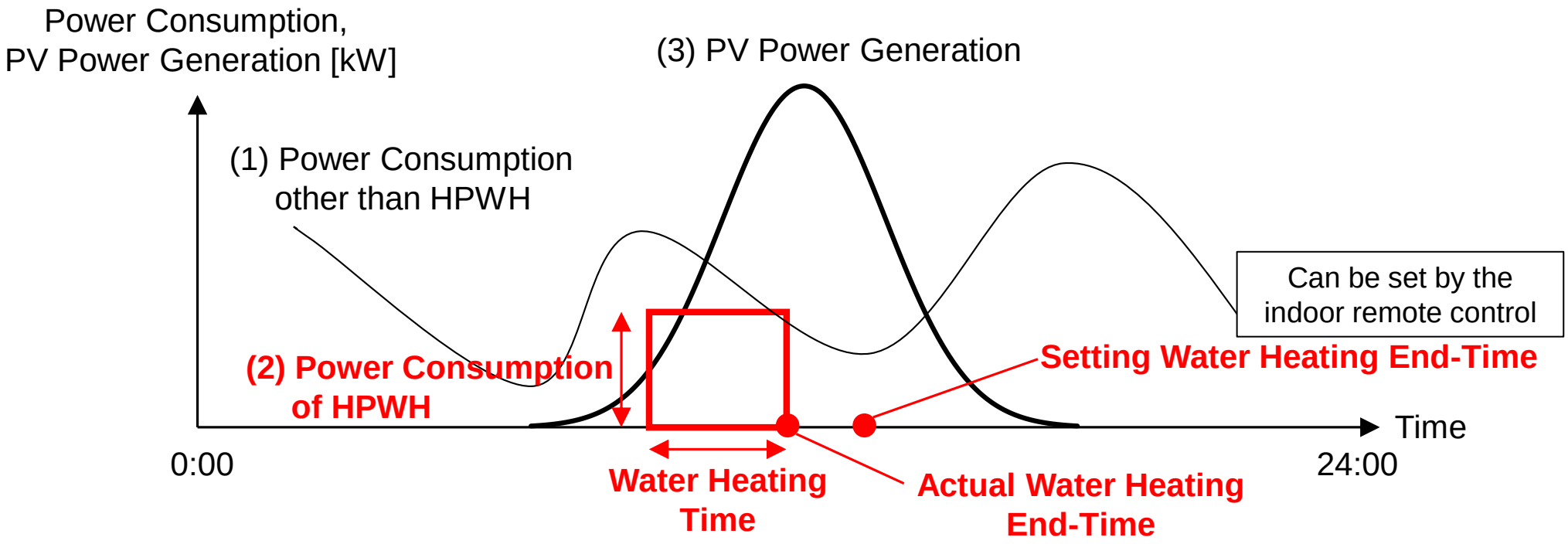


Note: SB = service breaker; ELB = earth leakage breaker

Parameters required for setting the water heating end-time

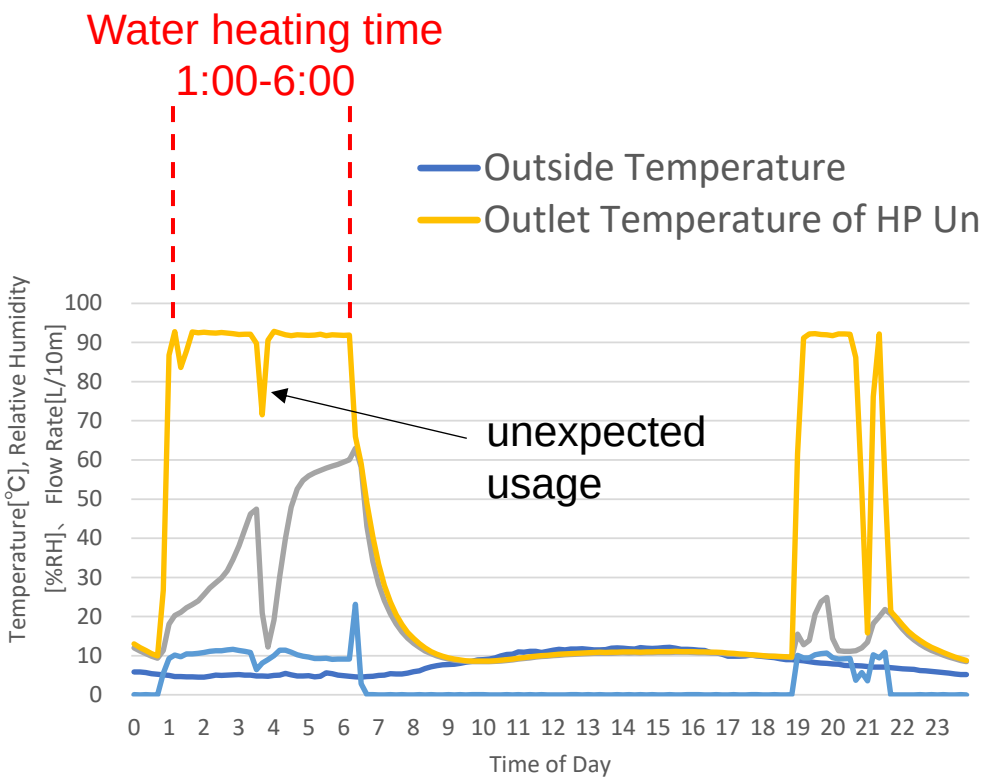
The parameters can be broadly classified as follow:

(1) power consumption other than HPWH
(2) power consumption of the HPWH
(3) PV power generation

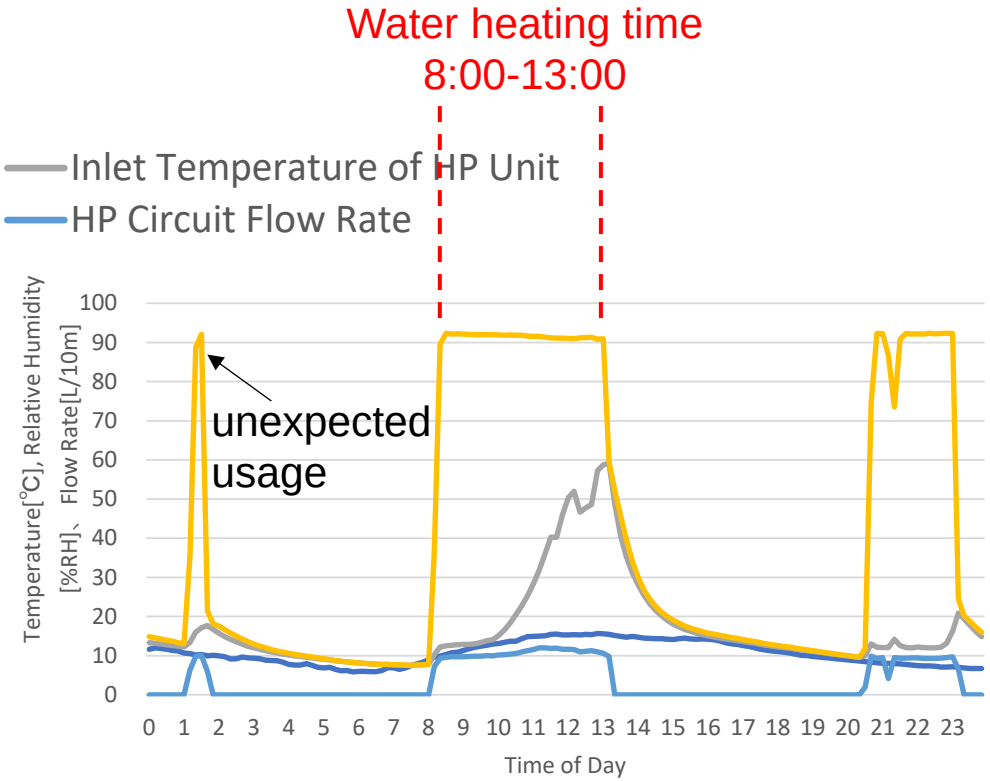


Operating status of the heat pump

These results indicate that the change in operation method works as intended.



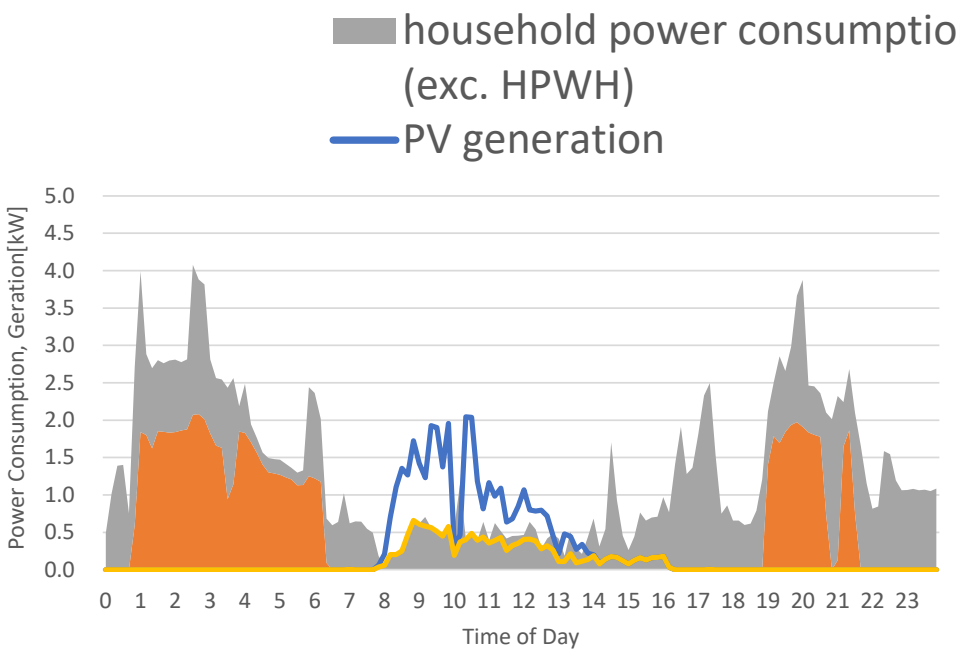
(February 1, 2020)
(**Nighttime** thermal storage operation)



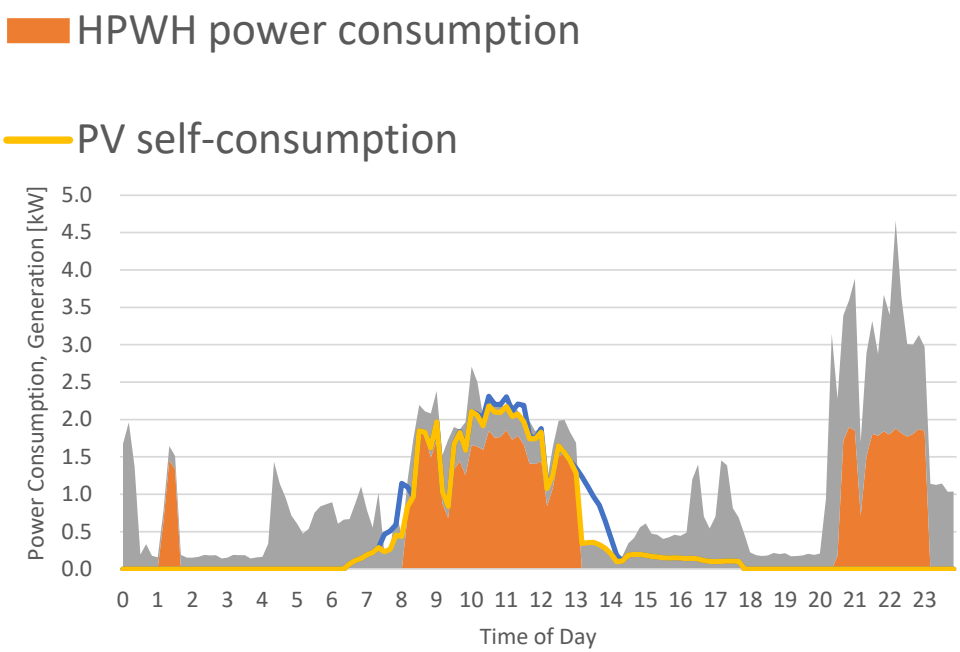
(February 23, 2020)
(**Daytime** thermal storage operation)

PV power output and household power consumption

the amount of self-consumption is large because the HPWH is in operation during the daytime.



(February 1, 2020)
(**Nighttime** thermal storage operation)



(February 23, 2020)
(**Daytime** thermal storage operation)

Breakdown of the heat pump water-heating heat quantity

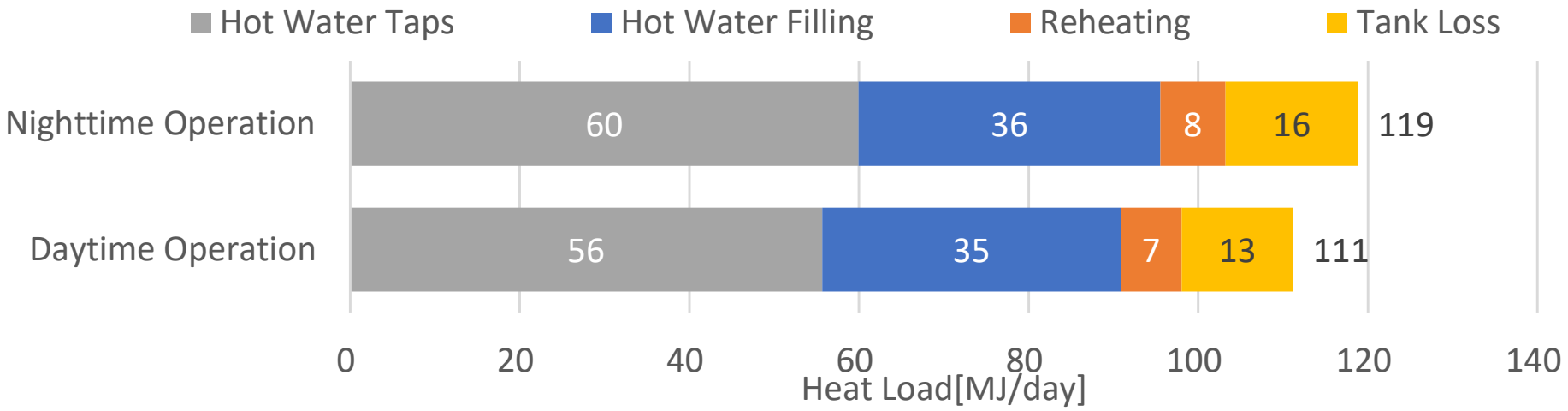
For nighttime thermal storage operation, the daily hot-water heat load is 103 MJ/day, with the largest heat load for hot water taps at 60 MJ/day.

The hot water usages of the study household are approximately 1.5 times greater than those of JIS C 9220: 2018 "Residential heat pump water heaters".

The tank loss accounts for:

Nighttime thermal storage operation: 13.2% (= 16MJ / 119MJ)

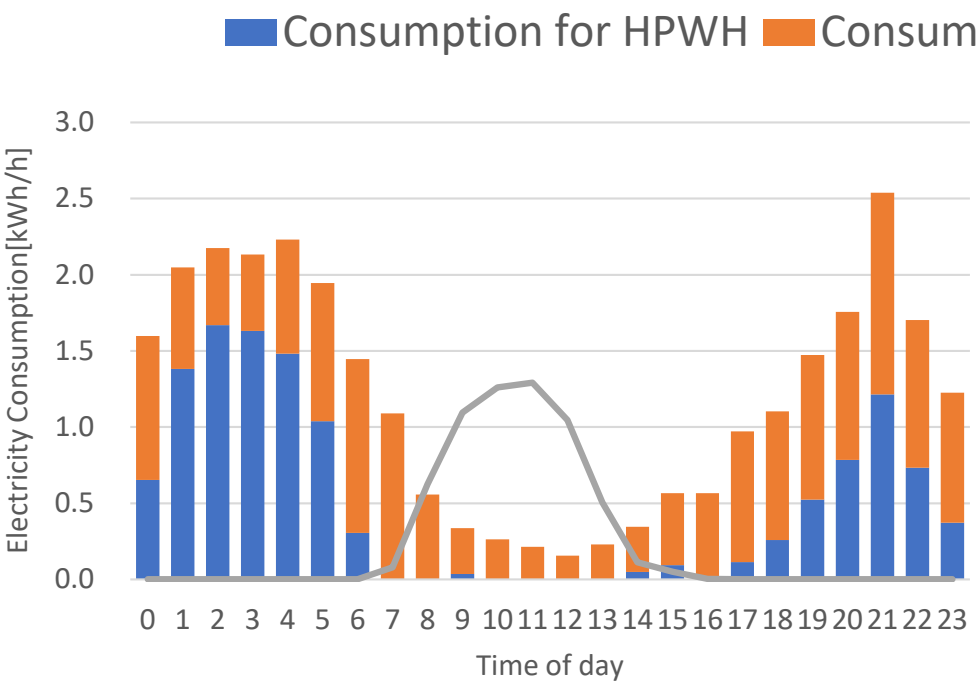
Daytime thermal storage operation : 11.8% (= 13MJ / 111MJ).



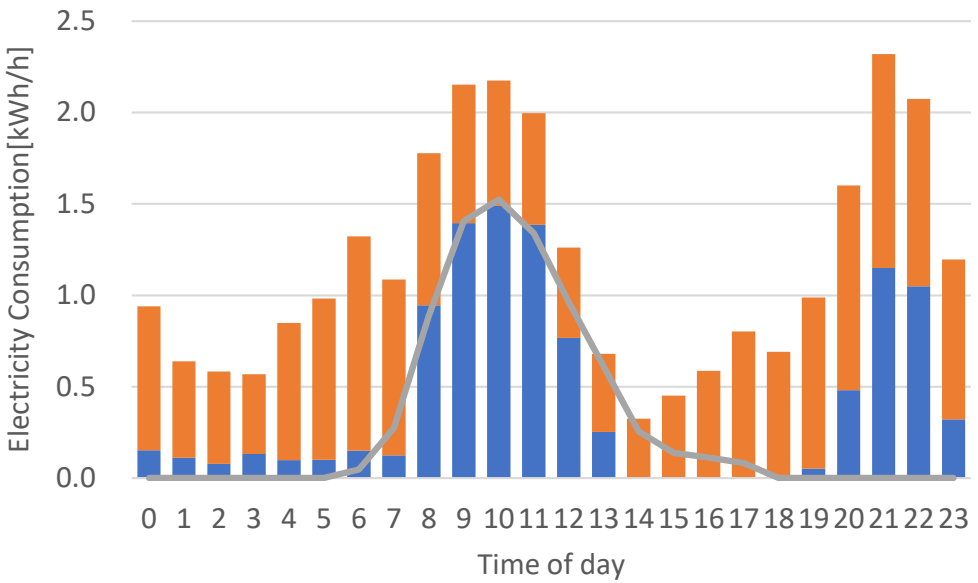
Electricity consumption and PV power generation by time of day

most of the PV power generation **is sold**

most of the PV generation **is consumed in-house**



(**Nighttime** thermal storage operation)

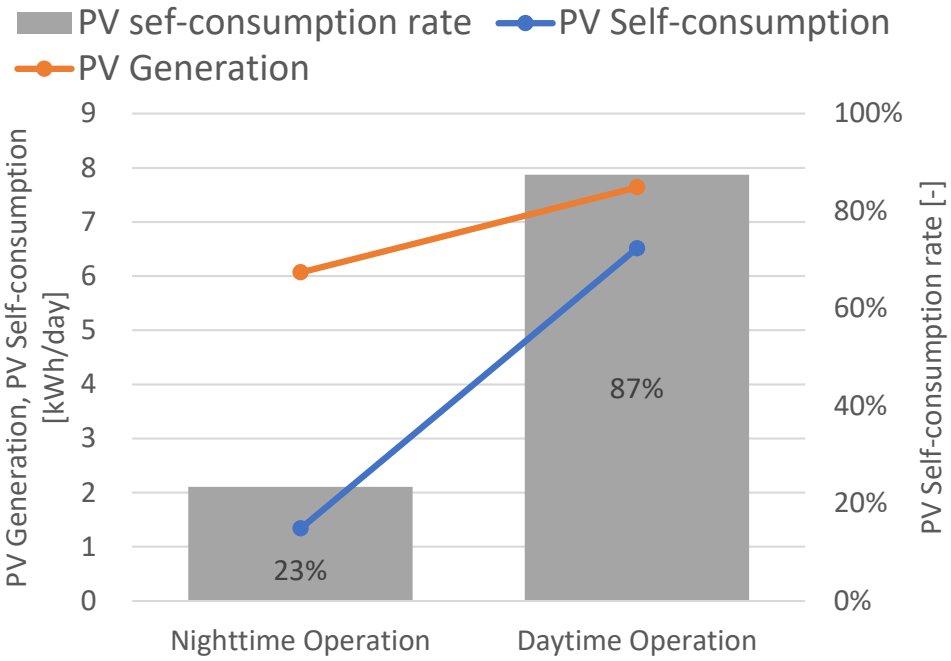


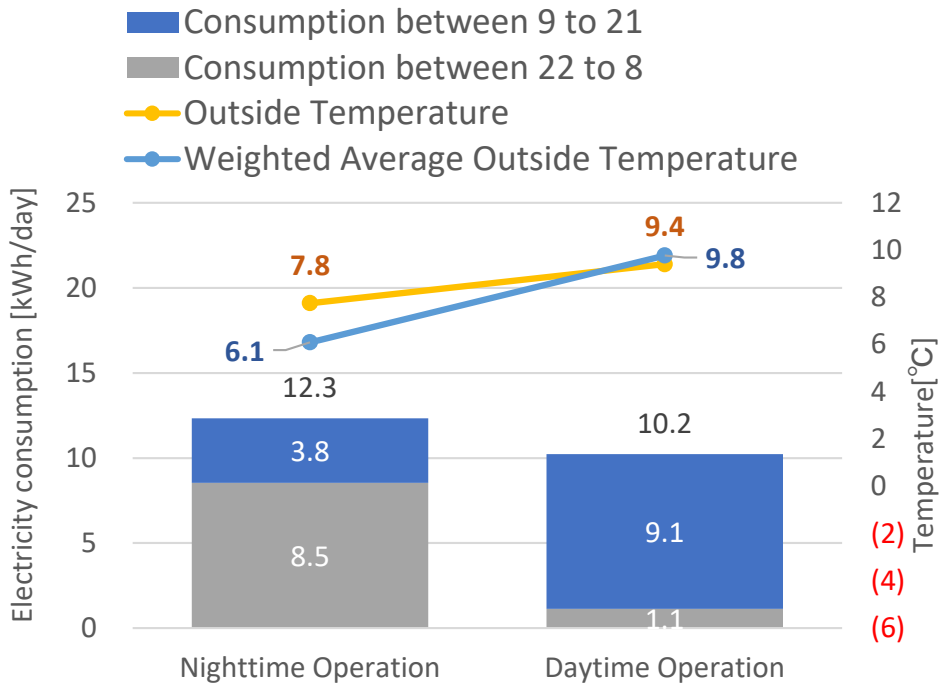
(**Daytime** thermal storage operation)

Breakdown of PV self-consumption rate and HPWH electricity consumption

The PV self-consumption rate is greatly improved by using daytime thermal storage operation.

The HPWH electricity consumption in daytime thermal storage operation is efficient.





Note: The weighted average outside temperature during HP water heating is the weighted average value of the outside temperature during HP operation weighted by the heat pump water-heating heat quantity.

HPWH COP

- **Nighttime** thermal storage operation -> **Daytime** thermal storage operation
  - The heat pump COP improved by 12%.
  - The system COP improved by 14%.

Category	Electricity consumption (kWh/day)	Heat Pump water-heating heat quantity (MJ/day)	Tank loss (MJ/day)	Hot water heat load (MJ/day)	Heat pump COP (-)	System COP (-)
Nighttime thermal storage operation	12.3	118.8	15.6	103.2	2.70	2.35
Daytime thermal storage operation	10.2	111.2	13.1	98.0	3.02	2.69

+12 %

+14 %

Note: Tank loss includes the heat lost from the hot water storage tank and pipes.

Summary of Multiple linear regression analysis

- All explanatory variables were statistically significant.

Objective variable: daily electricity consumption

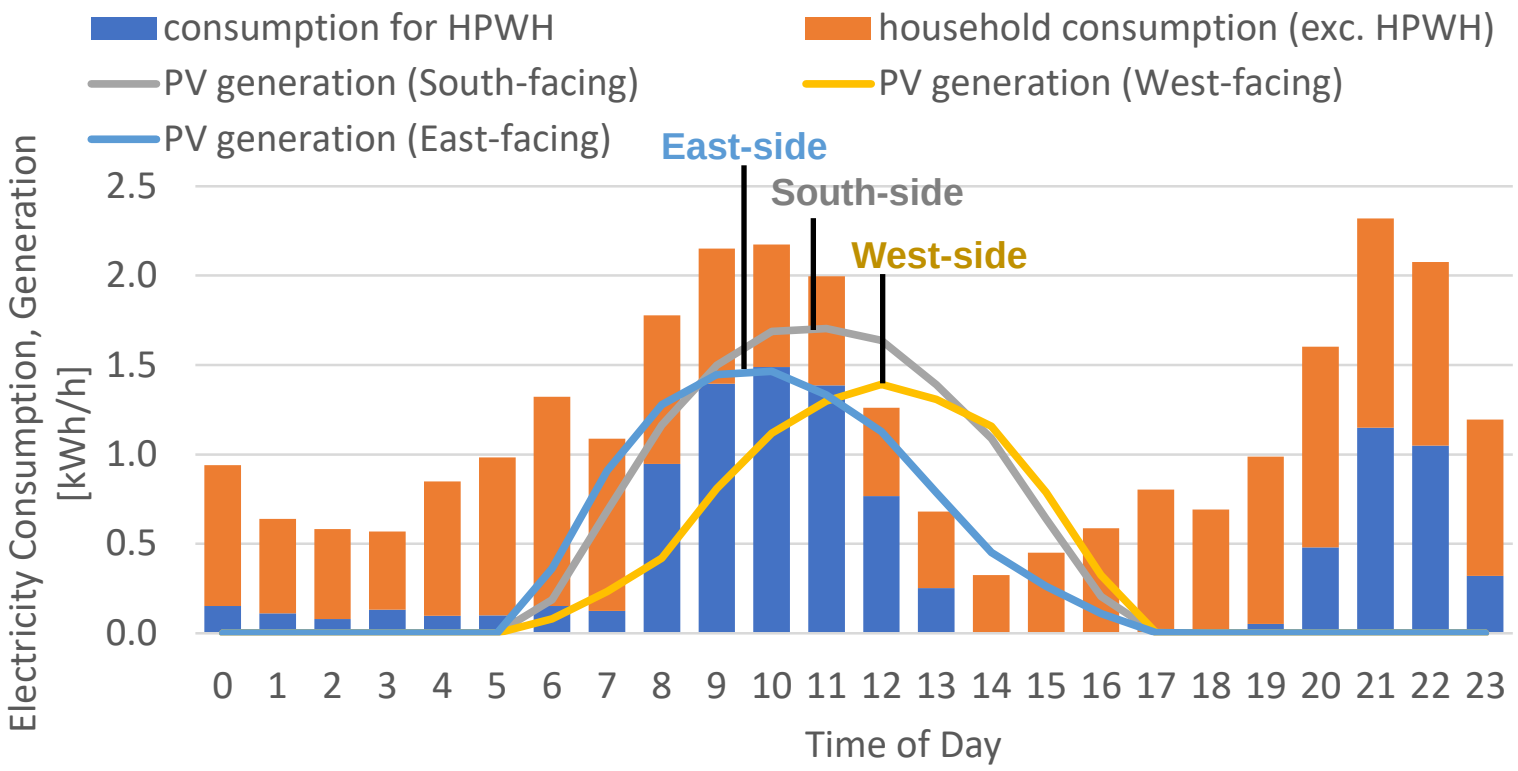
Variables	Coefficient	Std. Error	p value
Intercept	8.77	1.85	0.00
Daytime operation dummy	-1.38	0.43	0.00
Daily average outdoor temperature	-0.29	0.09	0.00
Hot water heat load	0.06	0.02	0.00

Note) $R = 0.811$, $R^2 = 0.658$, adjusted $R^2 = 0.627$, sample size = 37

- **System COP** under controlling the variables using the results of multiple linear regression analysis
  - 2.24 for nighttime thermal storage operation
  - 2.51 for daytime thermal storage operation
- **12% improvement** for daytime thermal storage operation

Case study of PV installation orientation

- The PV self-consumption rate can be improved by **shifting the setting water heating end-time**.
  - **The west-side installation**: delaying by approximately 2 to 3 hours
  - **The south-side installation**: delaying by approximately 1 to 2 hours



Case study of PV installation orientation

- The highest PV self-consumption rate is 83% for the **east-facing installation**,
- There is **a 13% point difference** depends on the PV installation orientation.
- **South is the most desirable orientation**.
- If a south-facing installation of PV is difficult and it needs to be oriented in some other direction, then **the effect of setting the water heating end time may be significant and should be considered**.

		South-facing Installation	West-facing Installation	East-facing Installation
PV generation	kWh/day	**11.9**	8.9	9.5
PV self-consumption	kWh/day	8.4	6.3	8.0
PV self-consumption rate	-	70%	70%	**83%**

Note 1: PV generation is calculated by the method of Housing Energy Efficiency Standards
Note 2: Estimated results with the setting water heating end-time fixed at 2:00 p.m.

Conclusion

- Measurements were made in the actual use environment in an occupied house.

  Note that only one household was measured and that the results were obtained only in winter

- **The PV self-consumption rate** in daytime thermal storage operation was **83%**, which was significantly higher than in nighttime thermal storage operation.
- **The HPWH system COP** for daytime thermal storage operation was **12%** higher than that for nighttime thermal storage operation.
- The optimal setting for the water heating end-time depends on the PV system installation conditions, so **it is important to optimize the design for each household**.
- It is very easy to change the settings to switch to daytime thermal storage operation, so **this measure can be quickly implemented in existing houses for an effective increase** in PV self-consumption.