NEDO Greater Manchester Smart Communities Project Final Report

Hitachi, Ltd.
Daikin Industries, Ltd.
Mizuho Bank, Ltd.

21st November 2017

This experiment is subsidized by the Ministry of Economy, Trade, and Industry, and by the independent administrative agency NEDO (New Energy and Industrial Technology Development Organization).

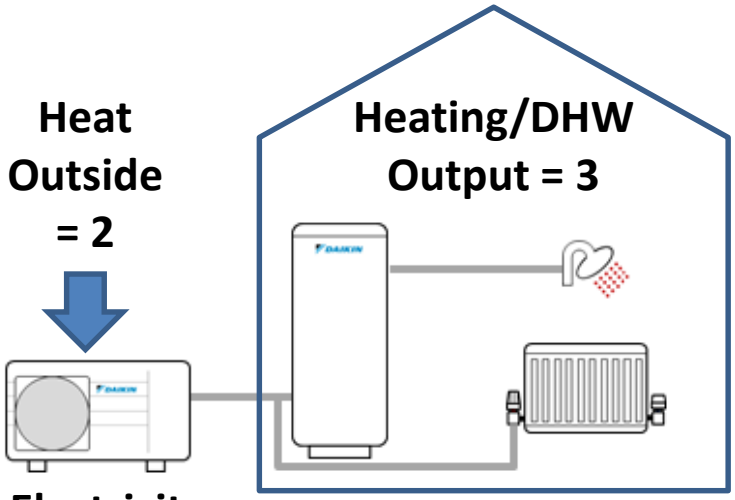
1. INTRODUCTION

Background of the Project

- United Kingdom
  - Promote Energy shift from Gas to Electricity in the Residential Heating Market

- Along with the pervasion of High Efficiency Heat Pumps, brought in Demand Response Systems for
  - Conserving Electricity, Power Grid and
  - Arbitration for Power Balancing function

Heat Pump is…

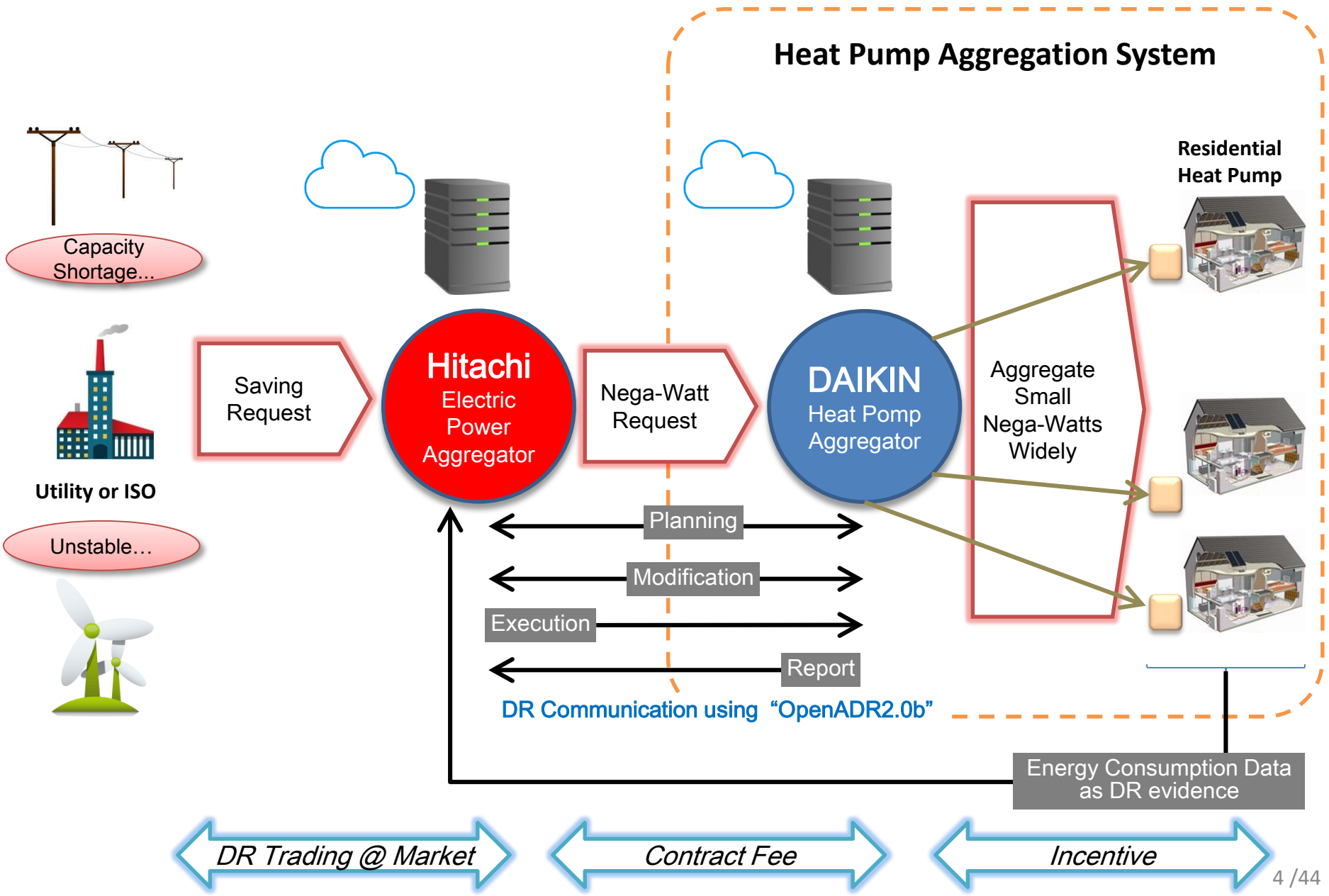


Demand Response is…

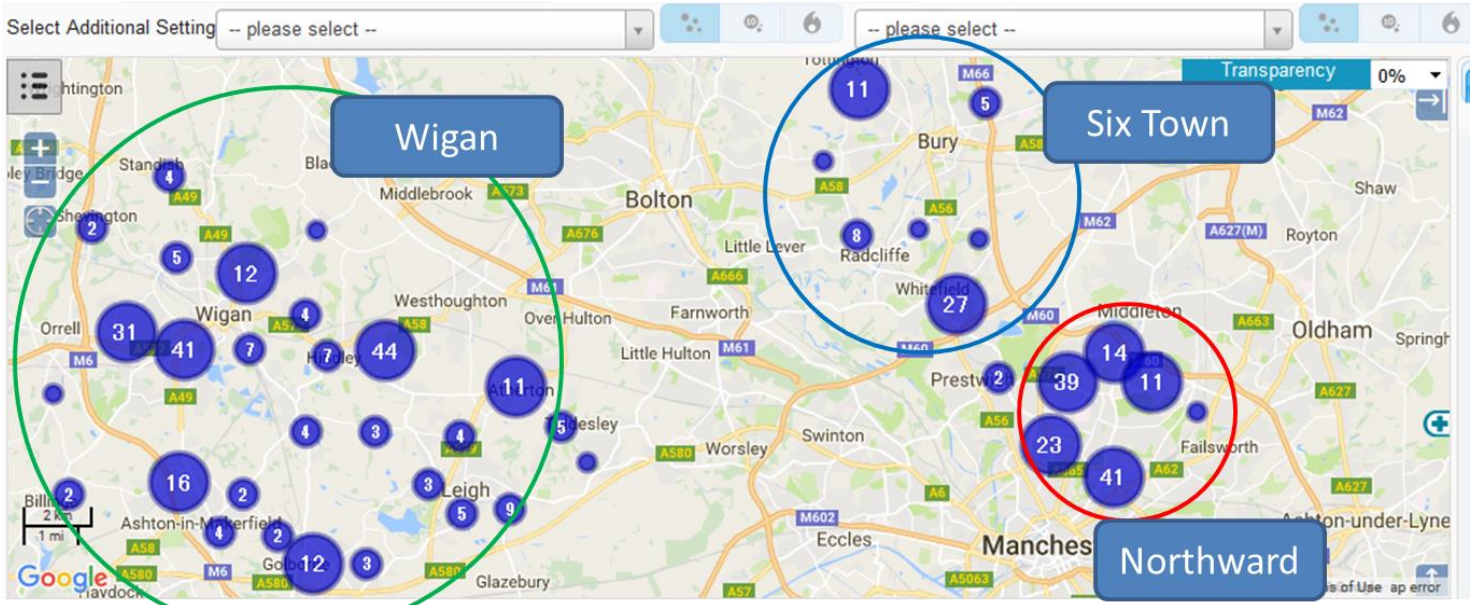
Demand response is a change in the power consumption of an electric utility customer to better match the demand for power with the supply.

From “Wikipedia”

Demand Response Structure

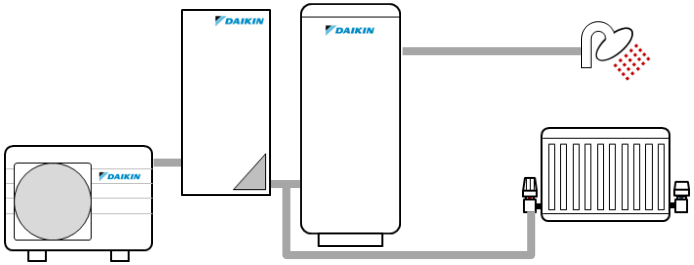
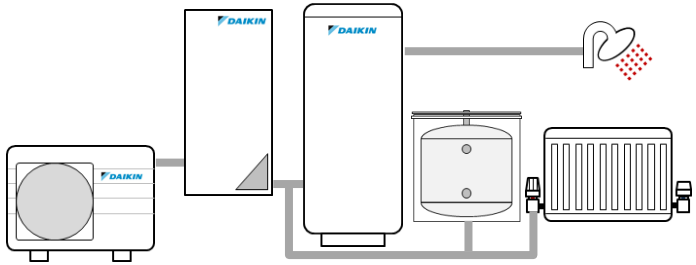
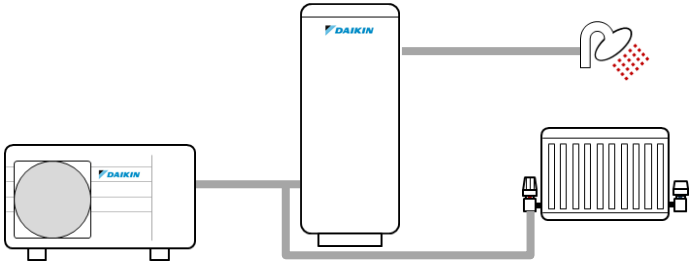
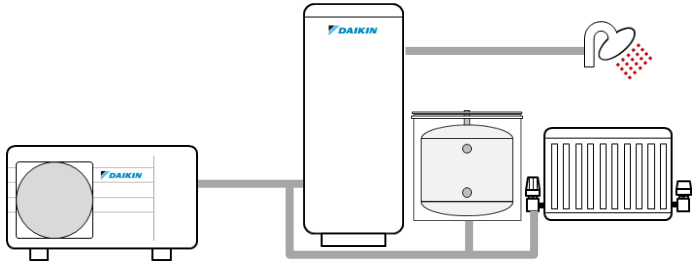
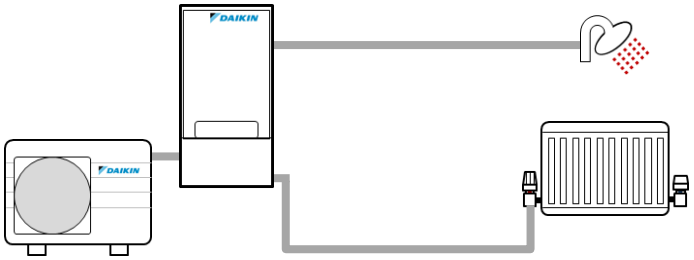


Location Maps



2. INSTALLATION OF HEAT PUMP UNITS
&
THEIR DEMAND RESPONSE AGGREGATION

Heat Pump Systems : Simplified Diagram

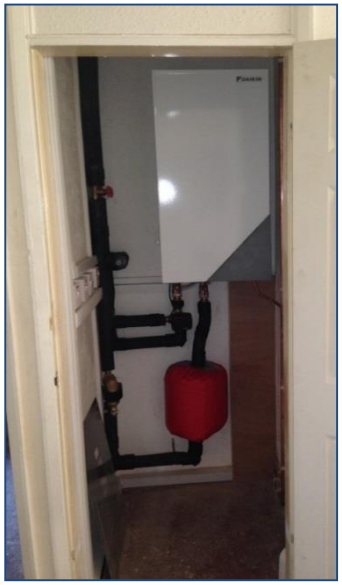
	Normal	+ Buffer Vessel
Split		
Monobloc		
Gus Hybrid		N/A

Installation Result

- Total of 550 Heat Pump Systems installed in Greater Manchester Area
- Normal Units of Electric Heat Pump, LT Split/Monobloc, and Gas Hybrid And Heat Pumps with Buffer Tank for Heating
- Among the Electric Heat Pump Split Units, 10 Units are from Hitachi

	Normal Units				With Buffer Tank			Sub Total
	Electricity			Gas Hybrid	Electricity		Gas Hybrid	
	LT	LT Hitachi	Mono	Hybrid	LT	Mono	Hybrid	
WALH	161	8	127	7	3	1	0	307
NWH	70	2	27	35	19	0	0	153
STH	0	0	15	75	0	0	0	90
Sub Total	231	10	169	117	22	1	0	550
Category Total	410			117	23		0	550

Site Surveys, Installation Jobs, and Units



Scenery: Installation Completed

Sheltered Flats at Wigan Council

Daikin Engineer checks settings

Sheltered Flats at Northwards Housing

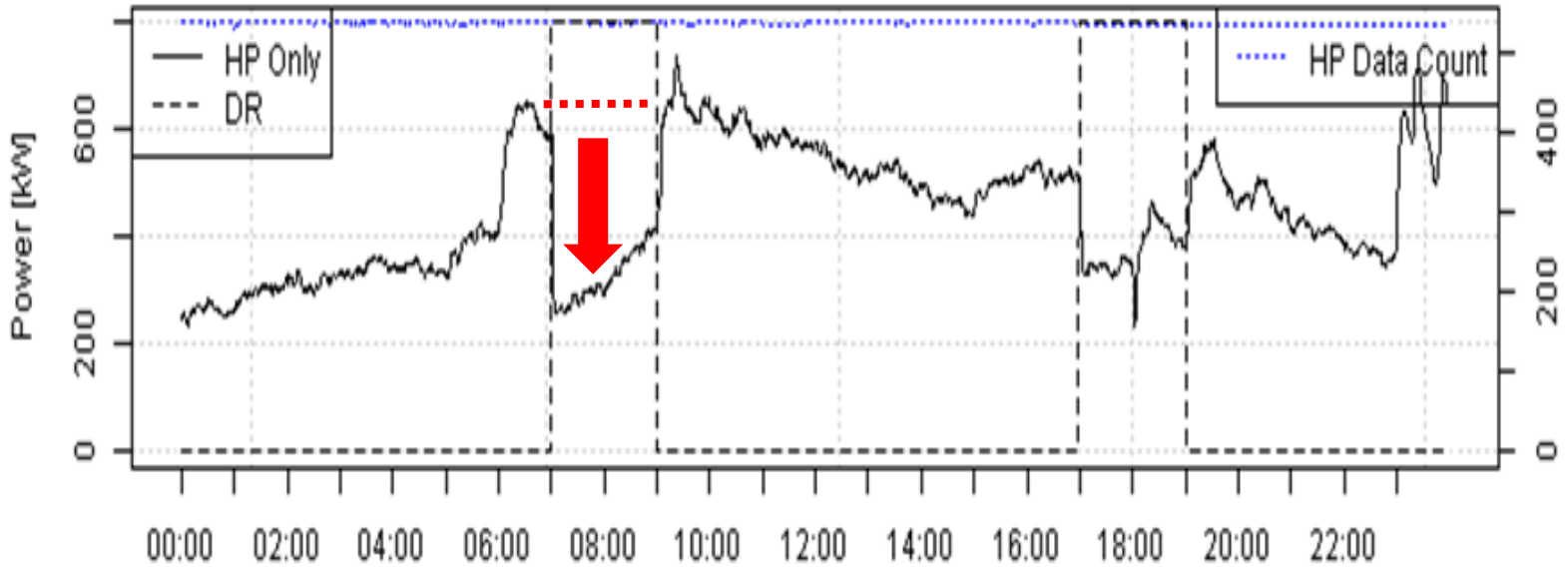
Demand Response Trials

- Period: October 2015 to March 2017
- DR command: Turn off the heating units
- DR schedules: Twice a day, morning and evening
- Duration
  - DR server side 1 hour to 2 hours
  - Property side: 30 minutes to 2 hours

Demand Response Result: 27/01/17

Demand Response reduced around 50% of Electricity than the assumed Base Line.

Total Power Profile over 460 properties, 27/01/2017



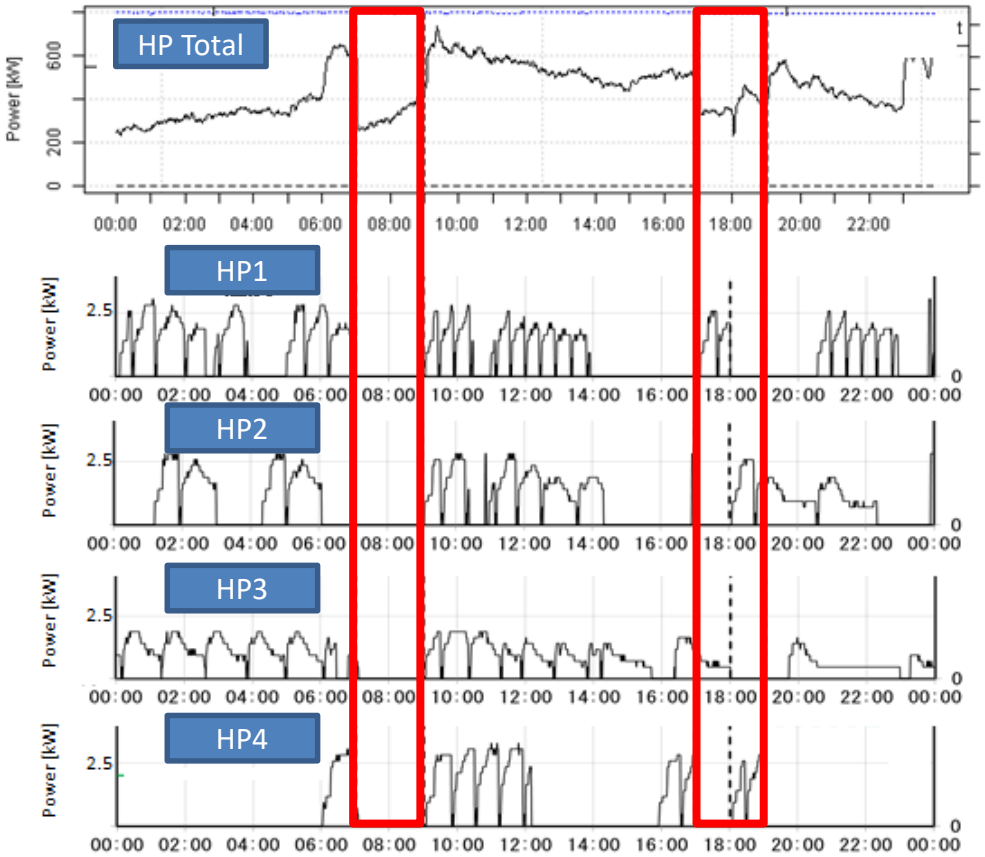
Date of Experiment	**27/01/2017, Friday, AM7:00～AM9:00**
Outdoor Temp	-2.9℃
Nega-Watt by DR	234.5 kW

HP Heating System for the DR Resource

- Each Heat Pump Unit starts/stops intermittently, but once these units are aggregated, the whole system provides a good secure NEGA-WATT value.
- Within two minutes of the DR event kicking in, it reduces to the target amount. Responsivity to the DR commands seems satisfactory.
- Heat Pump System can be valid to Fast DR resources.

Energy Total Sum

Each Unit
Energy Usage



Safety Functions for Tenant Comfortability

- Any Property connected to DR server is DR Application Property, for the Project
- During the DR event, it stops Heat Pumps running, and Heating Capacity decreases.
- To keep Tenants comfortability, Safety Functions are built in the DR Program.

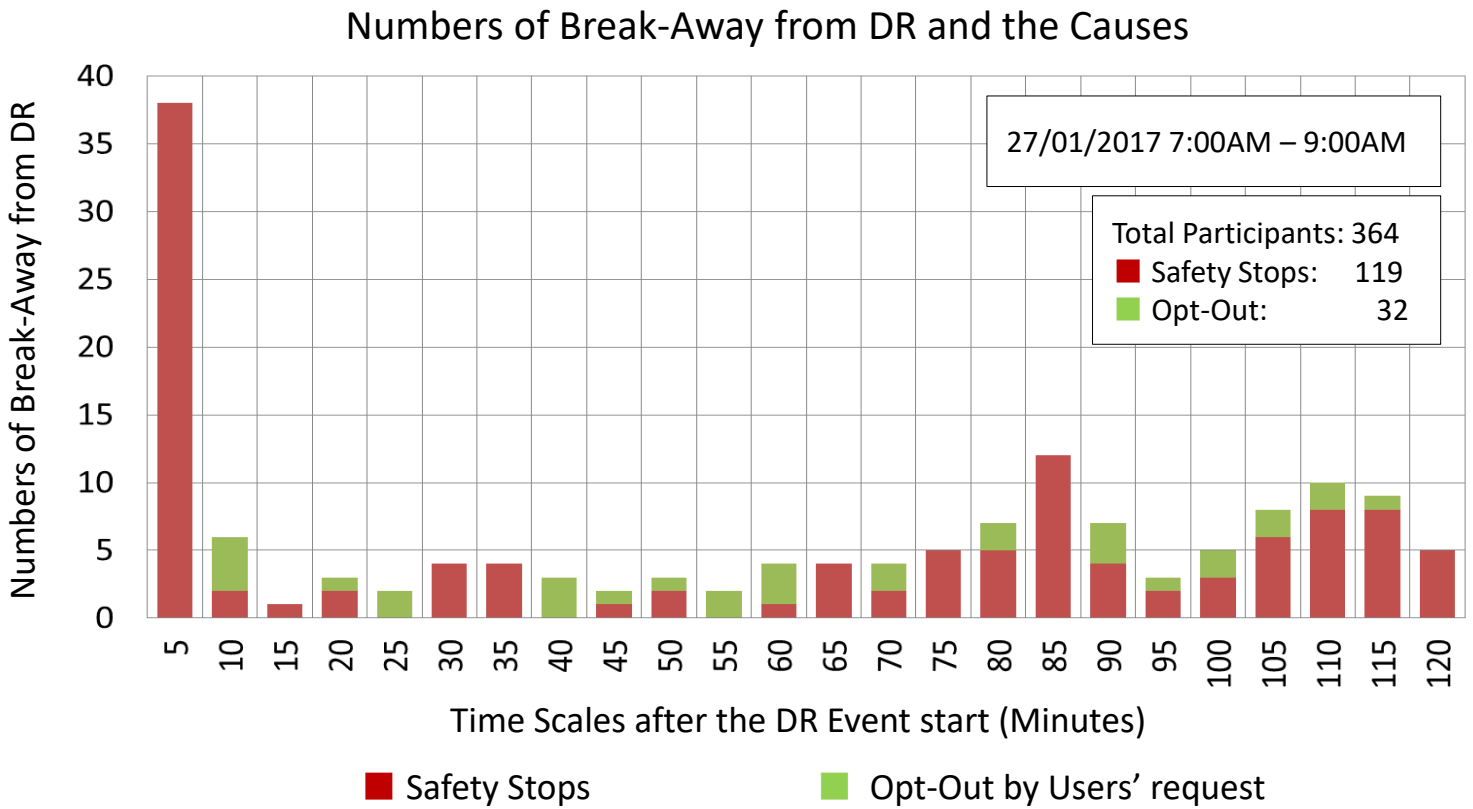
- Safety Function; Under any of the following conditions, the property is excluded from the DR event:
  - When the Room Temp is/becomes below 18 ℃, at any time of the DR event.
  - When the Room Temp drops 2℃ from the beginning temperature.
  - When the tenant(s) touched and changed the Set Point at the Remote Controller.

	Safety Function for Room Comfortability ("Automatic Opt-Out")		Opt-Out ("Manual Opt-Out")
	Room Temp < 18 d. C	Room Temp drops 2 d. C	Tenant(s) changes the Set Point
When the DR Event Begins	Excluded from the DR	If the Temp > 18 d. C, DR event starts	If the Temp > 18 d. C, DR event starts
During the DR Event	Excluded from the DR	When the Temp drops 2 d. C, excluded from the DR	No matter which temps, tenant(s) want to change the Set Point, DR ends as "Opt-Out".

Break Away from DR : Around 1/3, Totally

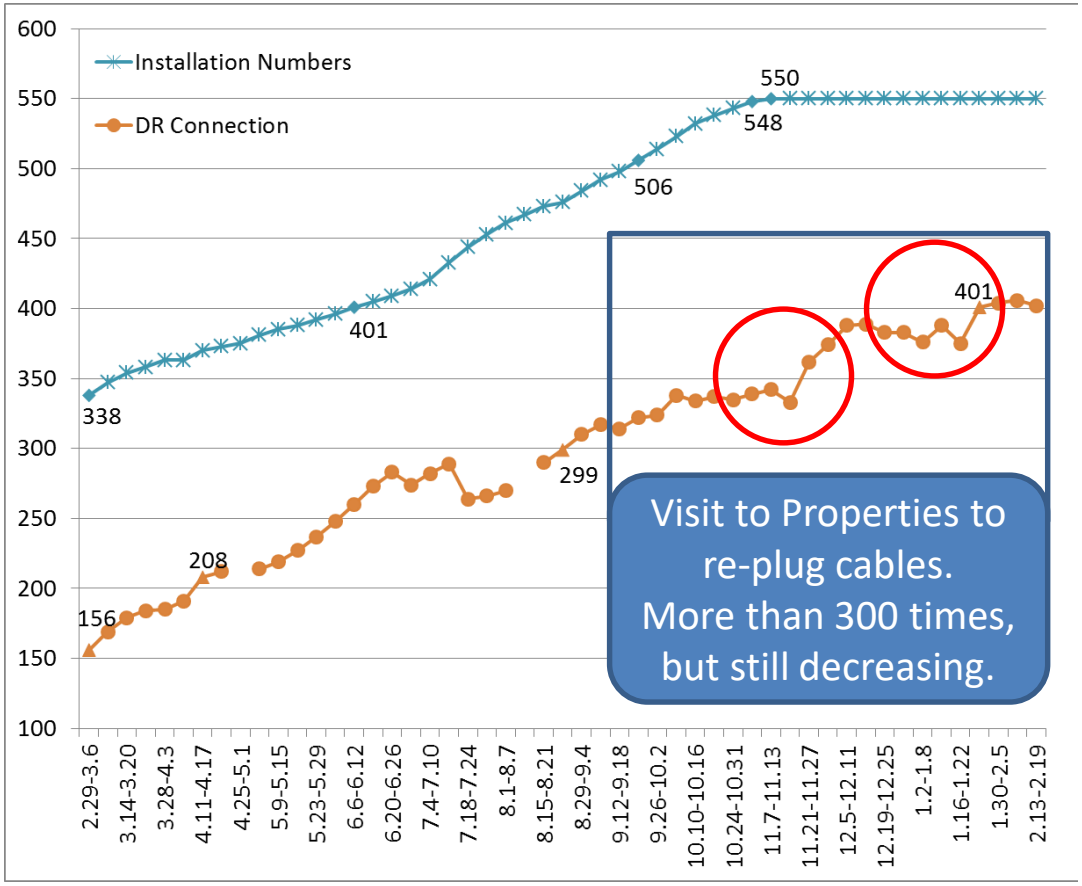
27/01/2017 7:00AM-9:00AM

- The DR system is designed on “Opt-Out” basis.
- All the properties participate in DR. When Tenants change the set point at the Remote controller, it is recognized as “Opt-Out”. This system secured the Electricity Reduction Management.
- Break Away from DR were 151: From 364 to 213. And 119/151 were Safety Stops.



Internet Disconnection at Properties

- High Speed Internet, ADSL wired the Heating/Monitoring Units to DR Servers via Broad Band Routers, but tenants frequently pulled out plugs or turned them off.
- Those communications are beyond Heat Pump Service Engineers, and internet engineers visited over 300 times to re-connect cables and re-boot.
- Mobile devices for Residential IoT units are highly recommended.



3. FINDINGS ON
HP POWER CONSUMPTION AND DR RESULTS

3. Findings on HP consumption and DR results

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3-1 HP power consumption

3-2 Demand response results

3-3 Tenant acceptance

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1. HP power consumption
Effect of aggregation

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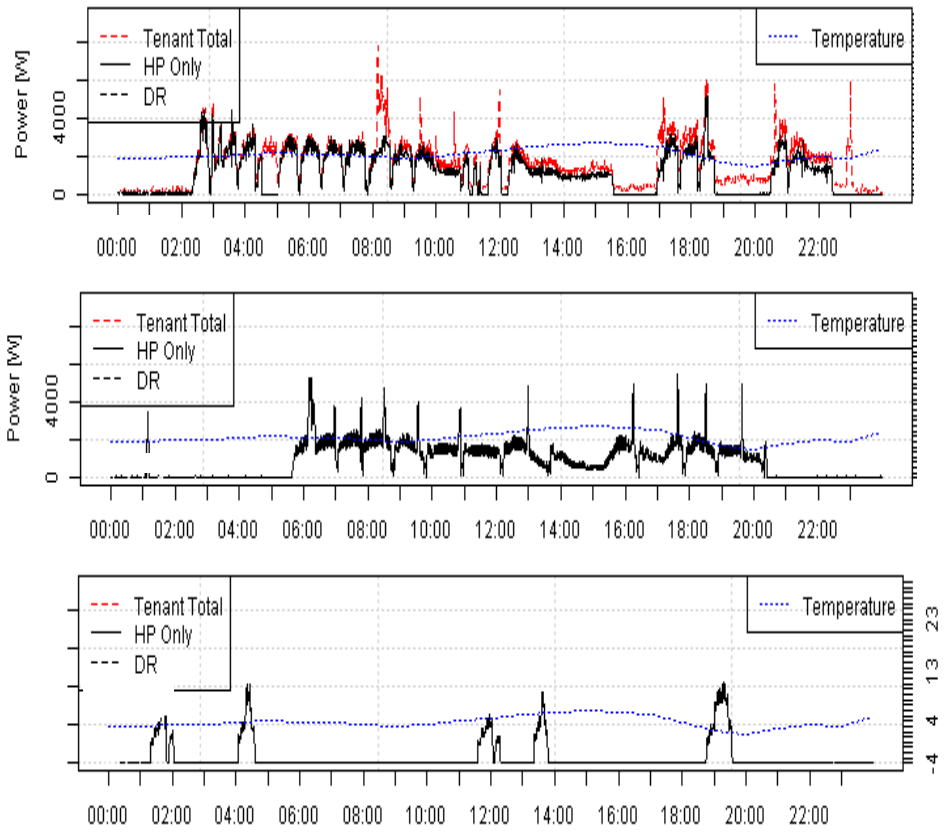
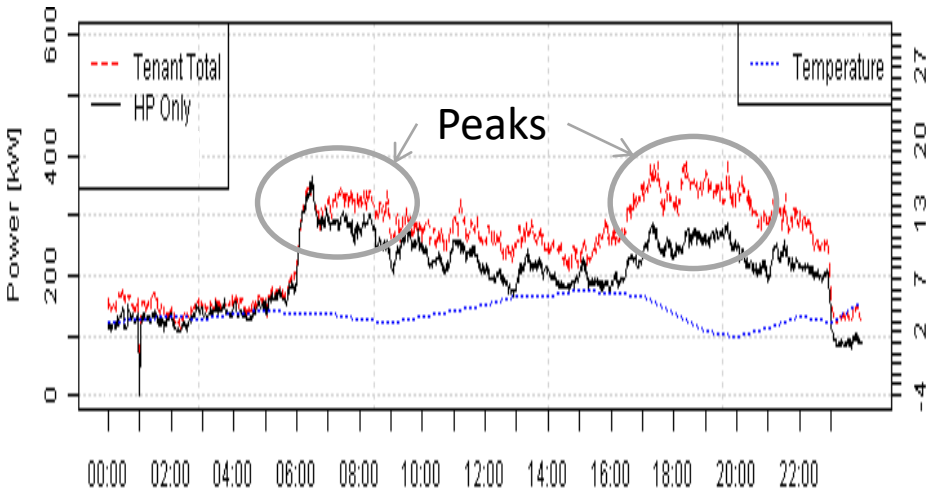
Individual Profile (9th Nov. 2016)



Aggregated Profile (9th Nov. 2016)



Num. of tenants: 372

- Individual profiles are quite different
  - Daily Habit
  - Set point of internal temperature
- Intermitted
  - Energy saving by HP local controller

- Aggregated profile shows a pattern
  - two peaks in morning and evening
- HP power consumption uplifts total

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1. HP power consumption
External temperature is a major factor

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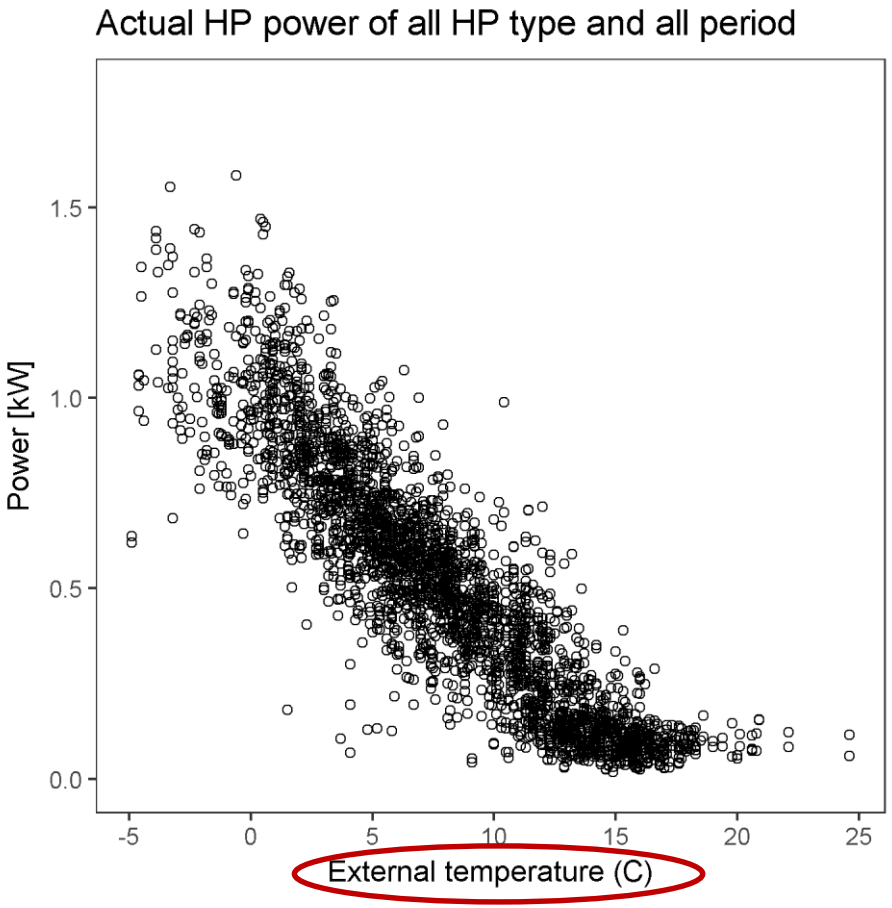
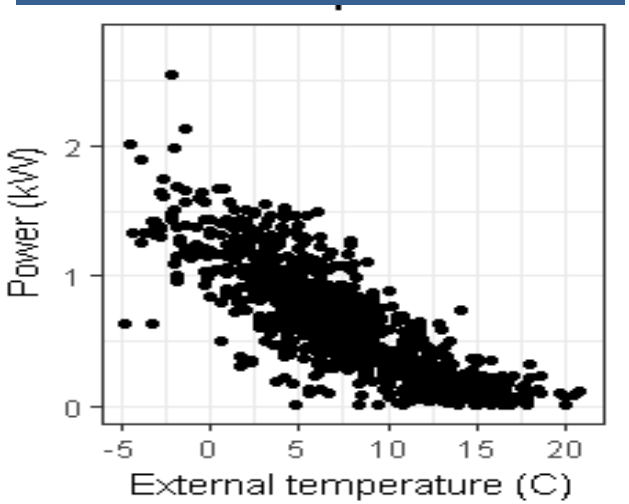
All HP type combined

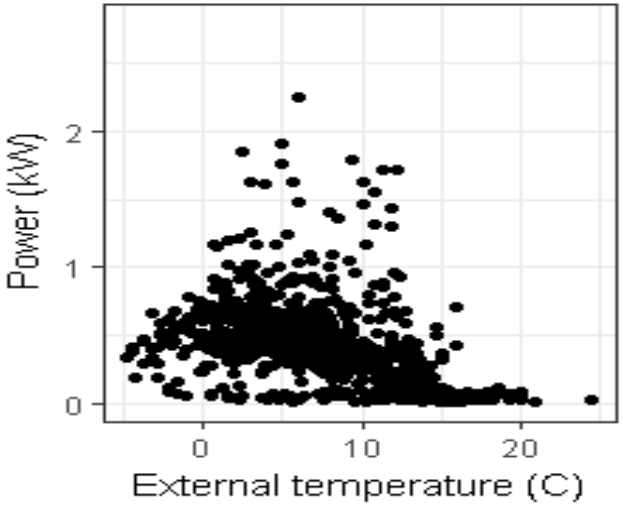


- External temperature is a major factor of HP power consumption

Electric HP



Gas Hybrid HP



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1. HP power consumption
Developed an estimation model with mix of HP types

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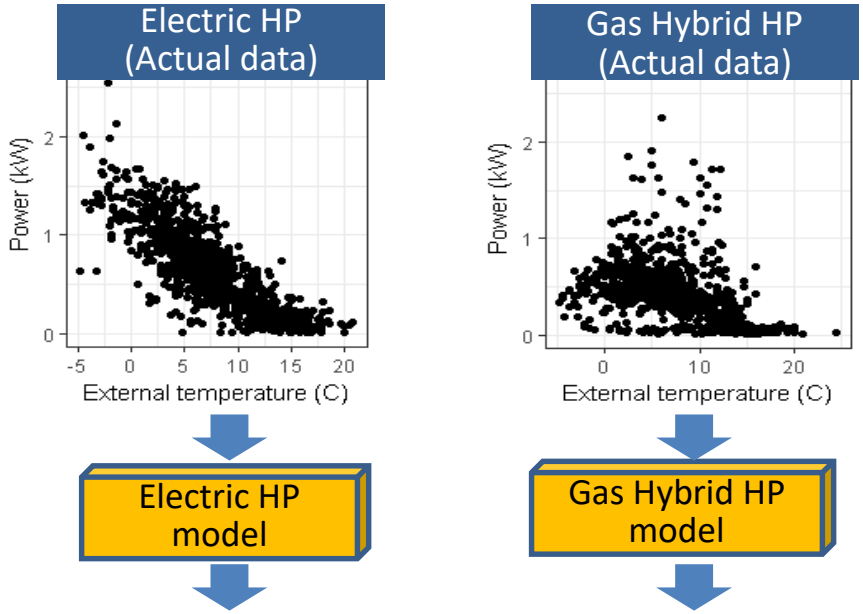
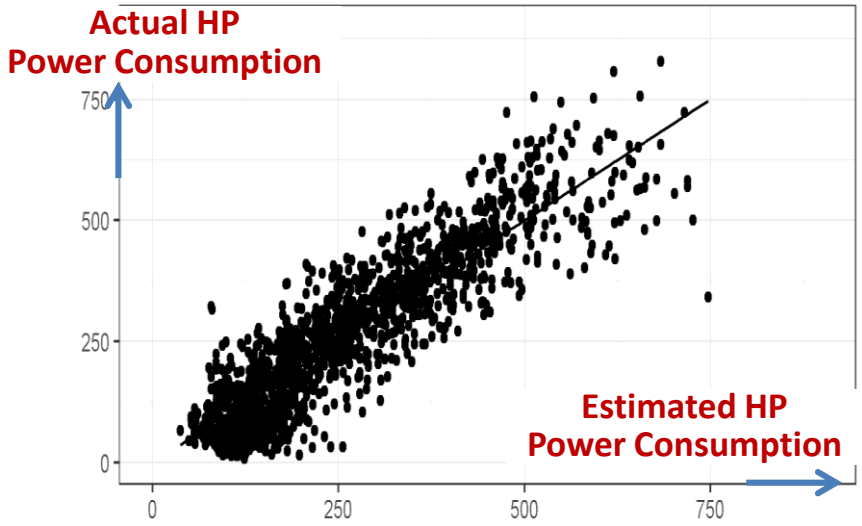


- Developed an estimation model for HP power consumption by each type
  - External temperature
  - HP power size (e.g. 4kw, 6kW, 8kW)
  - Number of HPs

Actual value vs Estimated value (550 HPs)



- Strong relation was observed between estimated values and actual values
  - X axis: Estimated values by the model supposing 550 tenants
  - Y axis: Actual HP power values adjusted to 550 tenants

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2. Demand Response Results
Three parameters of DR

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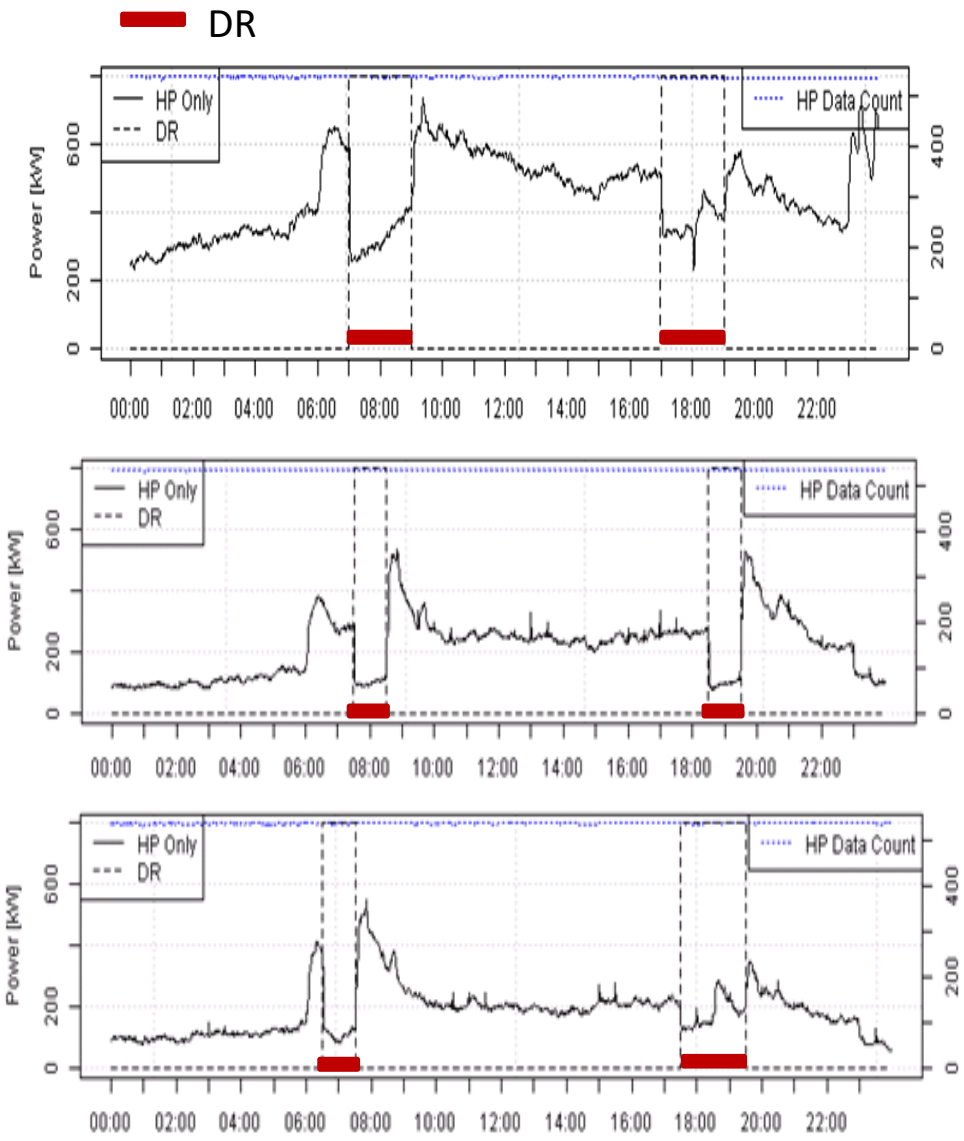
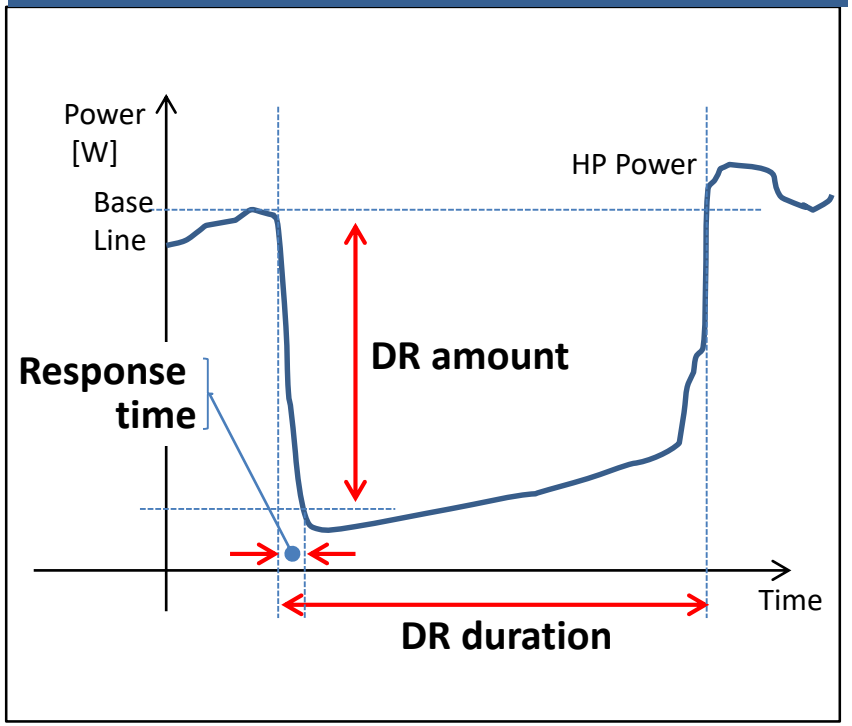
Examples of DR Profile (Aggregated)



DR Trials

Num. of target housing	4 – 550 housing
Period	18 month (Oct. 2015 –Mar.2017)
Total DR trial times	~ 360

DR Parameters



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2. Demand Response Results
Response time

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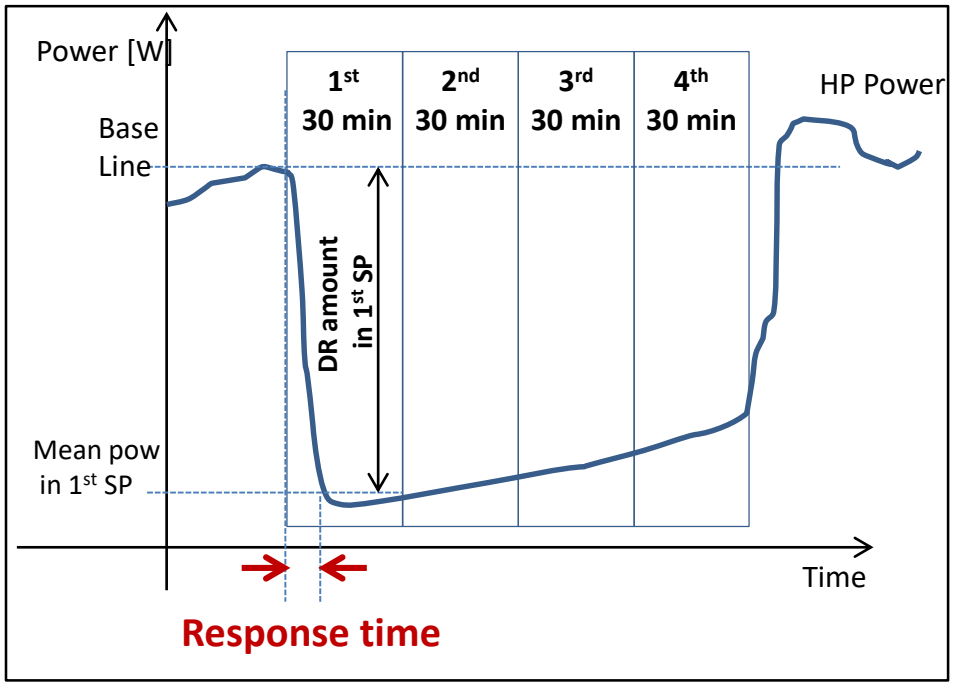
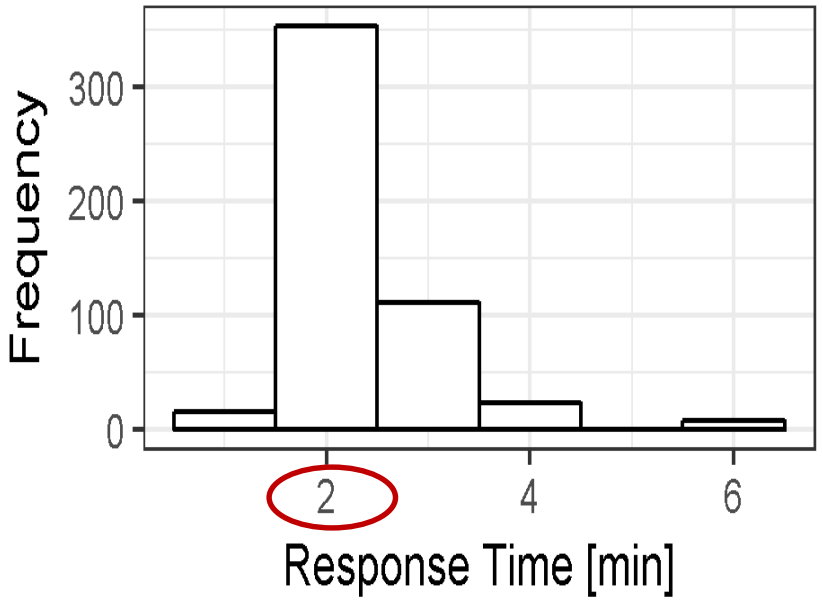
Definition of Response time



- Response time is;

  Time between DR start time and time HP power first reaches the average of the first settlement period

Histogram of Response time



Median	Average	Standard deviation	Maximum
2 min	2.3 min	0.75	6 min

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2. Demand Response Results
DR Duration

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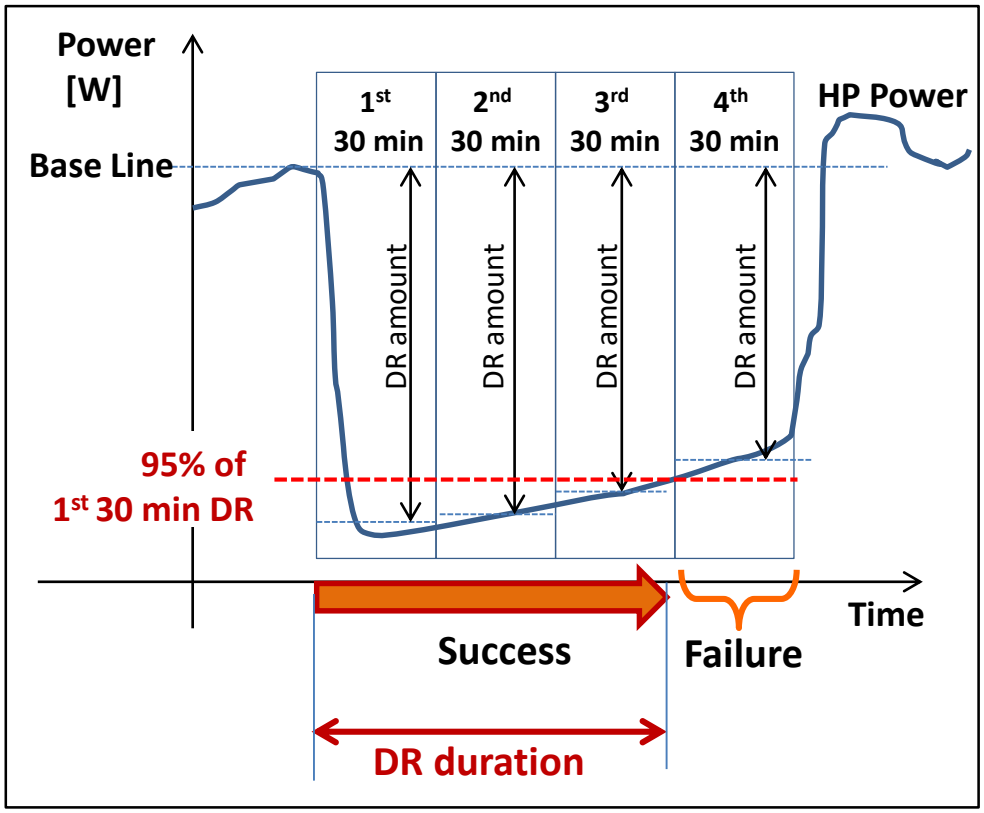
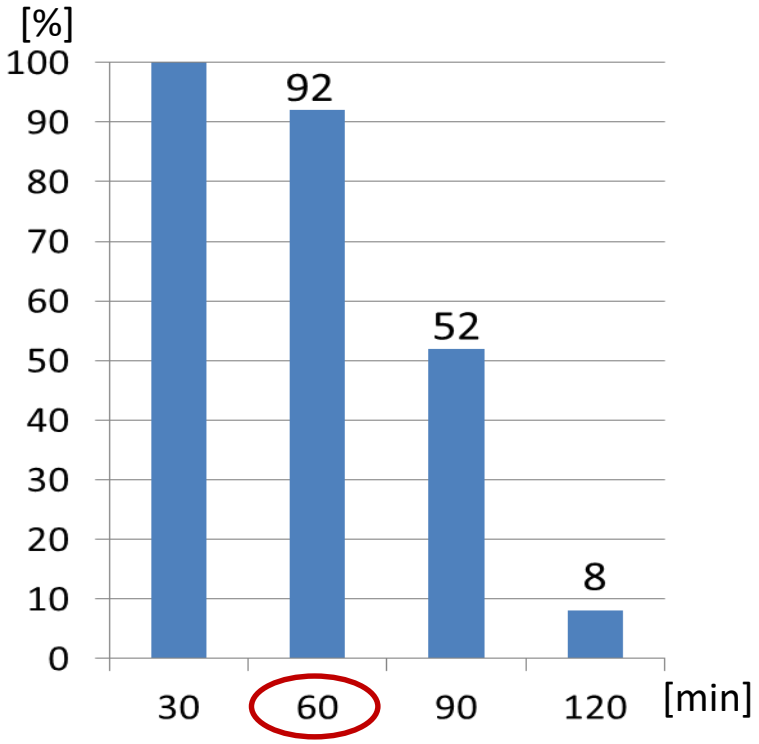
Definition of DR amount

- *Commercial Rule of "Flexitiricity" (UK aggregator)*
- *An example of 90 min duration DR (illustrative)*



- If DR amounts of following settlement periods keep under 95% of the first one, DR successfully continues

Success rate of DR duration



- Continuous "(auto) Opt-Out" decreases DR amount
- In the condition of the project, 60 min is relatively stable duration time

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2. Demand Response Results
DR amount

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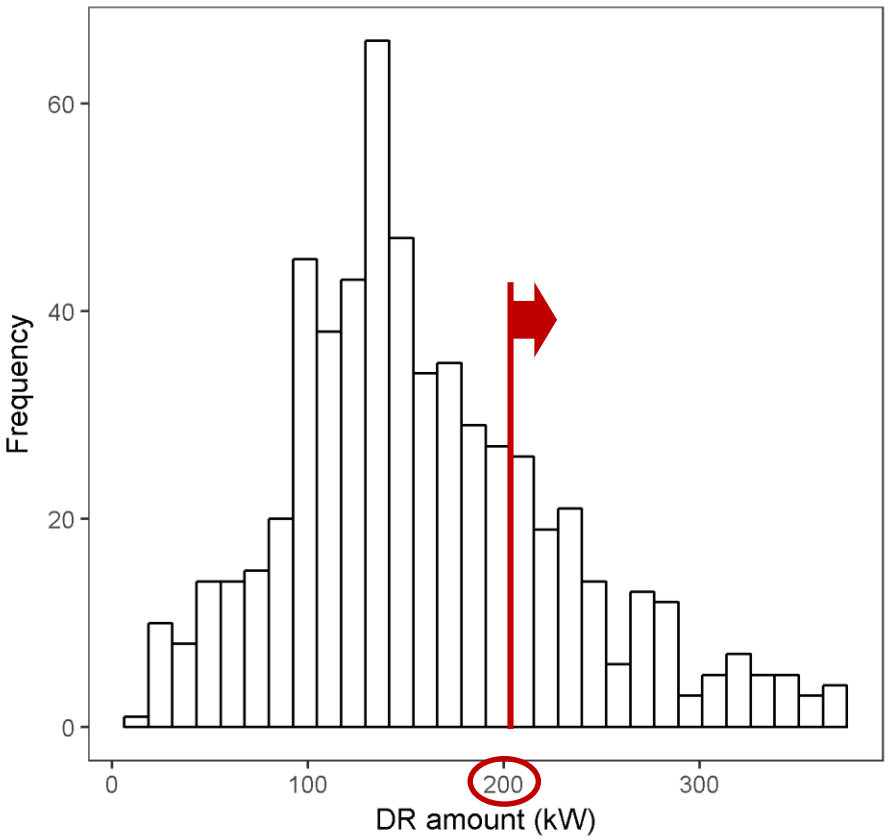
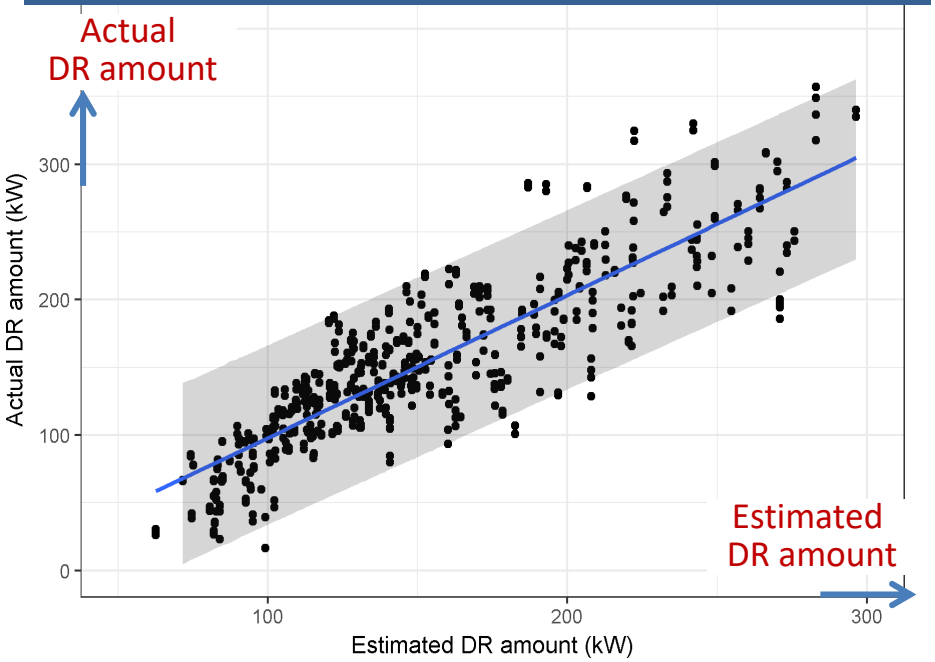
Histogram of DR amount



Target DR amount (200kW) in this project was achieved 144 times in actual values

Actual value vs Estimated value (550 HPs)



$$v = \alpha \cdot x_i + \beta \cdot y_i + \gamma \cdot z_i + \delta$$

- **Objective variable**:
  - DR amount (v)
- **Explanatory variable**:
  - HP power consumption estimation (x_i)
  - External temperature (y_i)
  - Opt Out ratio (z_i)

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2. Demand Response Results
DR amount estimation through a year

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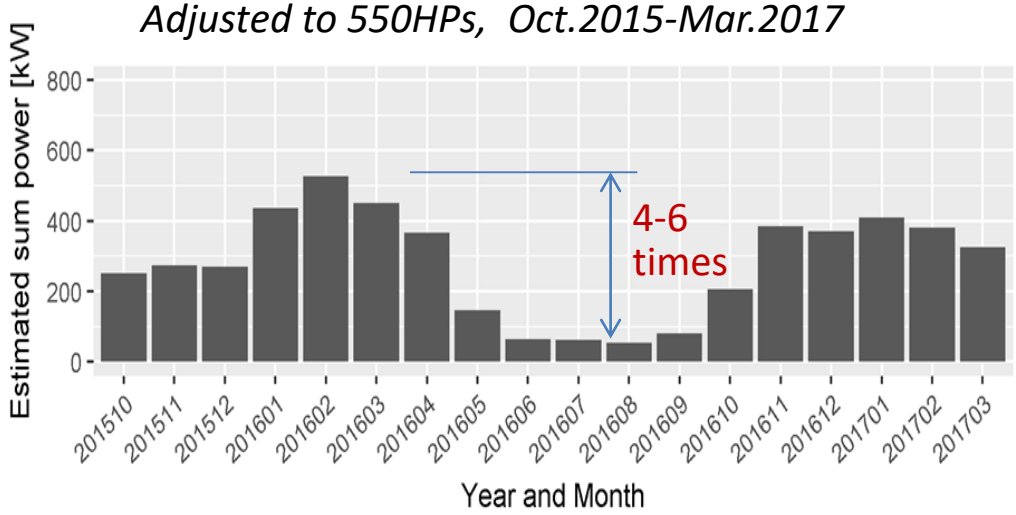
Monthly HP sum power for 3hrs (6am-9am)

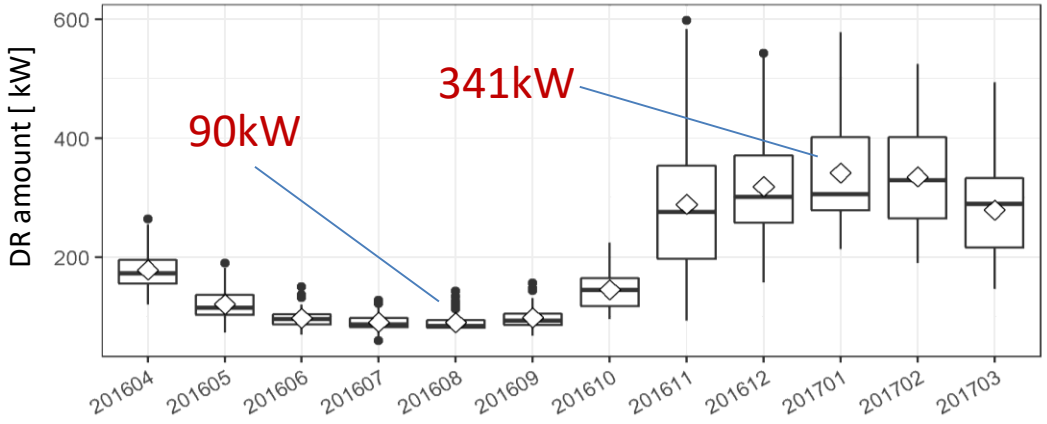
Adjusted to 550HPs, Oct.2015-Mar.2017



- Big variance of HP power through a year

Estimated DR amount

Adjusted to 550HPs, Apr.2016-Mar.2017



- DR amount is calculated with the estimation model using actual external temperature
- Maximum and minimum DR amount among monthly average ;
  - Jan. 341kW (621W/tenant)
  - Aug. 90kW (164W/tenant)

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2. Demand Response Results "Reactive Operation" of DR

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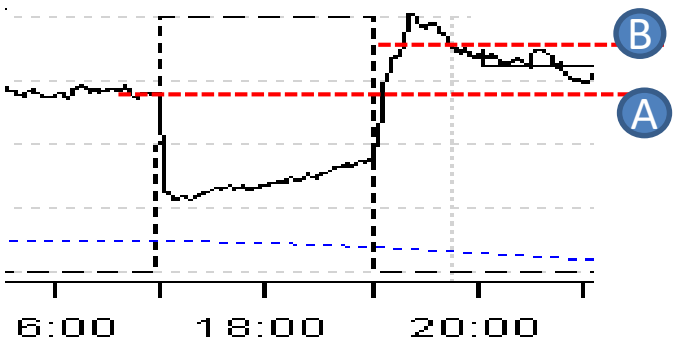
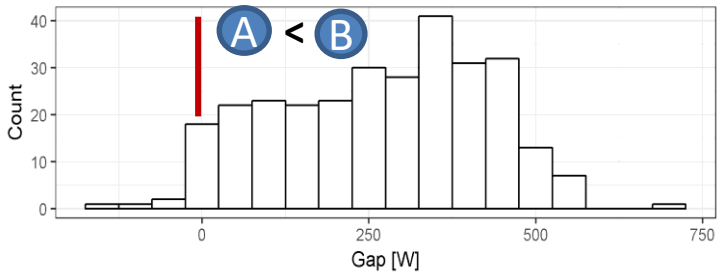
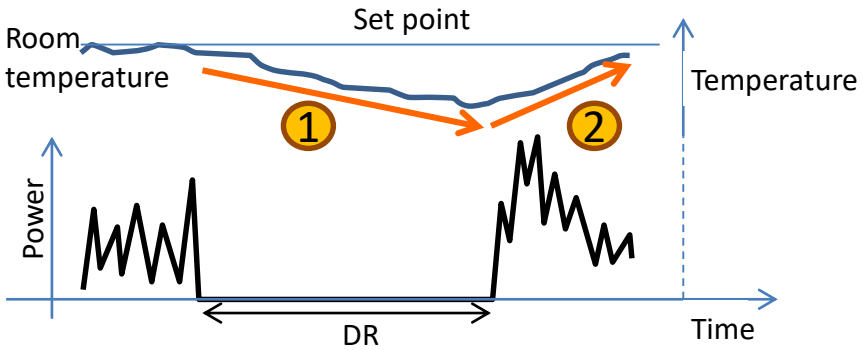
Definition of "Reactive Operation"



Histogram of gap between A and B



Mechanism of Reactive Operation



- "Reactive Operation" of DR is a phenomenon where B is higher than A
  - A : Pre 2 min mean of DR (~ baseline)
  - B : Post 30 min mean of DR

- "Reactive Operation" happened in almost all case of DR with HP

1 Temperature goes down during DR

Note: Drop of temperature is less than 2 degree (C) by "Safety Function"

2 Local controller turns up HP immediately to recover internal temperature back to the set point

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3. Tenant Acceptance
Automatic Opt-Out (Safety function) vs Manual Opt-Out

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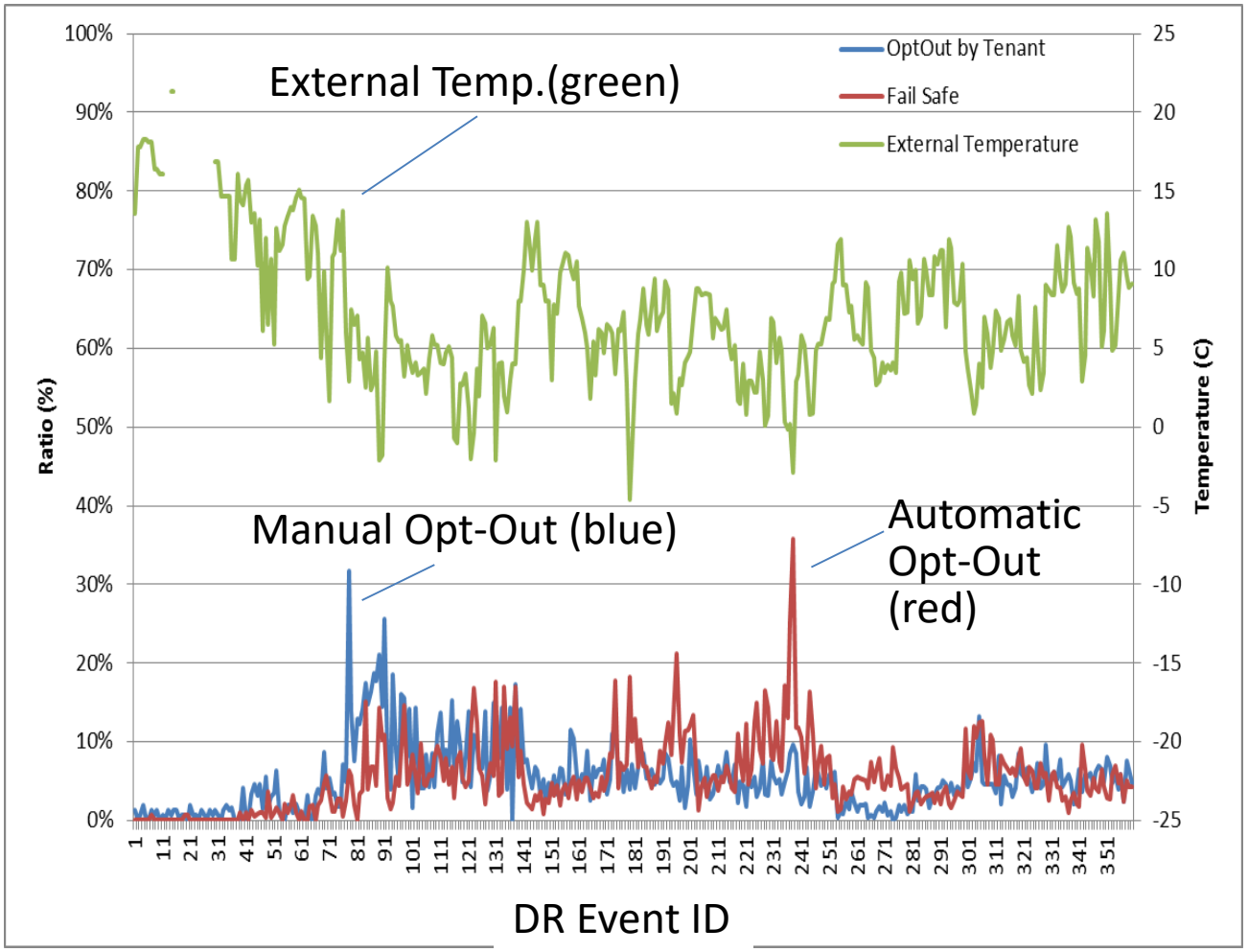
Opt-Out ratio



- Total Opt-Out (Auto + Manual) ratio
  - Ave. 10.6%
  - Standard deviation 7.3%
- Manual Opt-Out
  - Ave. 5.3%
  - Standard deviation 4.3%
- Correlation coefficient
  - Ext. Temp. vs Auto O/O -0.71 （Strong relation）
  - Ext. Temp. vs Manual O/O -0.39 （Weak relation）

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3. Tenant Acceptance
DR awareness

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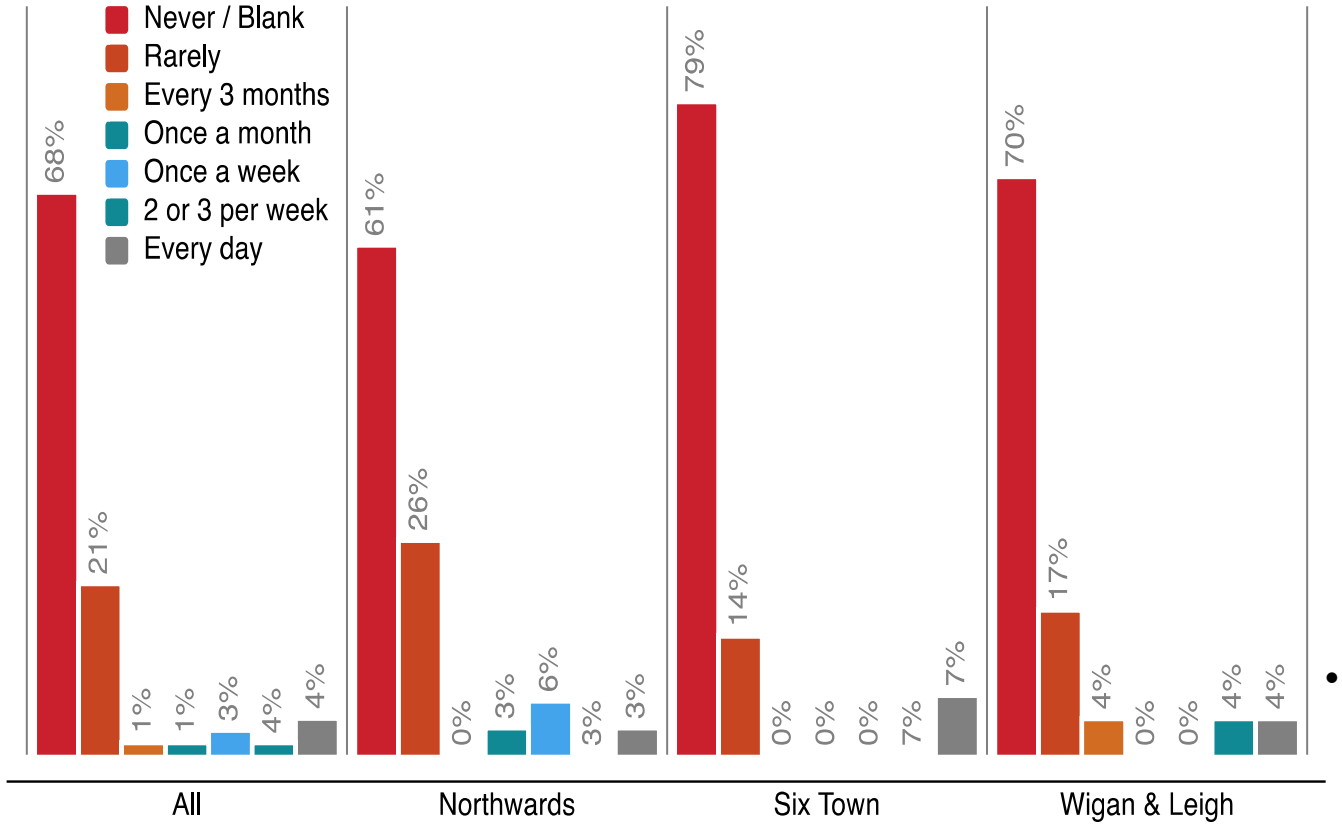
DR awareness



Ratio of tenants who didn't notice DR operation (%)

ALMO	Never, Blank, Rarely
All	89%
Northwards	87%
SixTown	93%
Wigan&Leigh	87%

- Sample size 70

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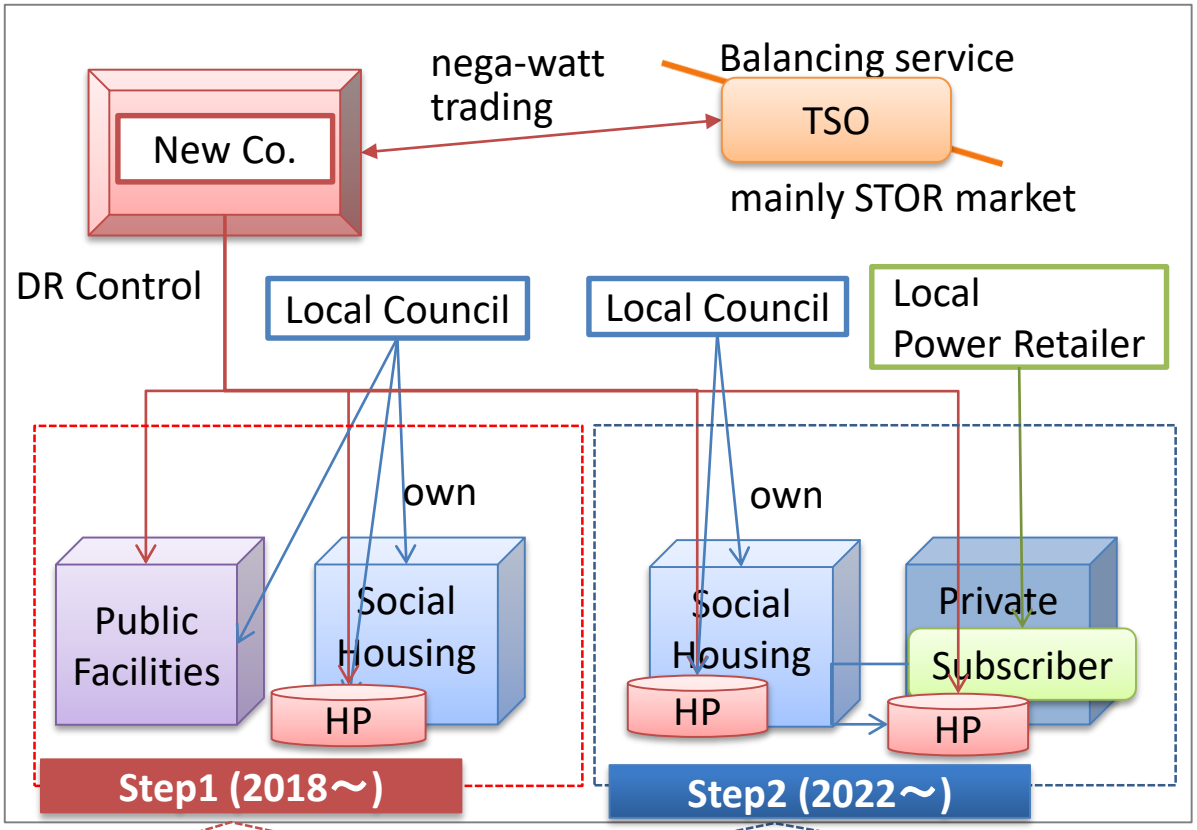
4. BUSINESS MODEL ANALYSIS

Business Model Analysis

- New Co. is a company to manage DR of HP mainly for public facilities and social housings.
- New Co. trades nega-watt aggregated from HPs as Balancing service.
- The economic evaluation of the New Co. is calculated based on measured data in the project and other assumptions.

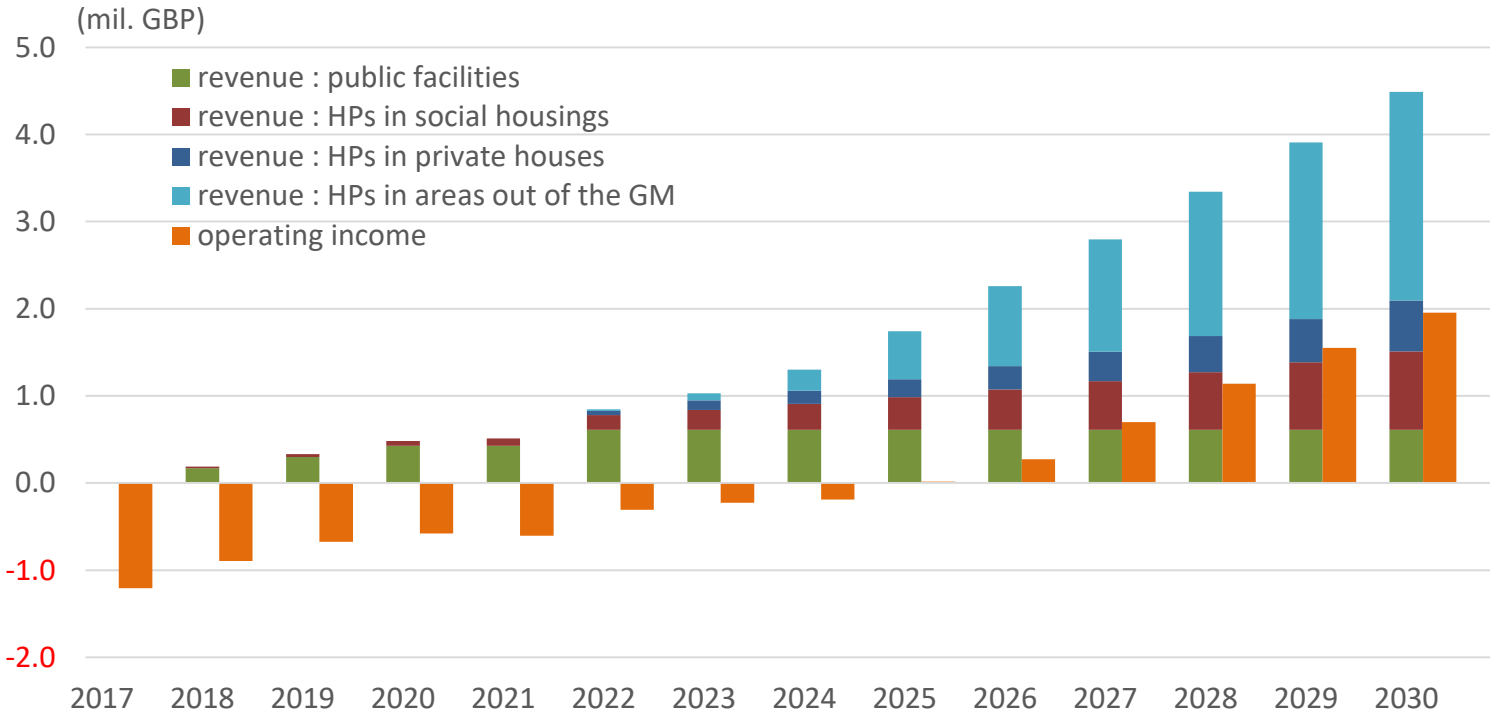


- Aggregation of assets in public facilities in GM
- Aggregation of HPs in social housings in GM

- Aggregation of HPs in private houses
- Aggregation of HPs in social housings in areas out of GM

Business Model Analysis

- To cover energy management system cost and working capital with income from Nega-watt trading, 55-60 thousands HPs are necessary to participate, which will take long term to realise.
- While DR based on HPs is a potential field, the business model that relies solely on DR based on HPs are limited. It is necessary to combine with other businesses such as ESCO business, or incorporate other DR sources to stabilize the business.



5. FUTURE WORK

Future work

- Post NEDO project started from Oct.'17
  - Data accumulation of HP power consumption for further analysis
- DERs(Distributed Energy Resources) will increase more in UK (e.g. EV, PV)
- Integrated management with HP and EV could be an interesting solution for;
  - Business model
  - Optimisation of network reinforcement

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