The 25th AIM
International Workshop

Assessing climate sensitivity of hourly electricity demand in Japan

Yuki HIRUTA, Lu GAO and Shuichi ASHINA

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National Institute for Environmental Studies
Center for Social and Environmental Systems Research

Research Associate **Yuki Hiruta**

■ Motivations

Global warming

Highly fluctuating electricity demand

- Decrease the efficiency of electricity supply system
- Increase the fossil fuel consumption

Warming urban environment in summer

- Multiple problems such as heat strokes

Urbanization

It is important to clarify the relationship
between **weather conditions**
and the **hourly electricity demand**

■ Overview

Target Areas

- **Jurisdiction of 10 <u>electric power companies</u> in Japan (EPC)**

Method over view

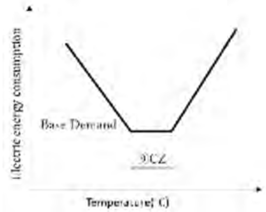
Build regression models for each EPC

Predictor
Multiple variables → Explained variable **Hourly electricity consumption**

Related to
- weather conditions
- daily cycle of human activities

Simulation

Represent the **Temperature response functions**
Based on simulation by the constructed models

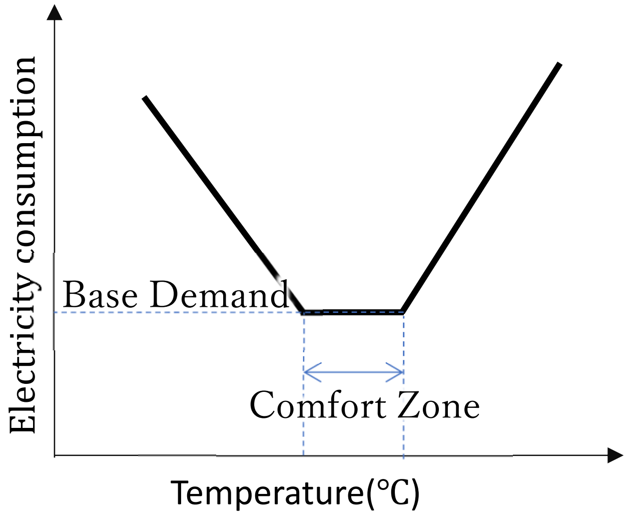


Understanding the relationship
between **weather conditions** and the **hourly electricity demand**

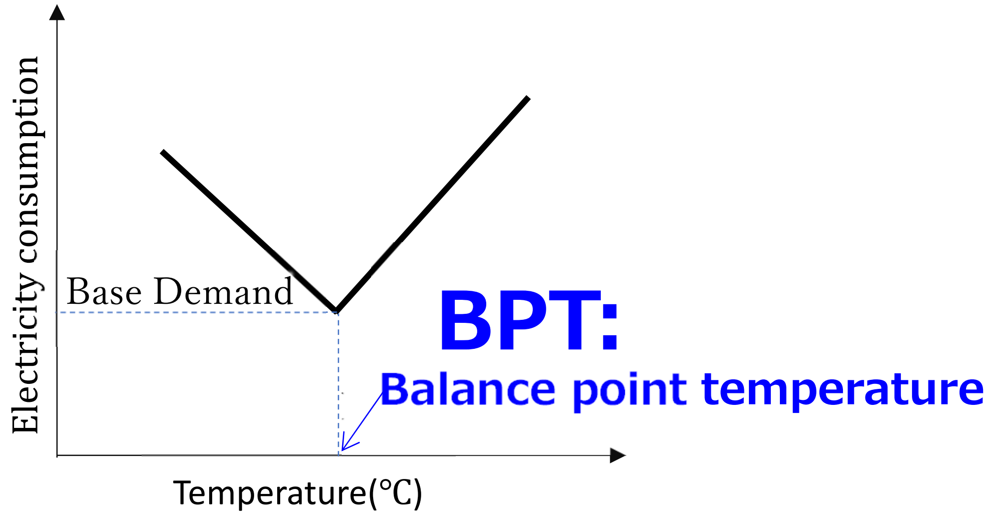
■ Temperature response function(TRFs)

*Also called Energy signature

U-shaped



V-shaped



Application:

TRFs → Basic Units

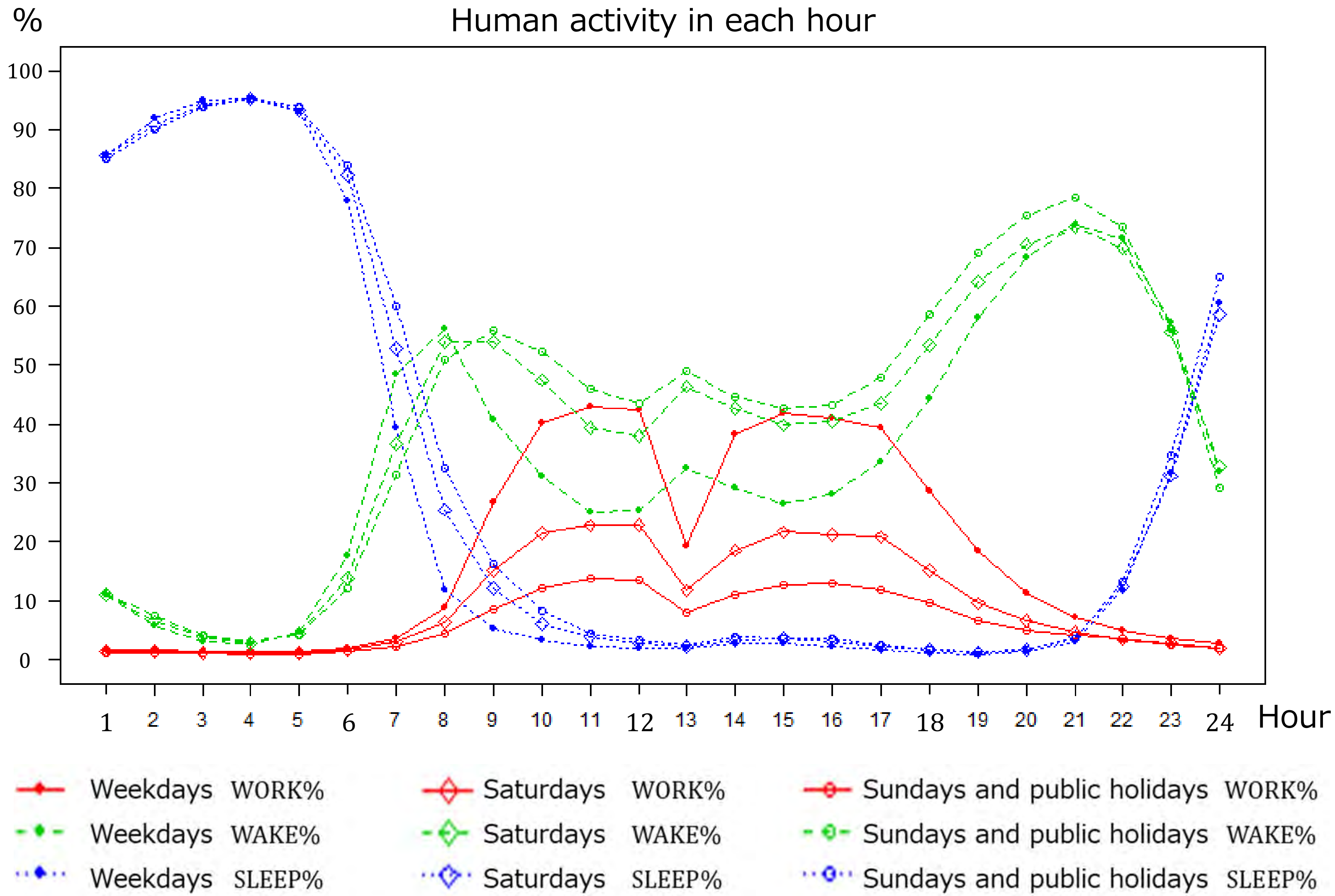
- **BPT** → **Reference temperature** for HDD/CDD
- **BPT**, Slope → Electricity demand projection

Important!
Affects assumptions of other models!

■ Data and Variables

		Names (Abbreviations)	Units	Data Description	Data Sauce
Explained Variable		**Historical electricity demand** (EC)	MWh	Hourly electricity demand in each EPC jurisdictional area.	Organization for Cross-regional Coordination of Transmission Operators Japan,
Predictors	Historical weather	**Temperature** (TEMP)	℃	Hourly averaged air temperature in FY2016 and FY2017	Japan Meteorological Agency
		Humidity (HUM)	%	Hourly averaged relative humidity in FY2016 and FY2017	
		Solar radiation (SUN)	MJ/m^2	Hourly averaged total radiation in FY2016 and FY2017	
		Wind speed (WIND)	m/s	Average wind speed in ten minutes before each hour in FY2016 and FY2017	
		Rainfall amount (RAIN)	mm	Hourly total rainfall amount in FY2016 and FY2017	
		Snow depth (SNOW)	cm	Hourly total snow depth in FY2016 and FY2017	
	Thermal index	**Discomfort Index** (DI)	–	Discomfort Index. $DI = 0.81\ (TEMP) + 0.01\ (HUM)\ (0.99\ (TEMP) - 14.3) + 46.3$	Derived from Historical Weather Data Above
		Wind Chill (WCI)	–	Wind Chill Index. $WCI = (33 - TEMP)(10.45 + 10(WIND^{0.5}) - WIND)$	
	Human activity	**Holidays and weekends dummy** (HDD)	–	Weekends, holidays, the New Year, and the Obon Festival were set as 1, and all other days were set as 0 in FY2016 and FY2017	Calendars in FY2016 and FY2017
		Working people (WORK%)	%	The percentage of people who are working at the hour.	NHK Broadcasting Culture Research Institute.
		Awake people (WAKE%)	%	The percentage of people awake in their homes at the hour.	
		Sleeping people (SLEEP%)	%	The percentage of people who are sleeping at the hour.	

■Human activity data



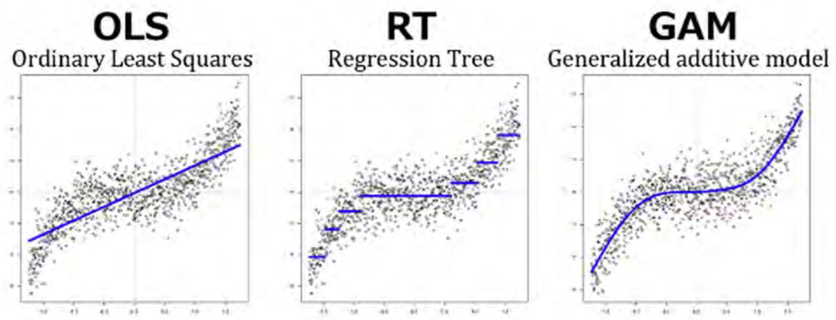
(Data source: NHK Broadcasting Culture Research Institute, 2015)

■ Model construction

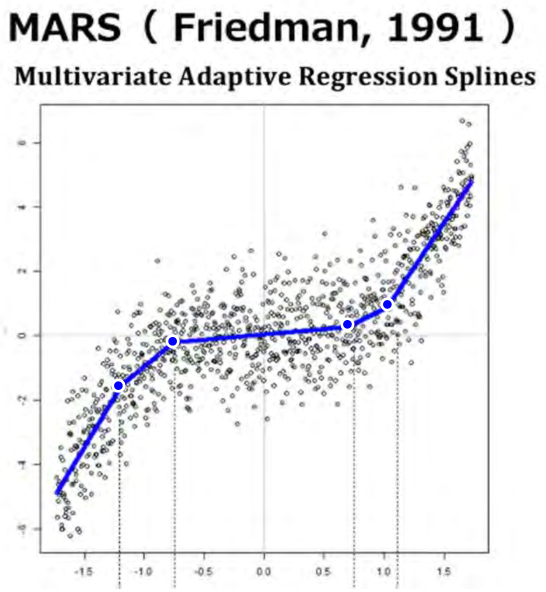
MARS : multivariate adaptive regression splines (Friedman, 1991)

- **Captures** the complexity of the potential model by applying a locally linear models.
- **Selects** important variables during the model building process.
- **Showed** excellent prediction performance in short-term power consumption modeling (Sigauke & Chikobvu, 2010; Al-Musaylh, Deo, Adamowski, & Li, 2018)

Intuitive understanding for MARS performance



Flexible and Highly generalizable modeling is expected



■ Constructed models

Performed well in all power company models.
0.870(Kyushu) ～ 0.953(Okinawa)

		Hokkaido	Tohoku	Tokyo	Chubu	Hokuriku	Kansai	Chugoku	Shikoku	Kyushu	Okinawa
R^2		0.922	0.909	0.935	0.902	0.890	0.933	0.908	0.903	0.873	0.953
generalized R^2		0.921	0.907	0.934	0.900	0.887	0.932	0.907	0.901	0.870	0.953
Number of terms		35	39	29	37	39	25	29	32	35	30
Number of predictors adopted		9	9	8	10	9	7	7	7	8	9
Number of input predictors		11	11	11	11	11	11	11	11	11	11
Adopted predictors	TEMP	○	○	○	○	○	○	○	○	○	○
	HUM	-	-	-	-	-	-	-	-	-	-
	SUN	○	○	○	○	○	○	○	○	○	○
	WIND	-	-	-	○	○	-	-	-	○	○
	RAIN	○	-	○	○	-	-	-	-	-	○
	SNOW	○	○	-	-	○	-	-	-	-	-
	DI	○	○	○	○	○	○	○	○	○	○
	WCI	-	○	-	○	-	-	-	-	-	○
	HDD	○	○	○	○	○	○	○	○	○	-
	WORK%	○	○	○	○	○	○	○	○	○	○
	WAKE%	○	○	○	○	○	○	○	○	○	○
	SLEEP%	○	○	○	○	○	○	○	○	○	○

■ Model performance

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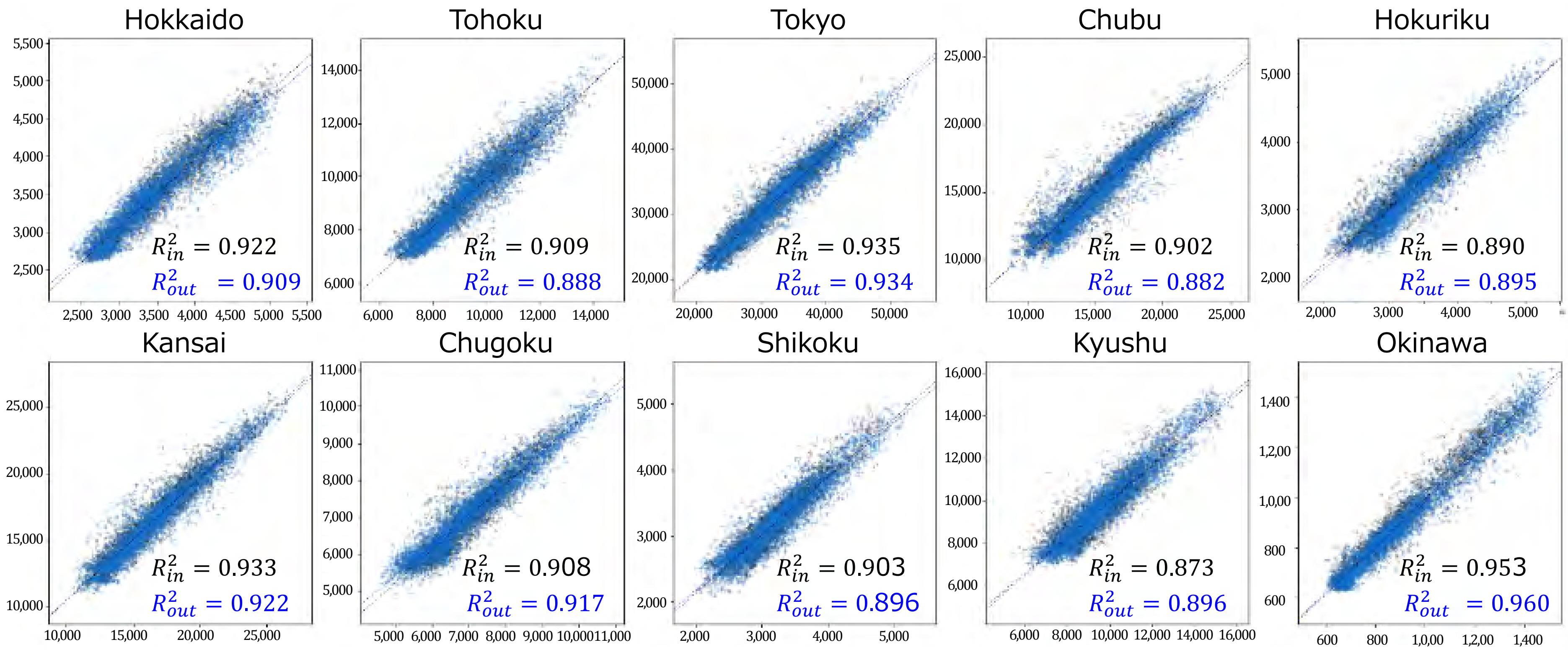
High-quality models in terms of both **fitting** and **generalization**

x-axis : Actual （MWh） y-axis : Prediction （MWh）

○ : In-sample result
+ : Out-of-sample result

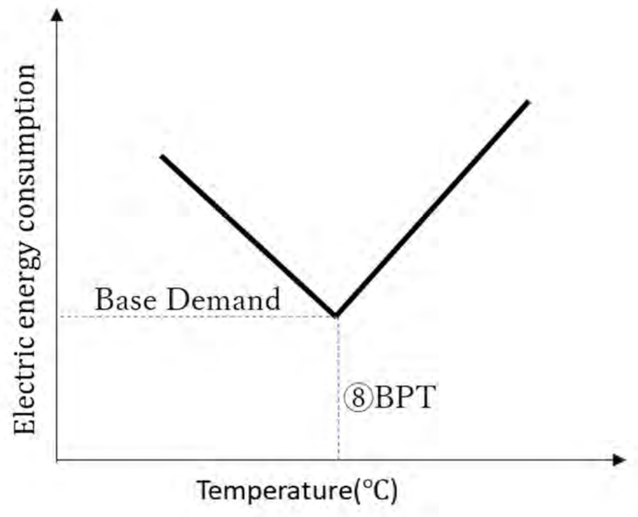
—— : OLS regression line for in-sample result
······ : OLS regression line for out-of-sample result

R^2_{in} : The coefficient of determination of OLS (in-sample)
R^2_{out} : The coefficient of determination of OLS (out-of-sample)



Observed values vs estimated values

Simulating
Temperature Response Functions



■ Hourly simulation

Settings for the simulation

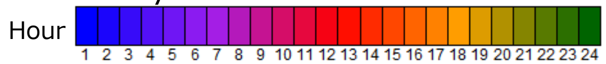
Weather predictors TEMP	Regular sequences of the value
Weather predictors HUM, SUN, WIND, RAIN, SNOW	Average values of each time period at each location in weekdays.
The thermal indicators DI, WCI	Calculated from the weather predictors .
Holiday dummy HDD	Weekdays: 0
Human activity predictors WORK%, WAKE%, SLEEP%	Values of each time period in weekdays.

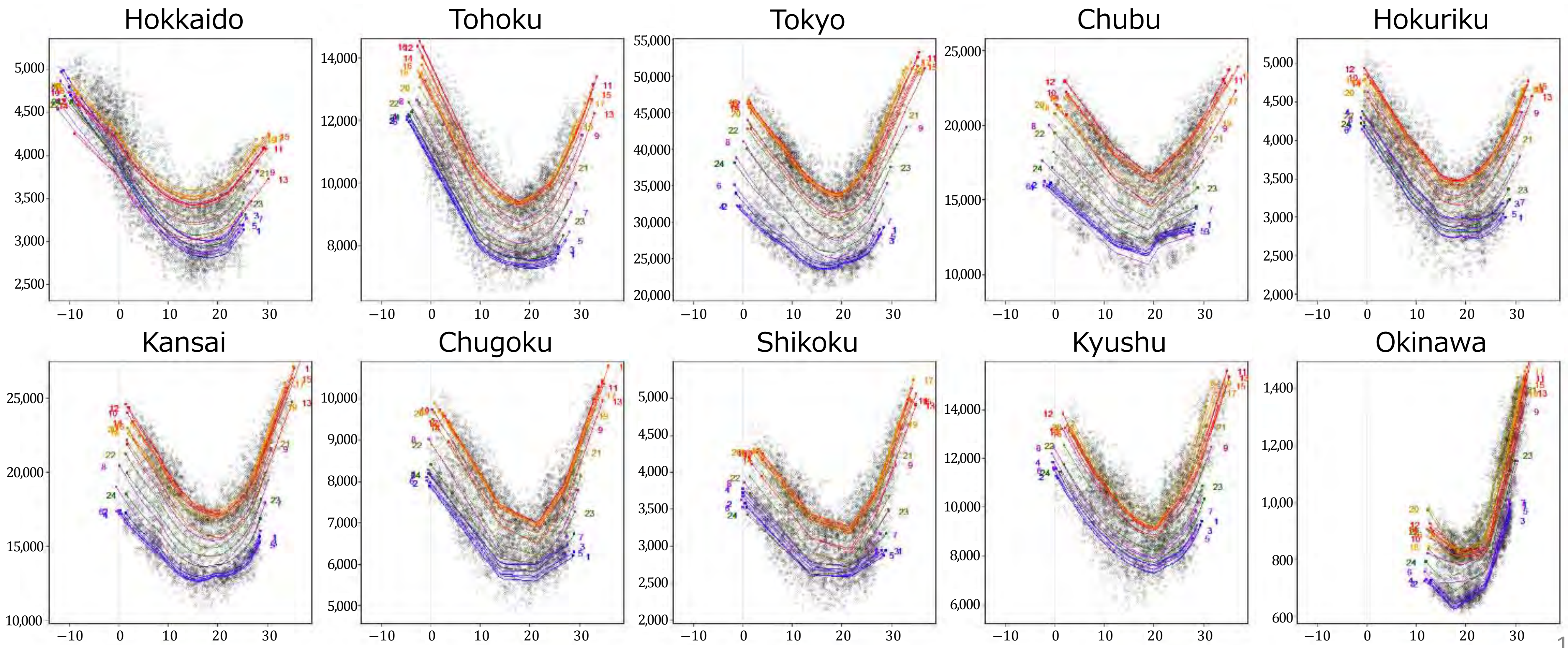
x-axis : Temperature（℃）

y-axis : Power consumption（MWh）

○ Observation

Hourly simulation





■ Simulation in day-time and night-time

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Settings for the simulation

Weather predictors TEMP	Regular sequences of the value
Weather predictors HUM, SUN, WIND, RAIN, SNOW	Average values in day-time and night-time at each location in weekdays.
The thermal indicators DI, WCI	Calculated from the weather predictors .
Holiday dummy HDD	Weekdays: 0
Human activity predictors WORK%, WAKE%, SLEEP%	Average values during day-time and night-time in weekdays.

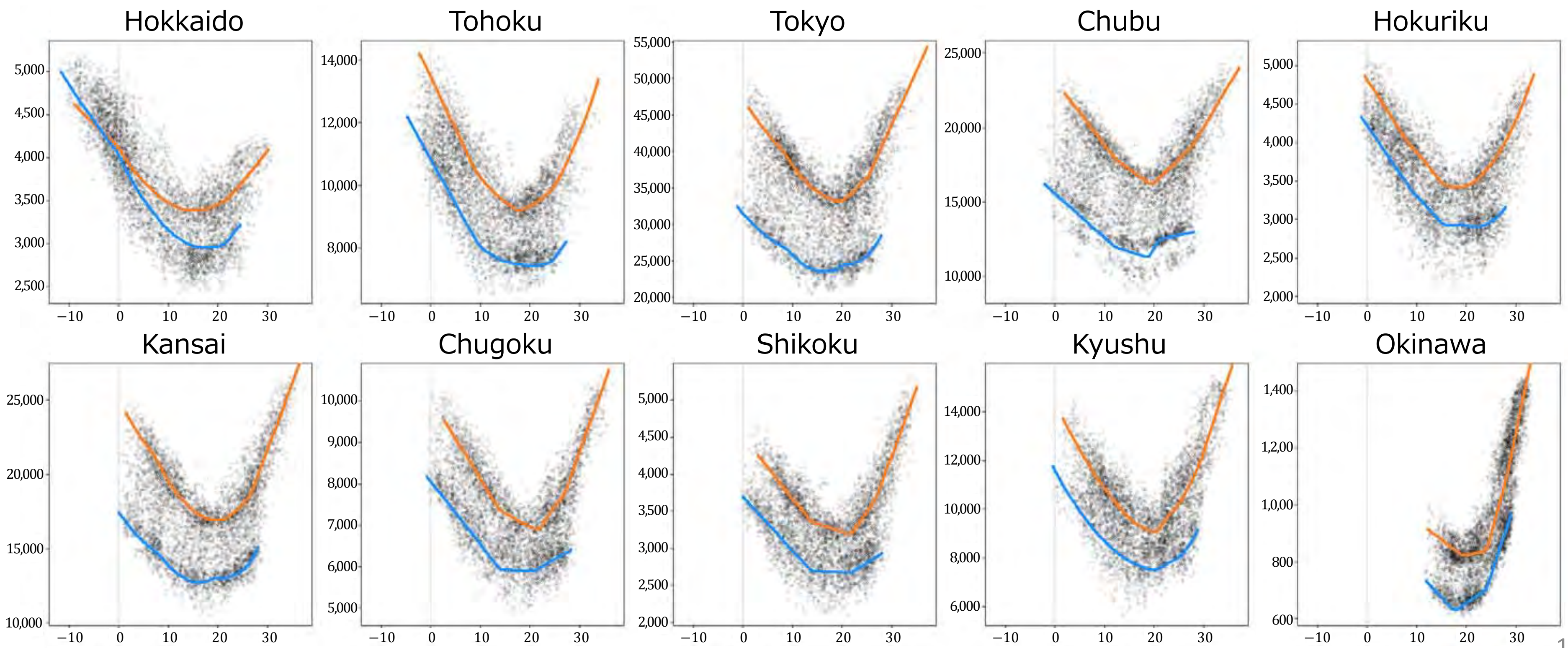
x-axis : Temperature（℃）

y-axis : Power consumption（MWh）

○ Observation

Day-time simulation (from 10:00 to 18:00)

Night-time simulation (from 1:00 to 5:00)



■ Approximation

x-axis : Temperature（℃）

y-axis : Power consumption（MWh）

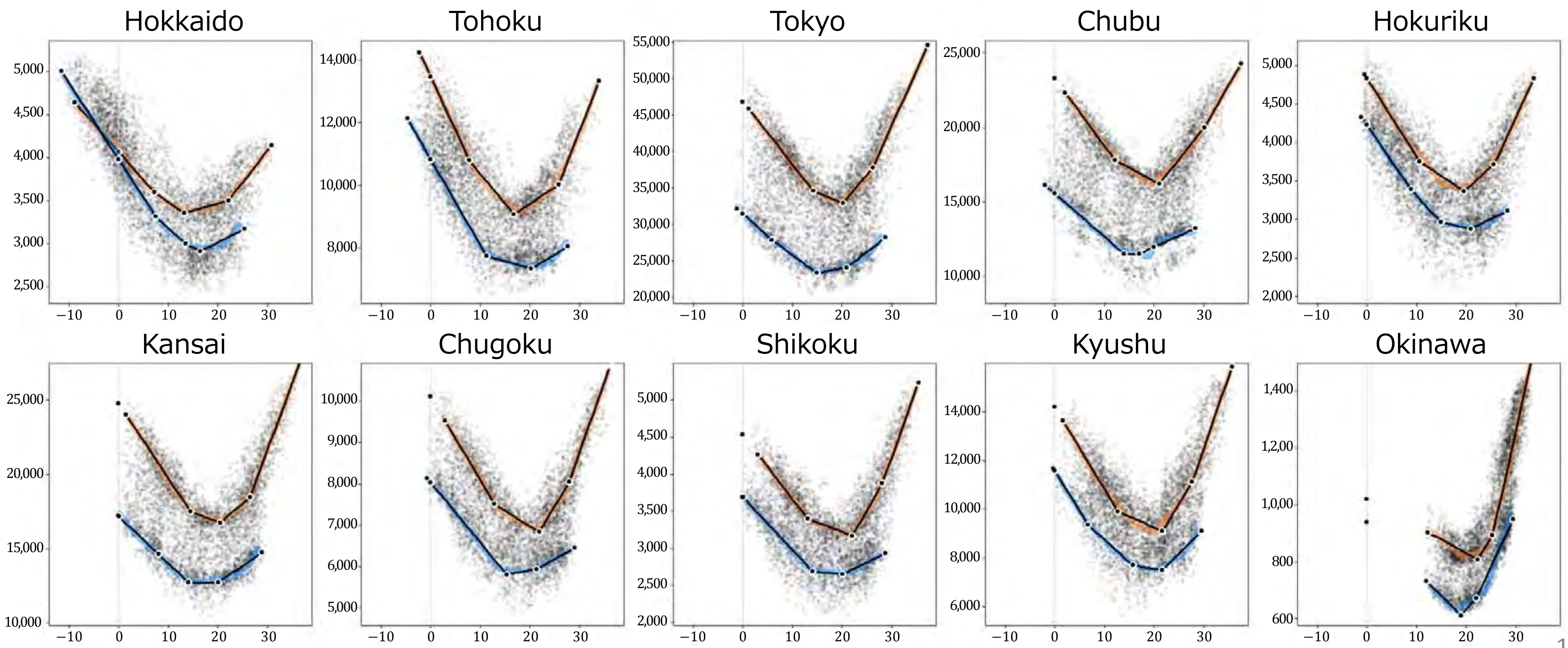
○ Observation

Day-time simulation

Night-time simulation

Approximate function ● breakpoints

"Temperature response functions" are approximated by **piecewise linear function** using MARS.



■Approximate function

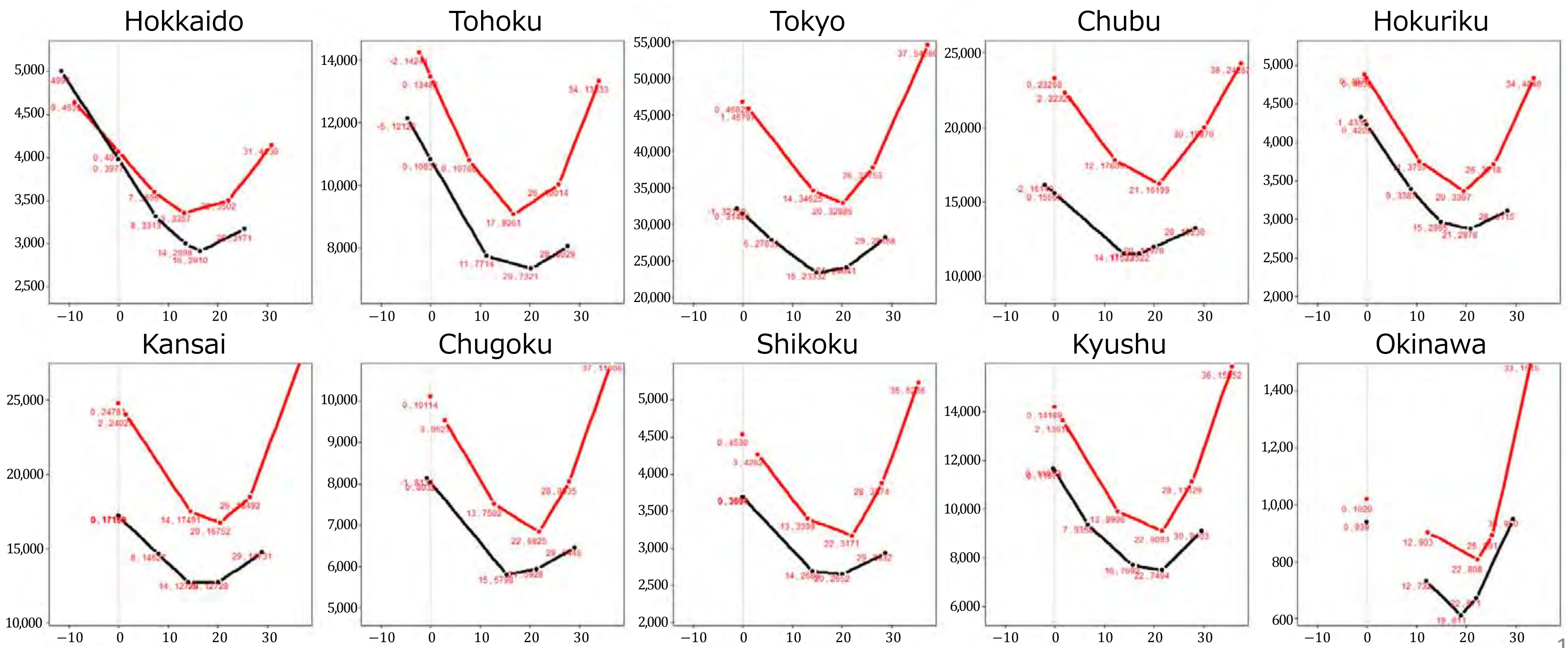
Parameters(the coordinates of breakpoints, the coefficients of each linear function)
can be obtained from the piecewise linear function

⬇

Provide the parameters to other models

x-axis : Temperature（℃）
y-axis : Power consumption（MWh）

○ Observation
Approximate function for day-time (red line)
Approximate function for night-time (black line)



■The effect of humidity on power consumption

Settings for the simulation

Weather predictors TEMP,HUM	Regular sequences of the value
Weather predictors SUN, WIND, RAIN, SNOW	Average values in day-time at each location in weekdays.
The thermal indicators DI, WCI	Calculated from the Weather predictors .
Holiday dummy HDD	Weekdays: 0
Human activity predictors WORK%, WAKE%, SLEEP%	Values for each time period in weekdays.

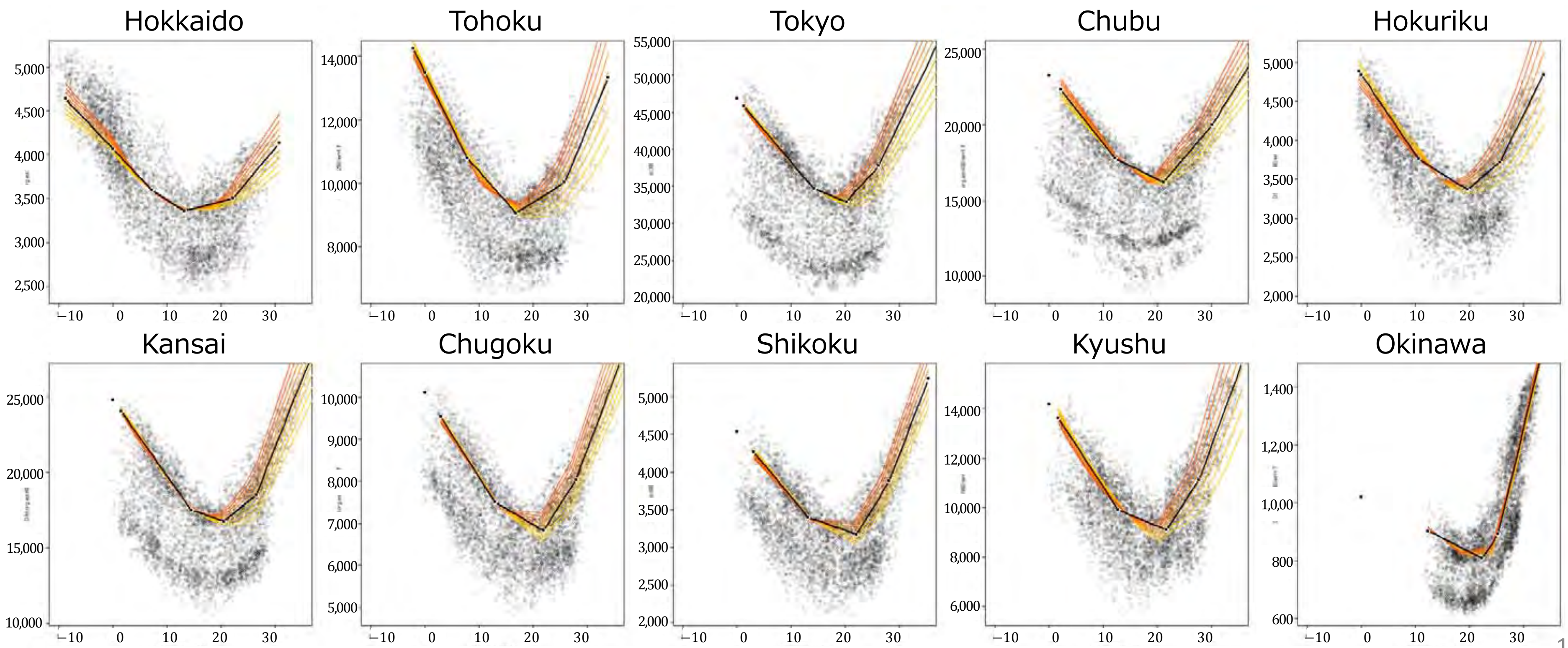
x-axis : Temperature（℃）

y-axis : Power consumption（MWh）

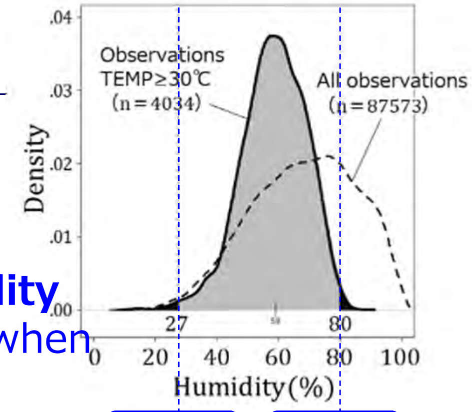
○ Observation

Relative humidity

10 20 30 40 50 60 70 80 90 100 %



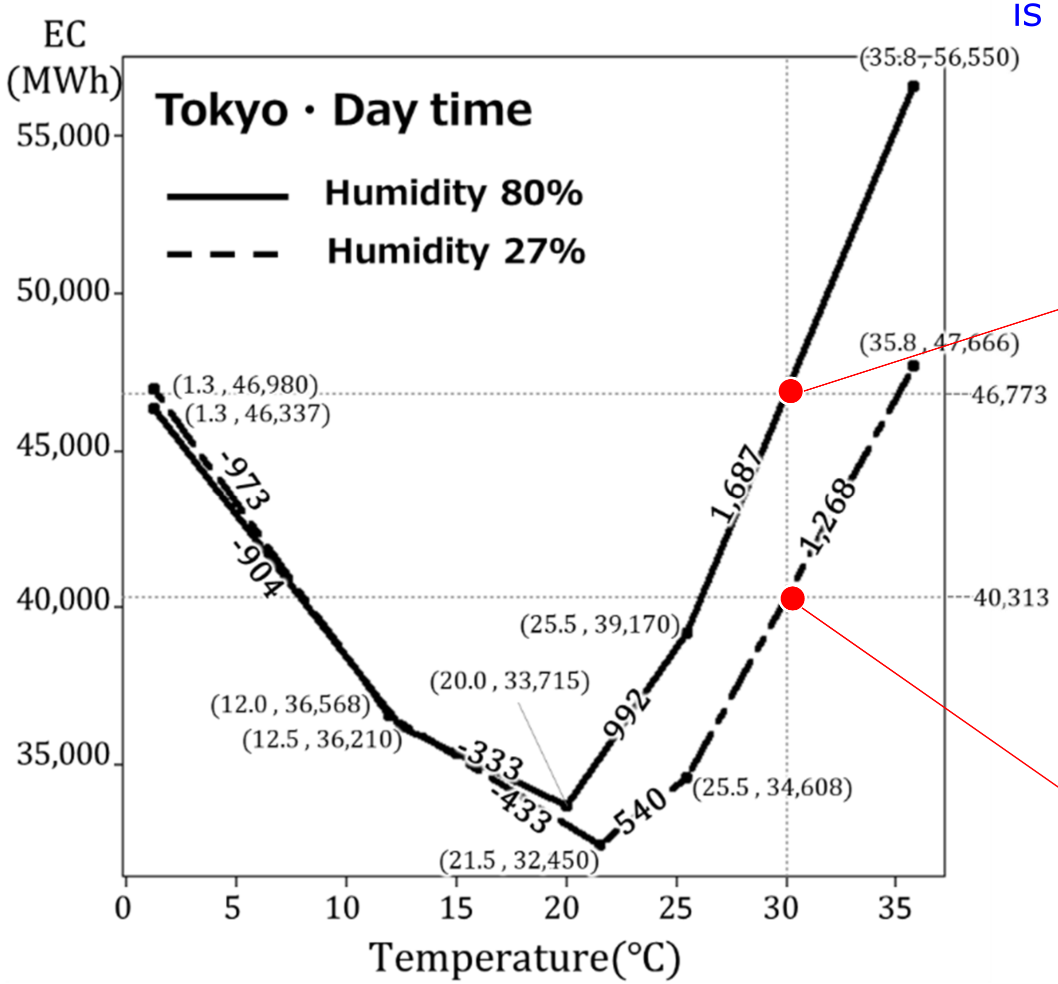
■The effects of humidity in detail



An actual **humidity range** in Tokyo when the temperature is higher than 30℃

27%　80%

A simulation for Tokyo in daytime as an example



Temperature 30℃
Humidity **80%**

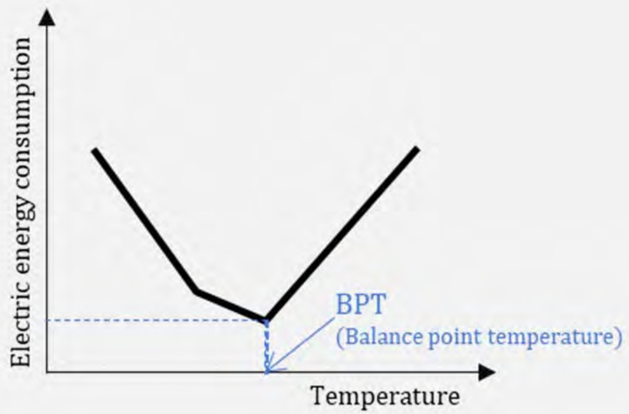
Power consumption reduced **by 13.8%.**

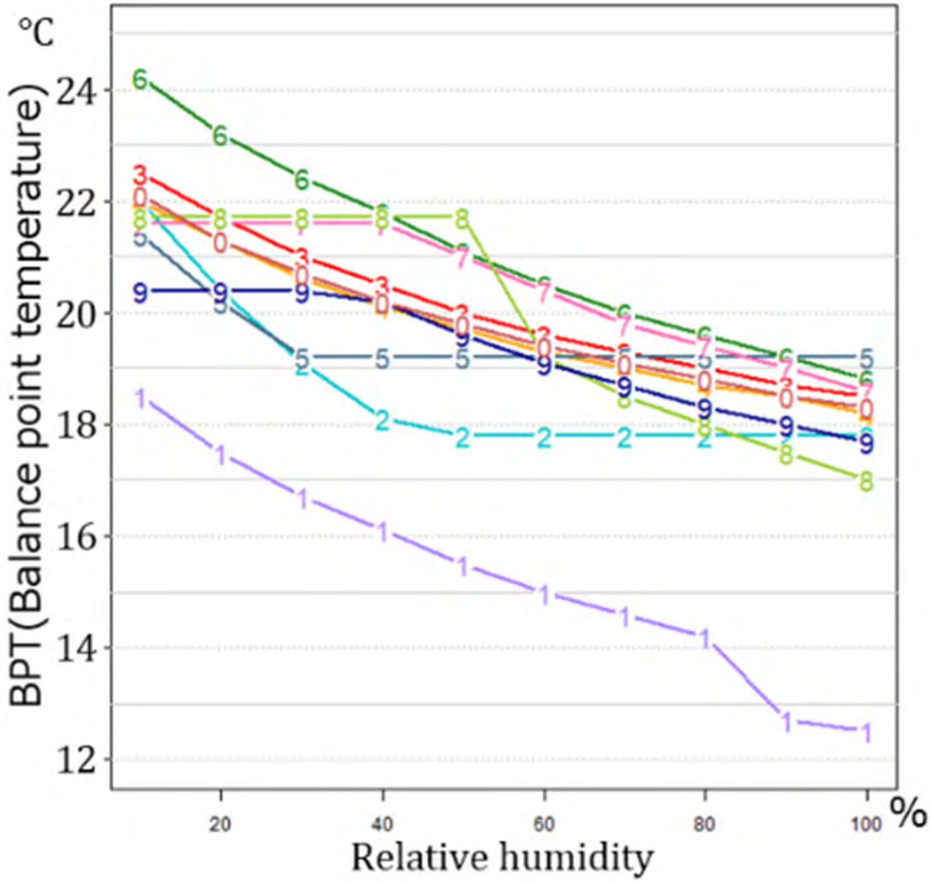
Temperature 30℃
Humidity **27%**

■ BPT(Balance point temperature)

BPT(Balance point temperature)

The bottom of the V-shaped temperature response function (Amato et al. 2005)





BPT decrease as humidity rises

:Under the conditions wherein the **humidity is high**, the power consumption for cooling **begins to increase at lower temperatures**.

■ Summary

we proposed a series of methods to understand the relationship between **weather conditions** and the **hourly electricity demand**

Summarized results

- The constructed models are of high-quality in terms of **1)fitting**, **2)generalization capability**, and 3**) simulating accurate temperature response functions**
- **Two different Temperature Response Functions** were identified in a day; for day-time (from 10:00 to 18:00) and for night-time (from 1:00 to 5:00).
- **Humidity affects electricity consumption significantly** when temperature is high
- Under the condition wherein the humidity is high, the power consumption for cooling begins to increase at lower temperatures.

Suggestions

- **The proposed method is recommended for identifying temperature response functions; especially the consideration of multiple factors are important.**
- **The effect of humidity should not be ignored.**

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Thank you

I always welcome your critical comments, suggestions, and corrections.