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9th International Conference on Urban Climate

12th Symposium on the Urban Environment

UDC6: Energy demand at city scale

@ Toulouse, France

**Sensitivity of electricity consumption to
air temperature, air humidity and solar radiation
in city-block scale
— Based on 2013 Osaka city observation —**

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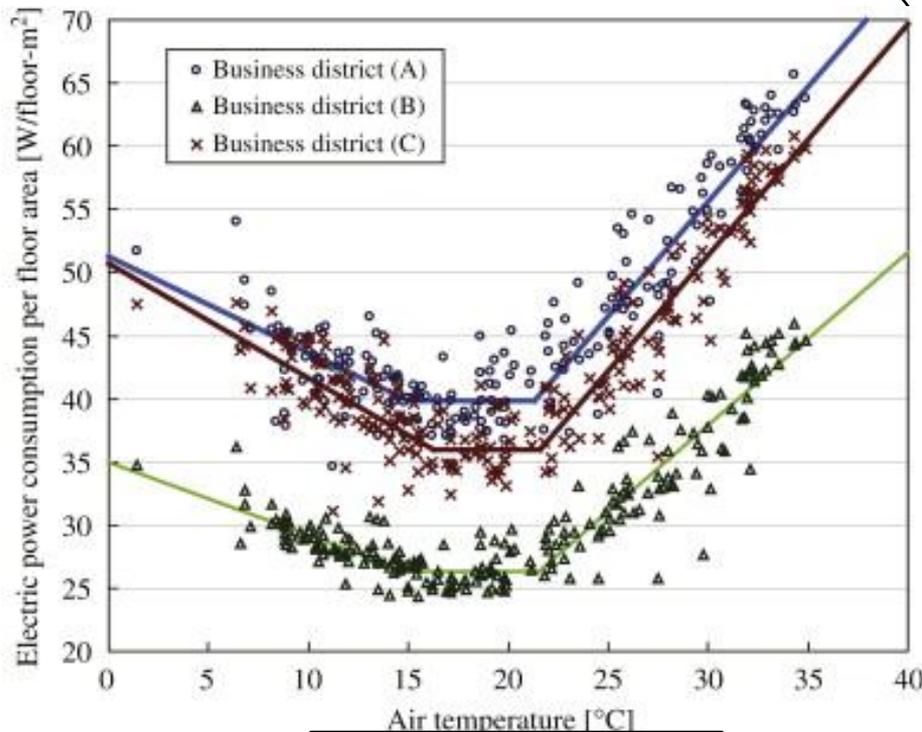
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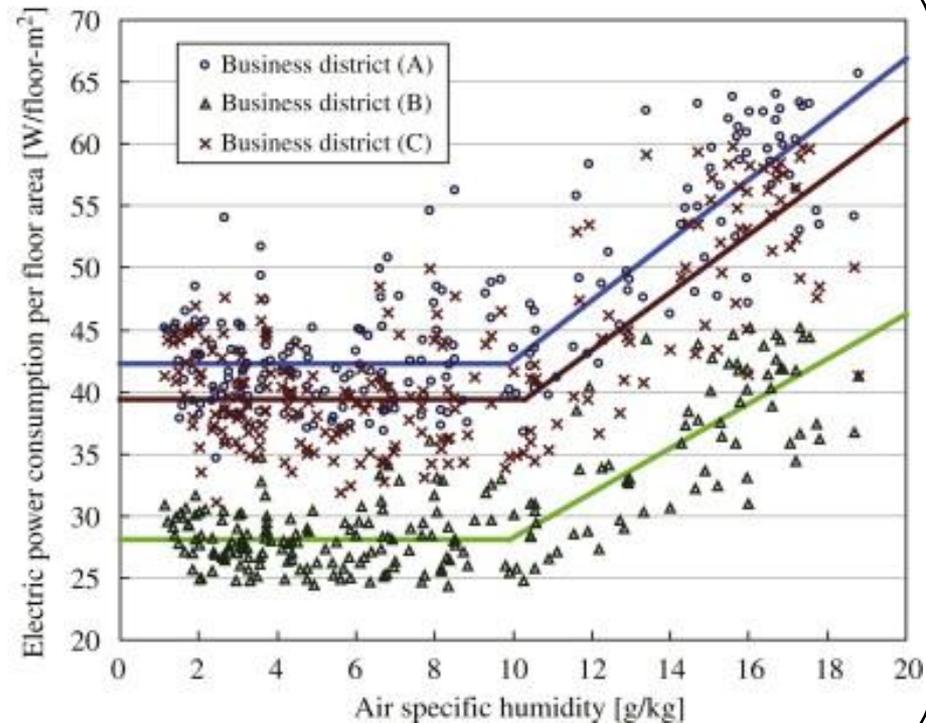
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Relationship between electricity consumption and meteorological factors.

Variation of the meteorological elements affects electricity consumption.



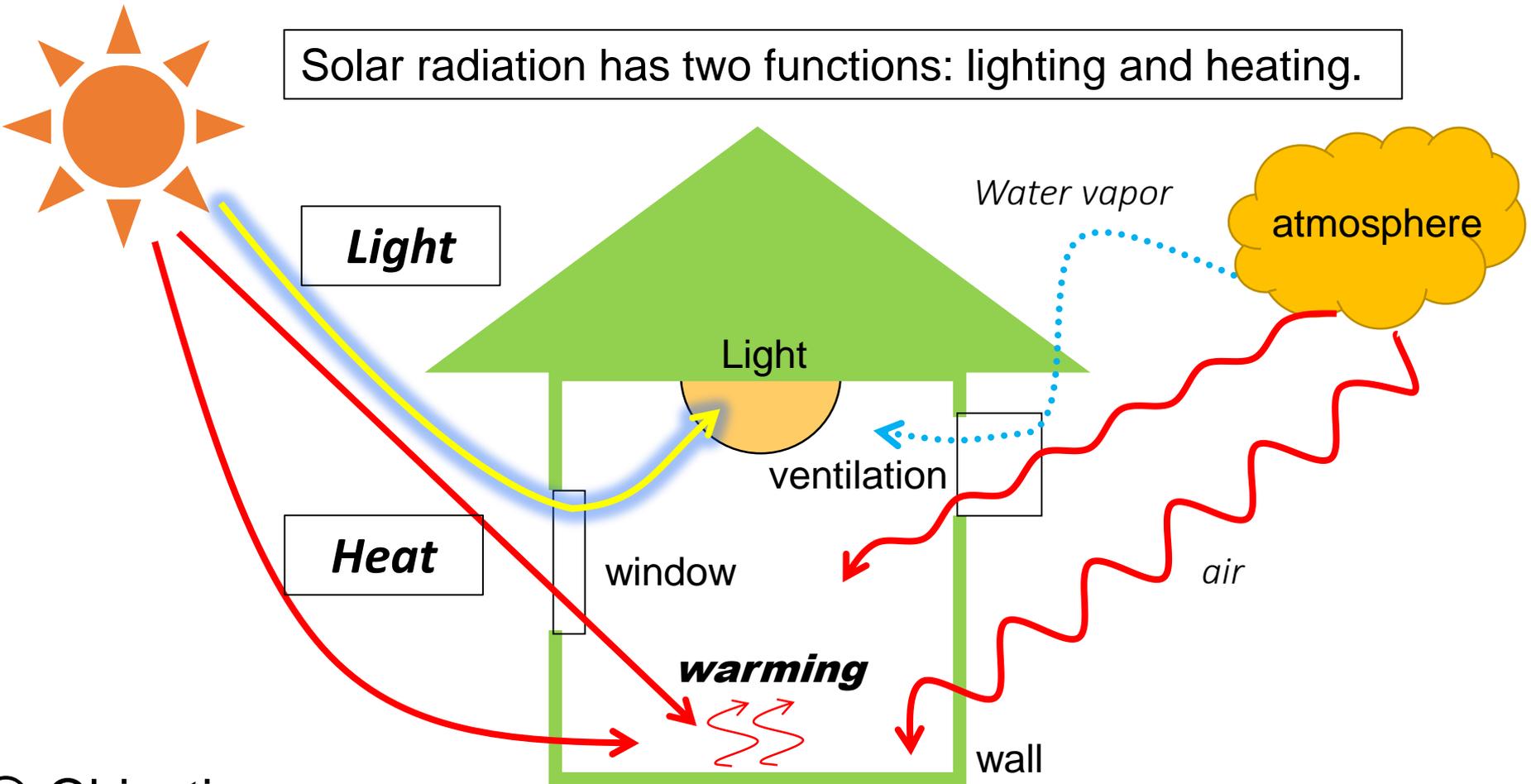
Air temperature



Air humidity

→ *Solar radiation also influences electricity consumption!*

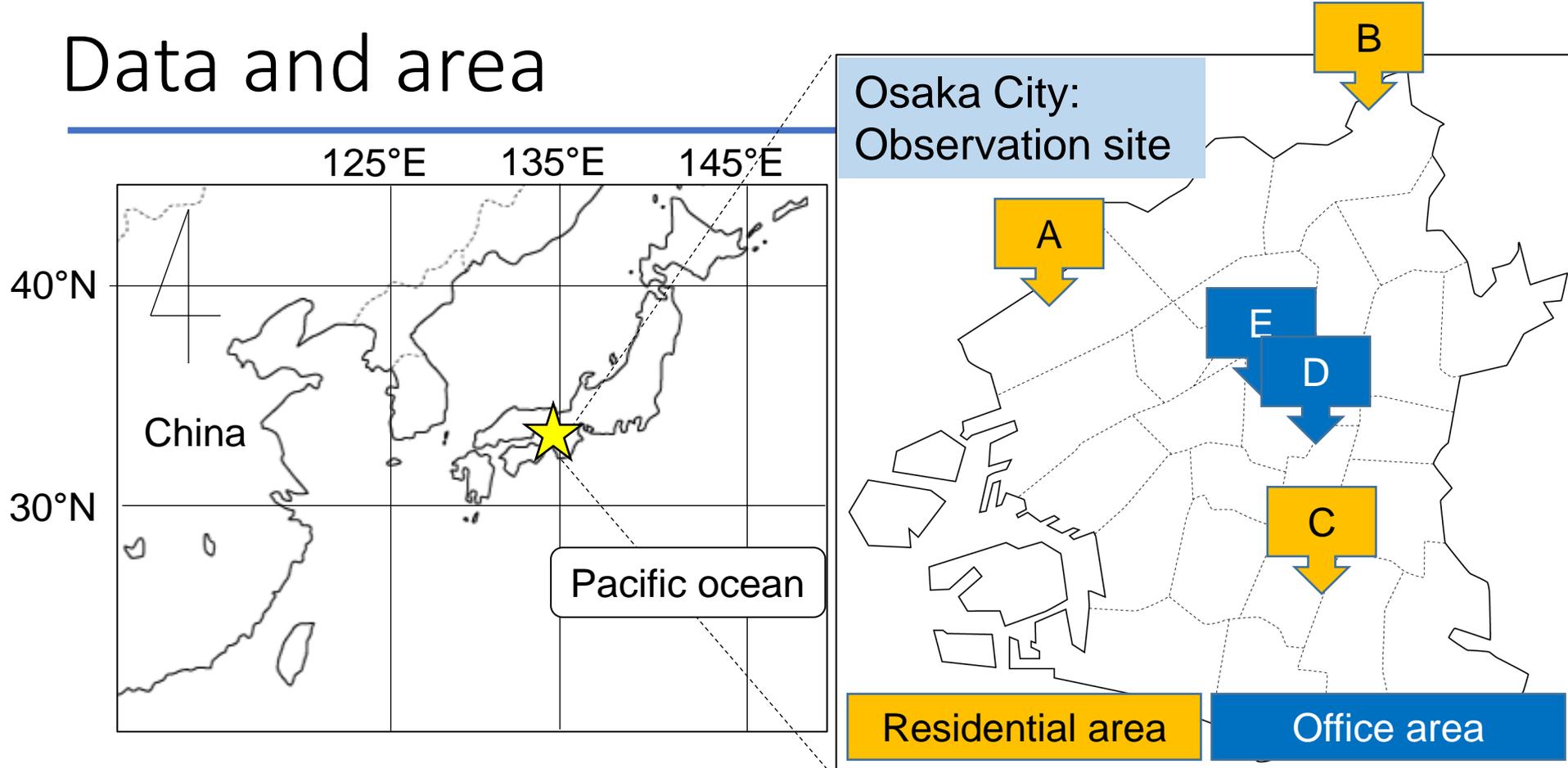
Relation between electricity consumption and solar radiation



© Objective

Quantification of relationship between electricity consumption and solar radiation

Data and area



Observation items

Air temperature [$^{\circ}\text{C}$], Relative humidity [%RH],

Air pressure [hPa] and Solar radiation [W/m^2]

Observation period

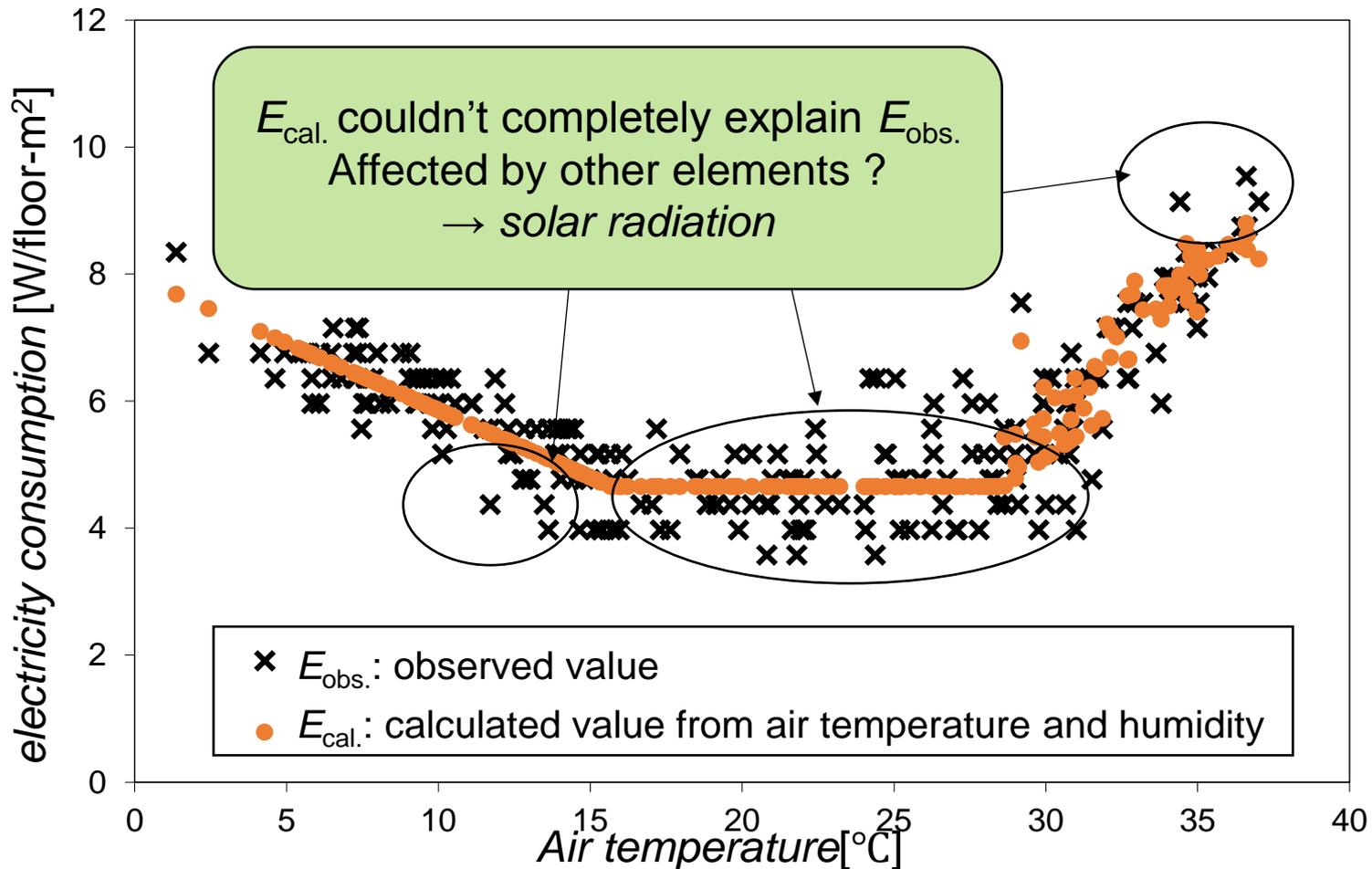
2013/4/1 – 2014/3/17

Comparison of observed and calculated data

$$E_{\text{cal.}} = E_0 + \underbrace{\left(\frac{dE}{dT}\right)_w (T - T_w)}_{T < T_w} + \underbrace{\left(\frac{dE}{dT}\right)_s (T - T_s)}_{T > T_s} + \underbrace{\left(\frac{dE}{dQ}\right)_s (Q - Q_s)}_{Q > Q_s}$$

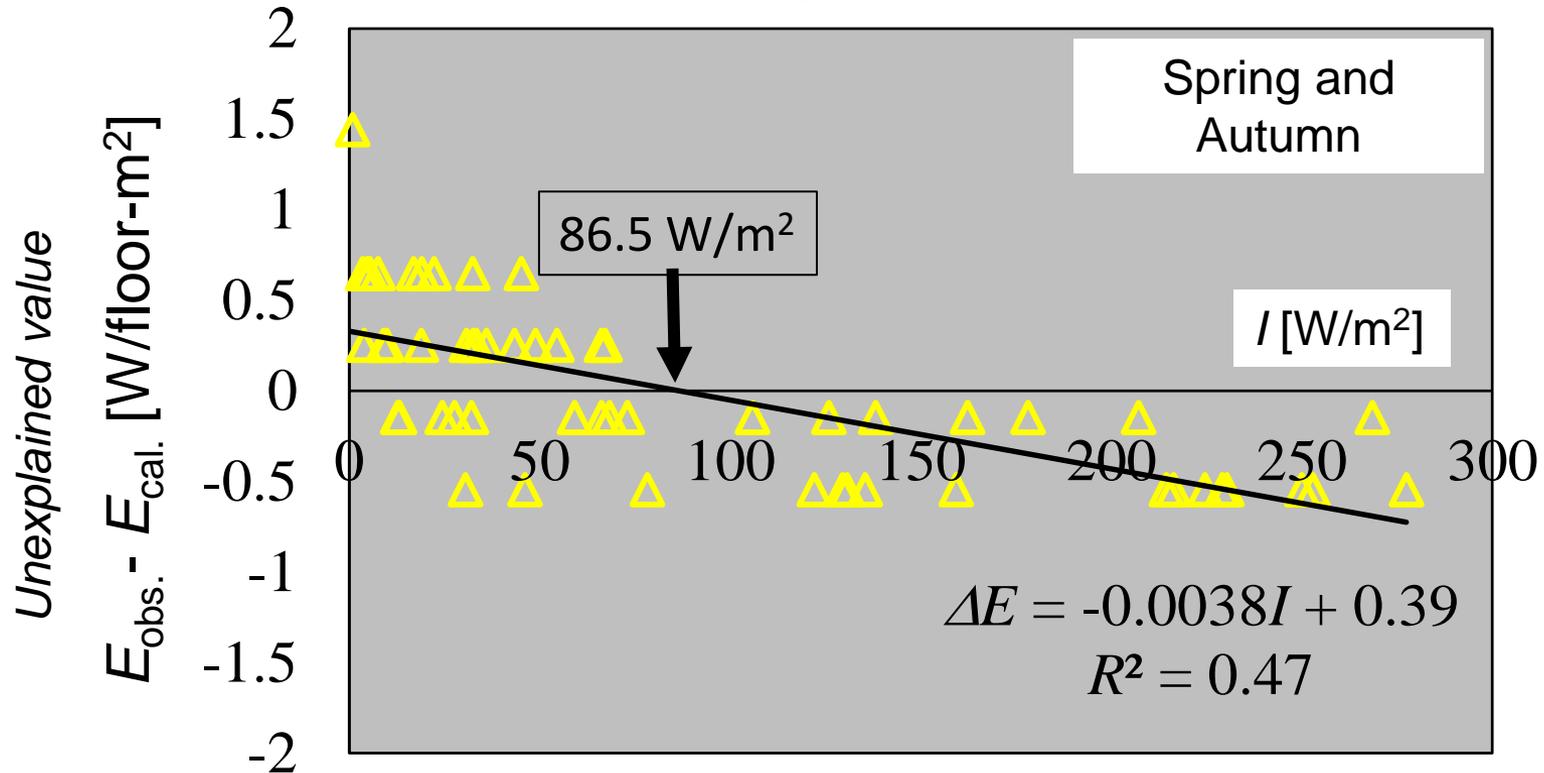
T : Air temperature
 Q : specific humidity

(Ihara et al., 2008)



Relationship between $E_{\text{obs.}} - E_{\text{cal.}}$ and solar radiation (SR) 1/3

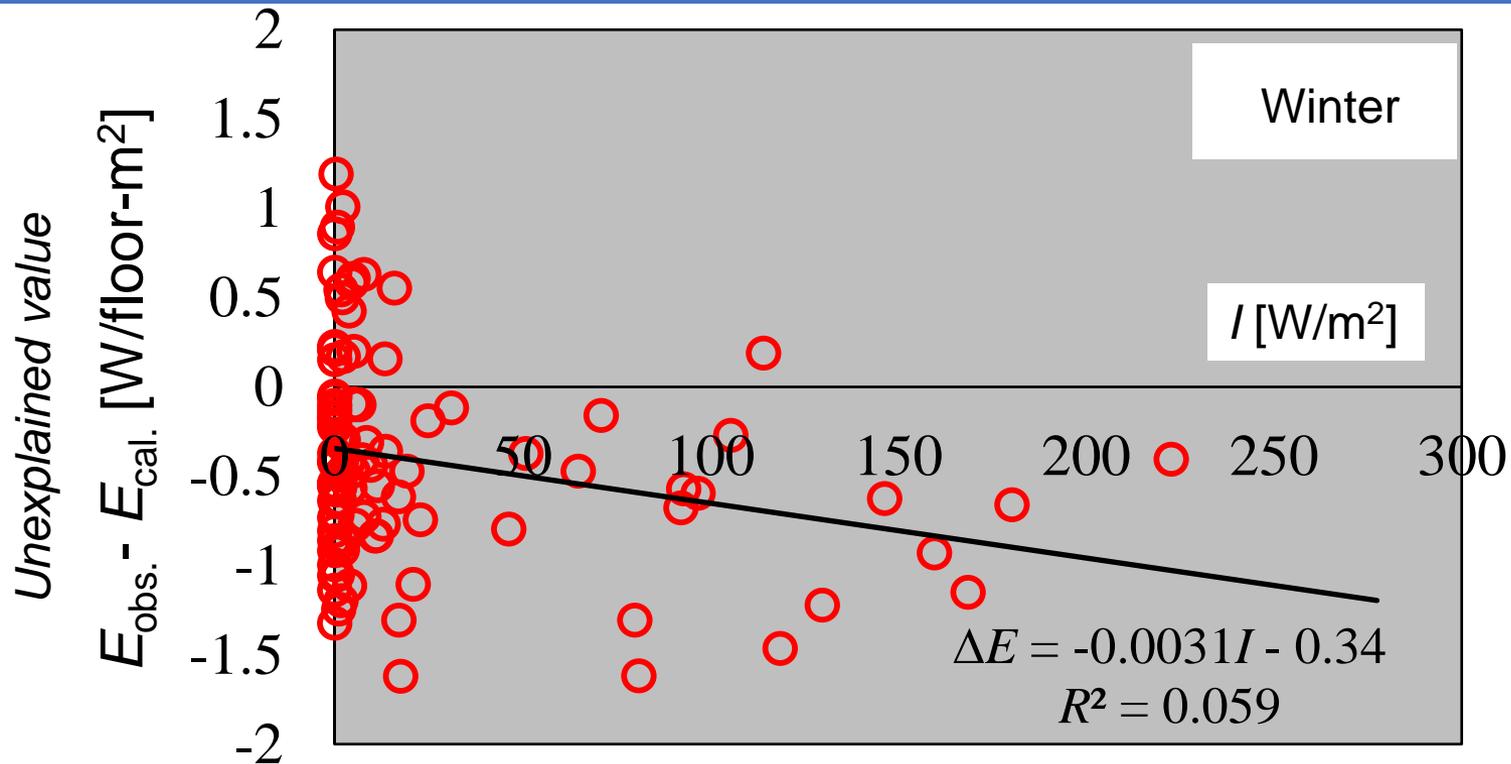
= Unexplained value



- $SR \uparrow$ and $Unexplained\ value < 0$
 $\hookrightarrow E_{\text{obs.}} - E_{\text{cal.}} < 0 \Leftrightarrow E_{\text{obs.}} < E_{\text{cal.}}$ (overestimation)

SR \uparrow is brighter so lighting demand \downarrow

Relationship between $E_{\text{obs.}} - E_{\text{cal.}}$ and solar radiation (SR) 2/3



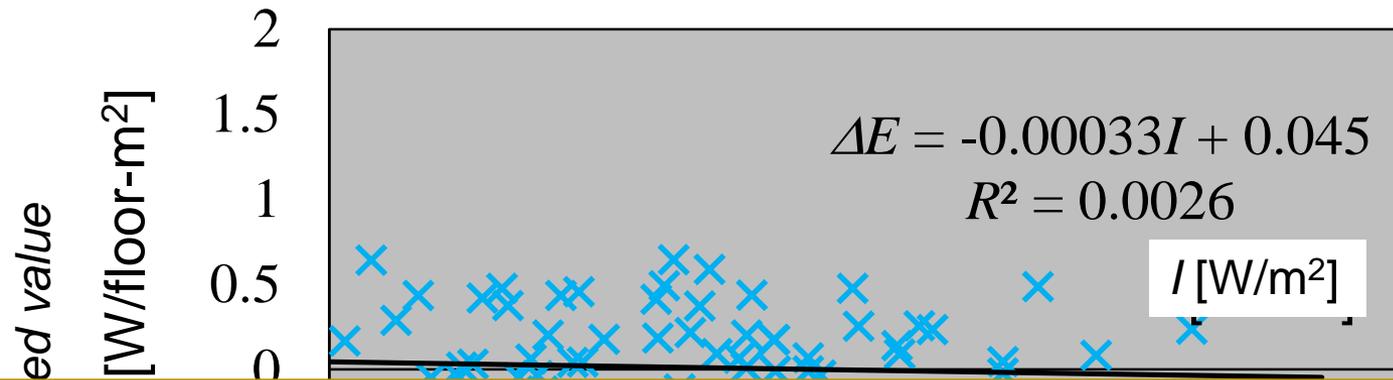
- $SR \uparrow$ and $Unexplained\ value < 0$
↳ $E_{\text{obs.}} - E_{\text{cal.}} < 0 \Leftrightarrow E_{\text{obs.}} < E_{\text{cal.}}$ (overestimation)

$SR \uparrow$ gives more heat so heating demand \downarrow

and

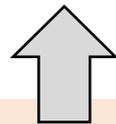
$SR \uparrow$ is brighter so lighting demand \downarrow

Relationship between $E_{\text{obs.}} - E_{\text{cal.}}$ and solar radiation (SR) 3/3



All of these relationships found between electricity consumption and solar radiation are physically reasonable!

- SR is not correlated to *Unexplainable value*



balance out

SR ↑ is brighter so lighting demand ↓

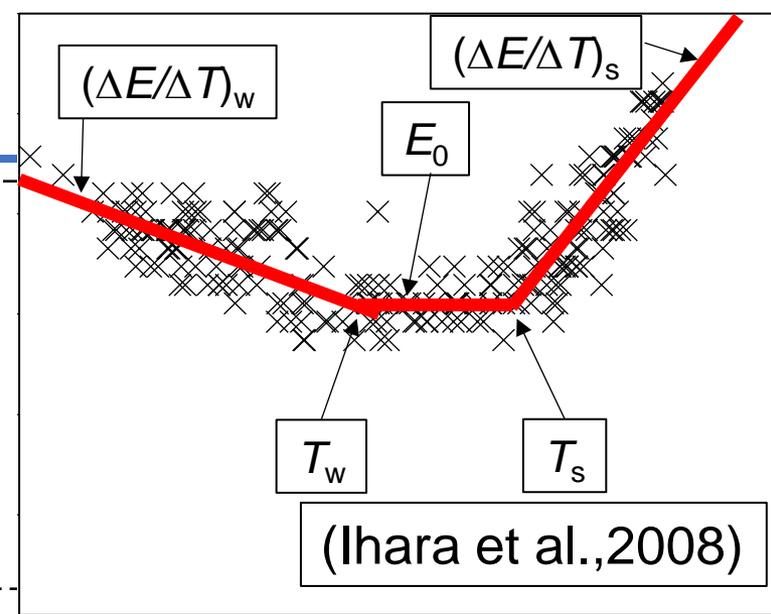
and

SR ↑ gives more heat so cooling demand ↑

The new model in consideration of solar radiation

$$E_{\text{cal.}} = E_0 + \left(\frac{dE}{dT}\right)_w (T - T_w) + \left(\frac{dE}{dT}\right)_s (T - T_s) + \left(\frac{dE}{dQ}\right)_s (Q - Q_s)$$

$T < T_w$ $T > T_s$ $Q > Q_s$



We developed a new model in consideration of solar radiation!

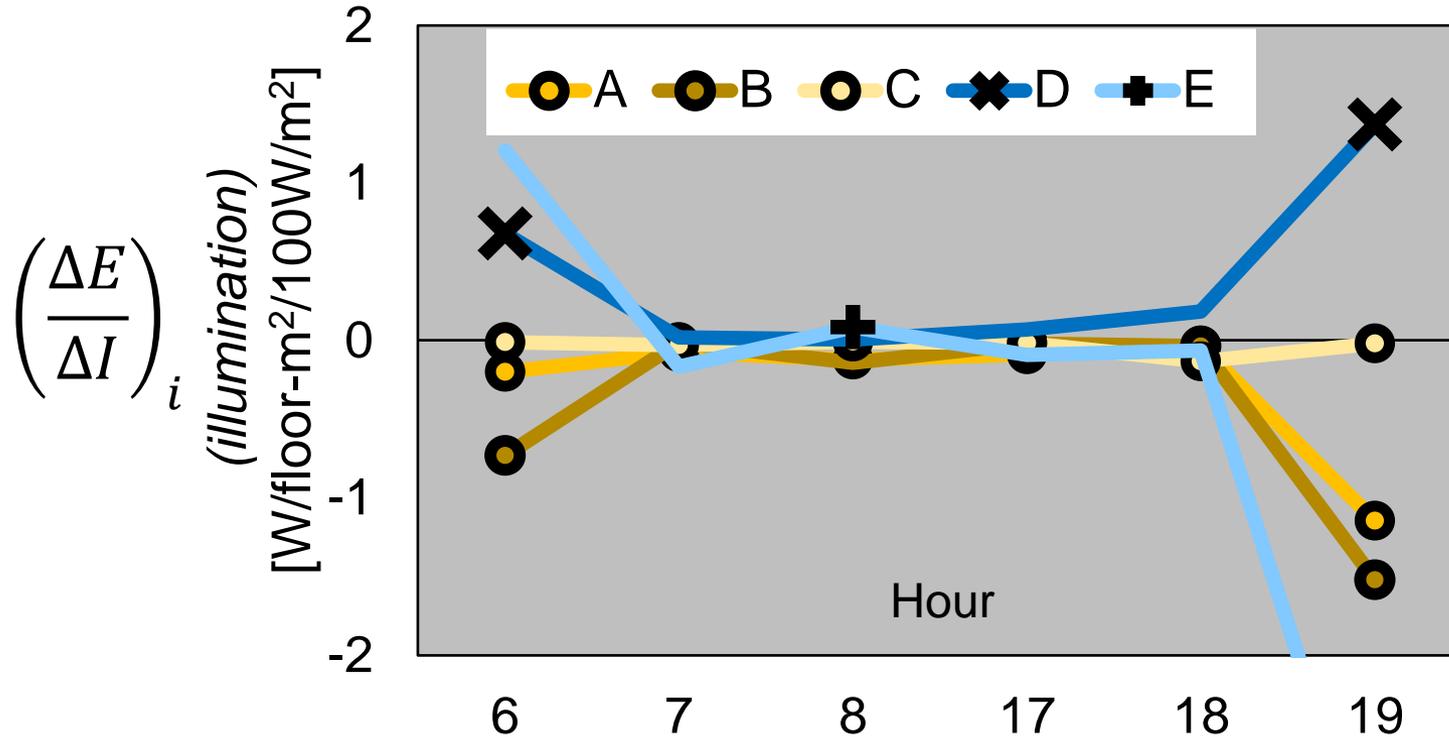
lighting

$$E = E_0 + \left(\frac{\Delta E}{\Delta I}\right)_i (I - I_i) + \left(\frac{\Delta E}{\Delta T}\right)_w (T - T_w) + \left(\frac{\Delta E}{\Delta I}\right)_w (I - I_w) + \left(\frac{\Delta E}{\Delta T}\right)_s (T - T_s) + \left(\frac{\Delta E}{\Delta Q}\right)_s (Q - Q_s) + \left(\frac{\Delta E}{\Delta I}\right)_s (I - I_s)$$

$T < T_w$ $T > T_s$ $Q > Q_s$

heating *cooling*

Sensitivity of electricity consumption to SR (illumination) $\left(\frac{\Delta E}{\Delta I}\right)_i$



Note: Marker is statistical significant ($P < 0.1$)

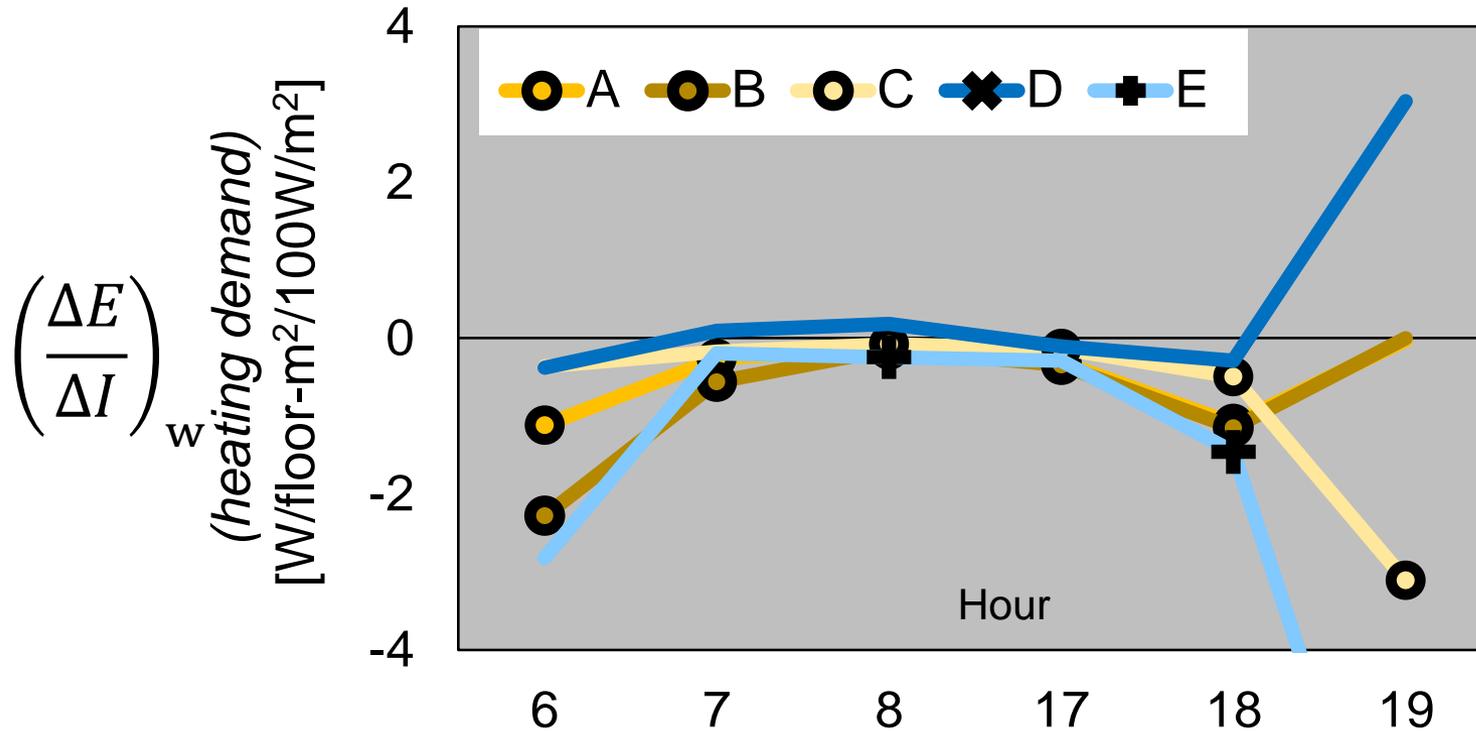
In residential areas,

- Sensitivities in the morning and evening were higher than that in daytime.
→ Occupancy rate is higher in the morning and evening.

In office areas,

- Sensitivities were not significant by t -test all the time.
→ Lights are on even if it is sunny.

Sensitivity of electricity consumption to SR (space heating) $\left(\frac{\Delta E}{\Delta I}\right)_w$



Note: Marker is statistical significant ($P < 0.1$)

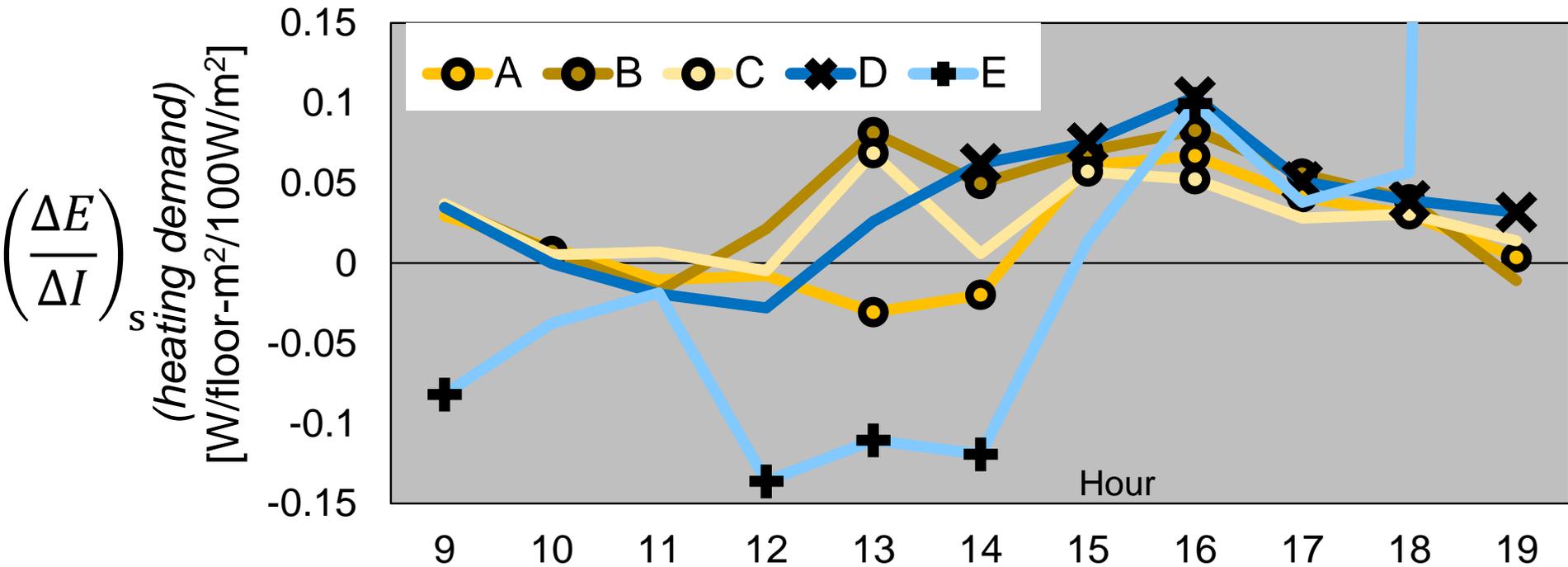
In residential areas,

- Sensitivities in the morning and evening only were significant by t -test.
 → Air temperature in the morning and evening is more sensitive to heat of solar radiation.

In office areas,

- Sensitivities were not significant by t -test all the time.
 → Range of human activity is more distant from the envelop of a building.

Sensitivity of electricity consumption to SR (space cooling) $\left(\frac{\Delta E}{\Delta I}\right)_s$



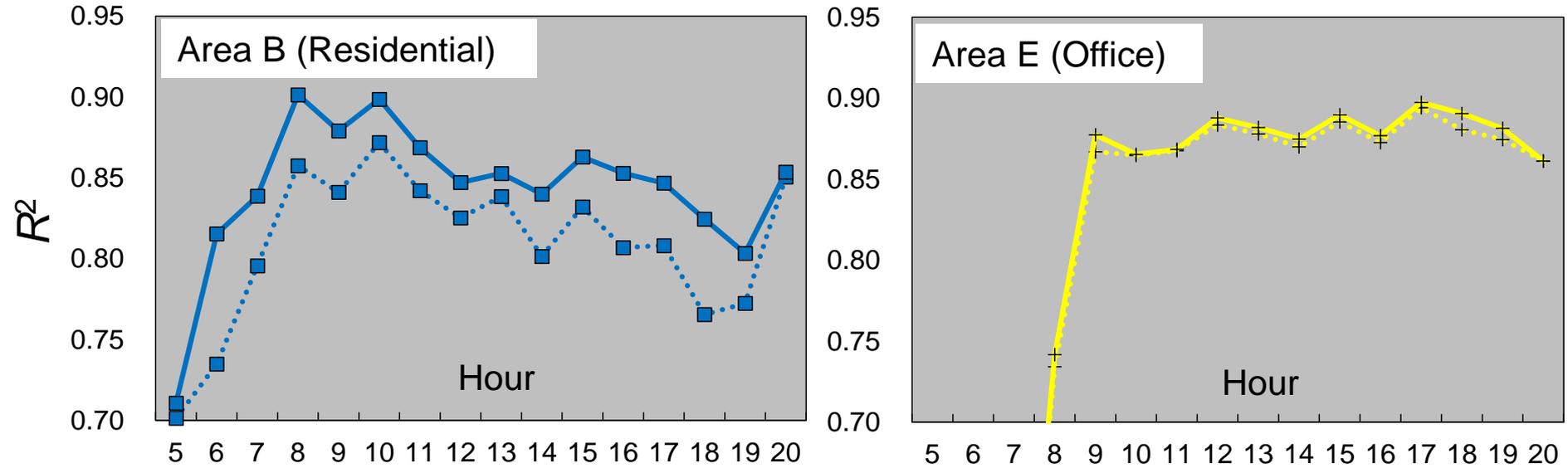
Note: Marker is statistical significant ($P < 0.1$)

In residential areas,

- Sensitivities from 9am to 7pm were significant by t -test.
→ Due to heat of solar radiation, buildings become warm, so cooling demand increases.

Comparison of the new model to the previous model

solid line: the new model, dotted line: the previous model (Ihara et al.,2008)



The residential area is more affected by solar radiation than the office area.

This is because

- Lighting in the residential area is turned on or off according to brightness.
- Range of human activity is close to the envelop of a building.

Conclusion and further application

- We developed the new model in consideration of solar radiation which affects lighting, heating and cooling effects.
- In residential areas, a term of lighting demand in sensitivities in the morning and evening were higher than in daytime due to occupancy rate. Also, a term of heating demand in sensitivities in the morning and evening only were significant by t -test due to lower air temperature.
- In office areas, sensitivities to solar radiation were not significant by t -test all the time because lights are on even if it is sunny and range of human activity is not close to the envelop of a building.
- The new model is better than the previous model in the residential area.

Further applications:

If Japan introduces **daylight saving time**,

- how will lighting demand decrease?
- how will cooling demand decrease?

**Derived sensitivities were useful for
validation of the numerical simulation model**

*The new model is
the best solution for
these applications!*

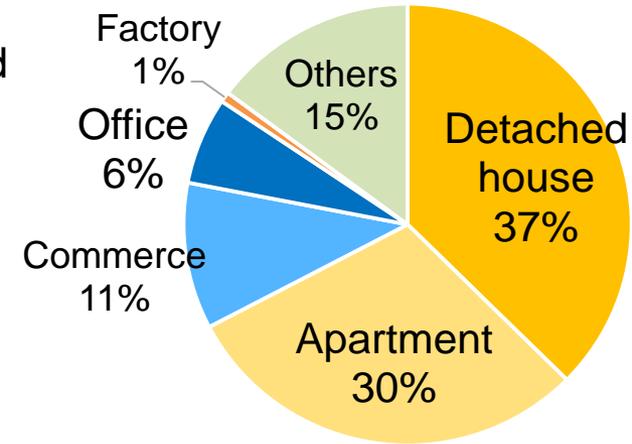
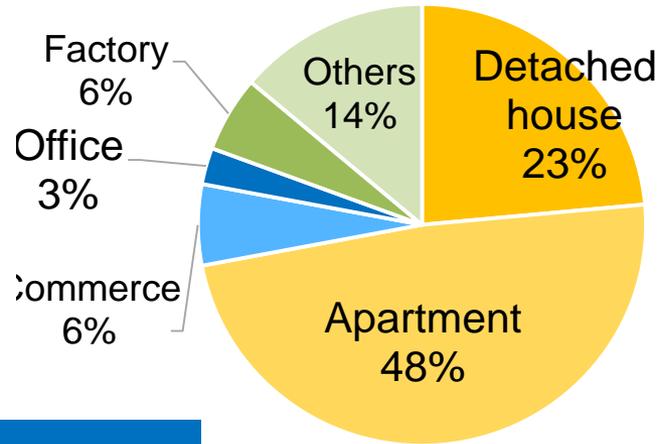
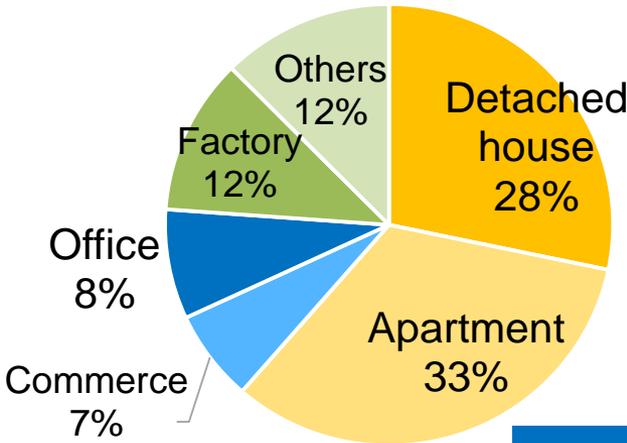
Data and area 2/2

Residential areas

A: 2.73km²

B: 2.52km²

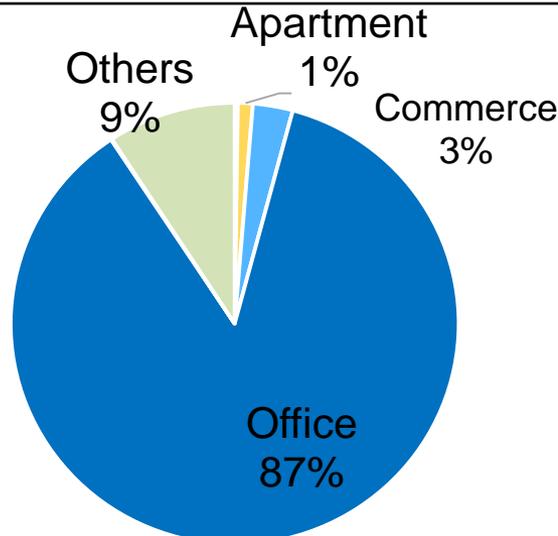
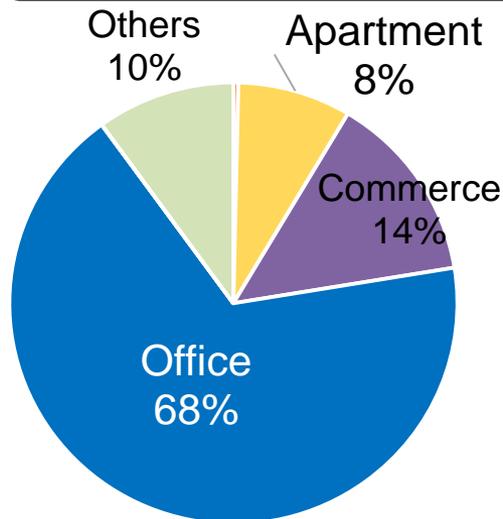
C: 2.20km²



Office areas

D: 2.25km²

E: 1.08km²



Meteorological instruments

Global solar radiation



CMP3 (PREDE Co.,Ltd.)

Air temperature and humidity



TR-72U (T&D Co.,Ltd.)

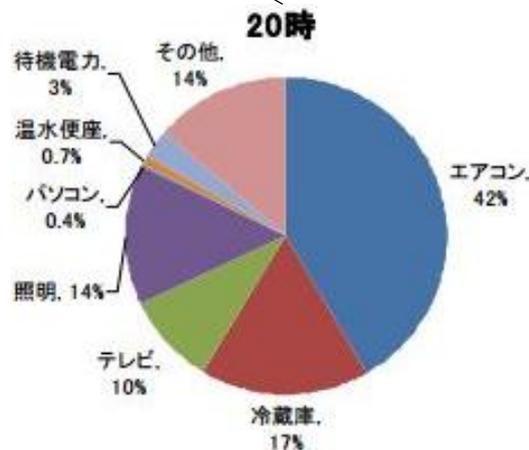
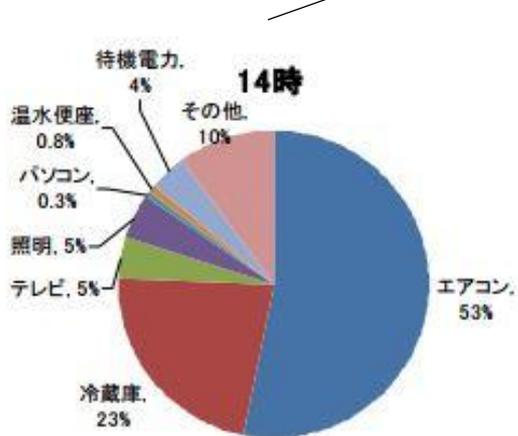
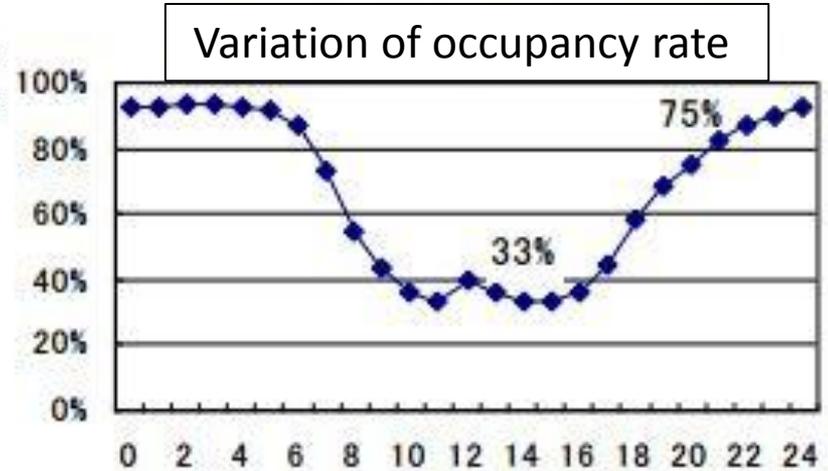
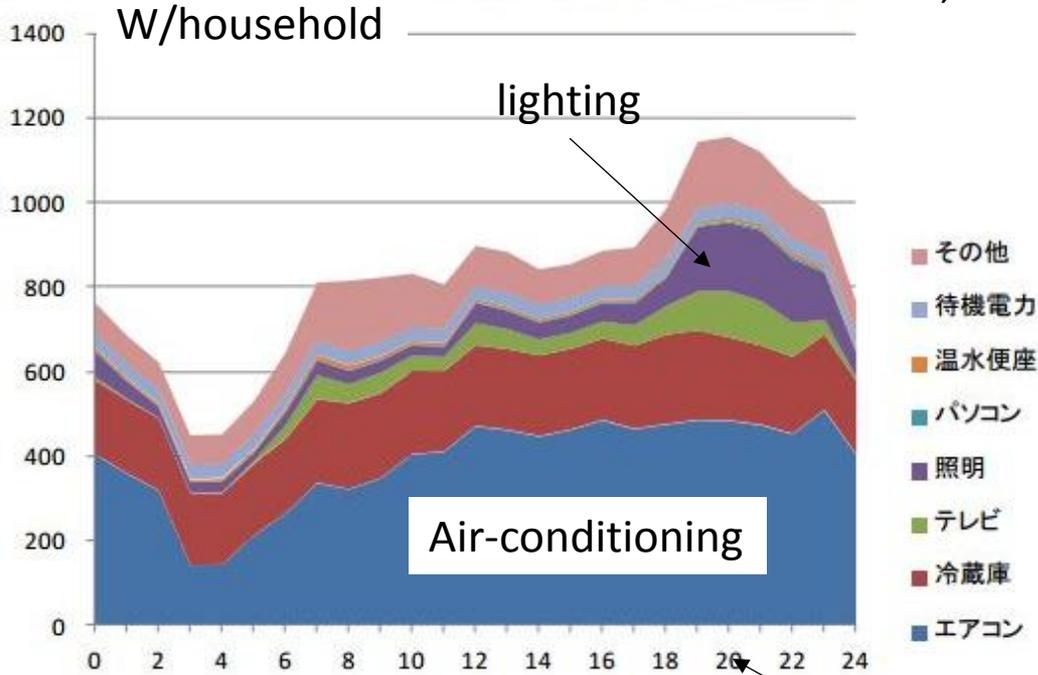
Electricity consumption data

We received it from Kansai Electric Power Company (KEPCO).

- Hourly
- Unit : MWh

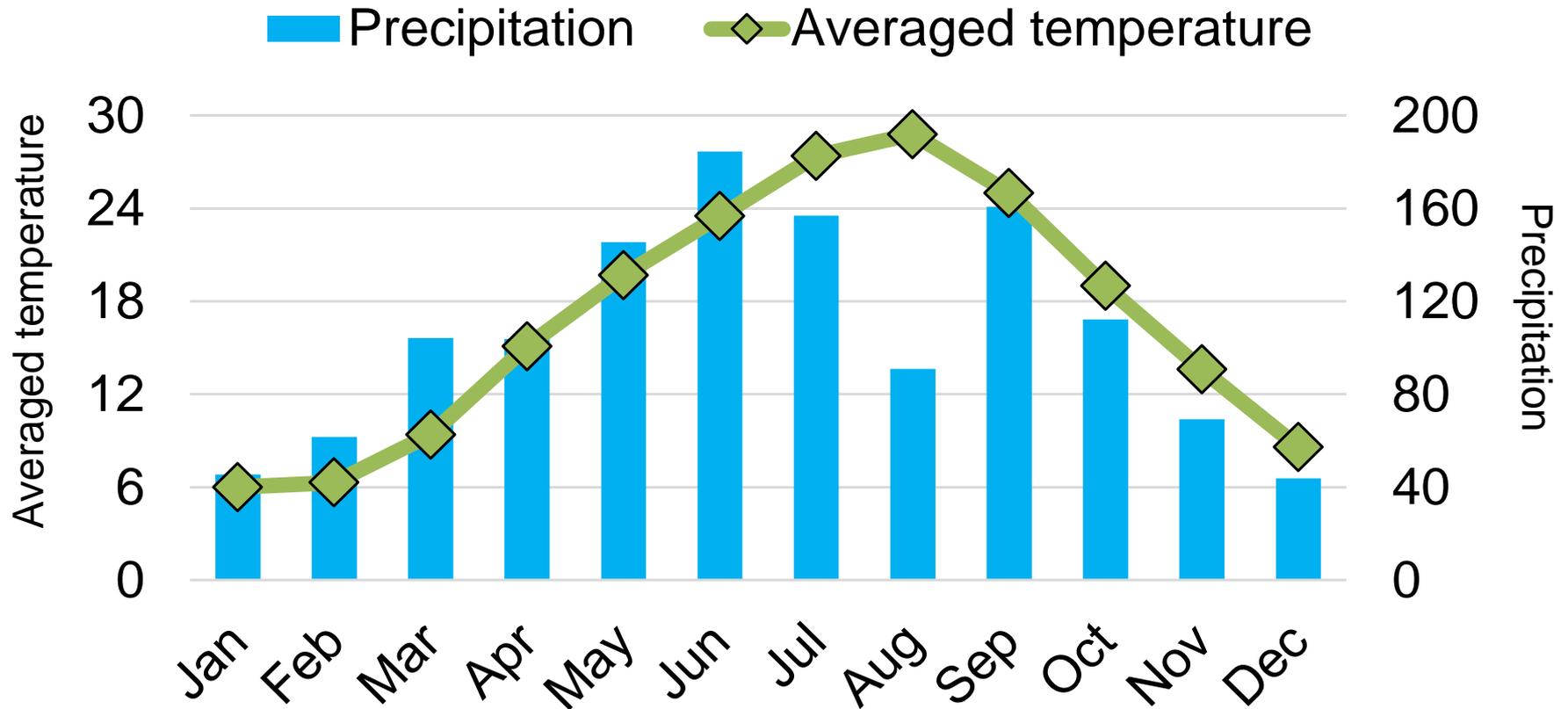
Electricity demand in a household

Estimation on Jul. 23th, 2010 by Agency for Natural Resources and Energy



Climate in Japan

Source by Japan meteorological agency



Standard Illuminance in Japan

日射量
(W/m²)

照度(lx)

居間

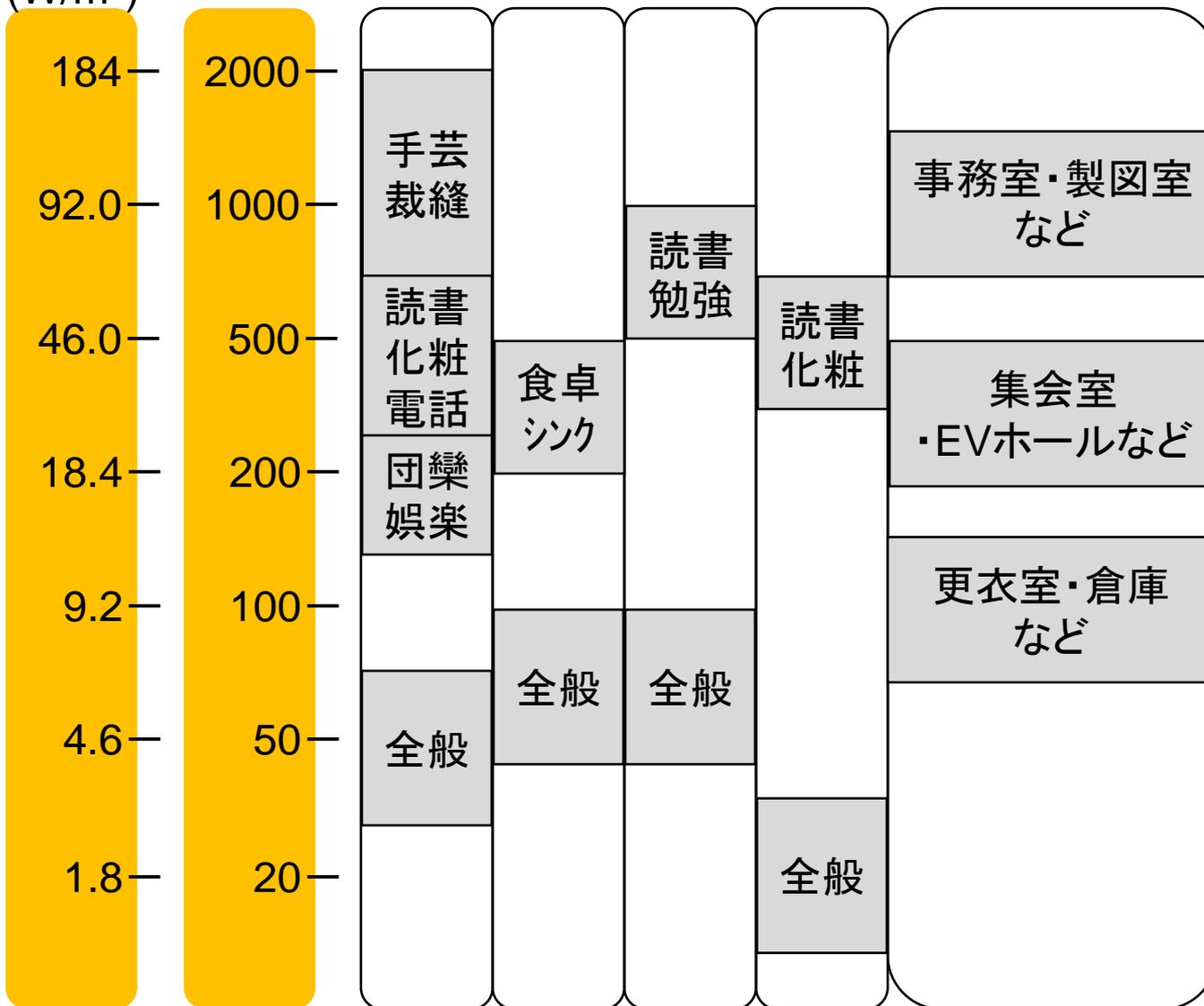
食堂

書斎

寢室

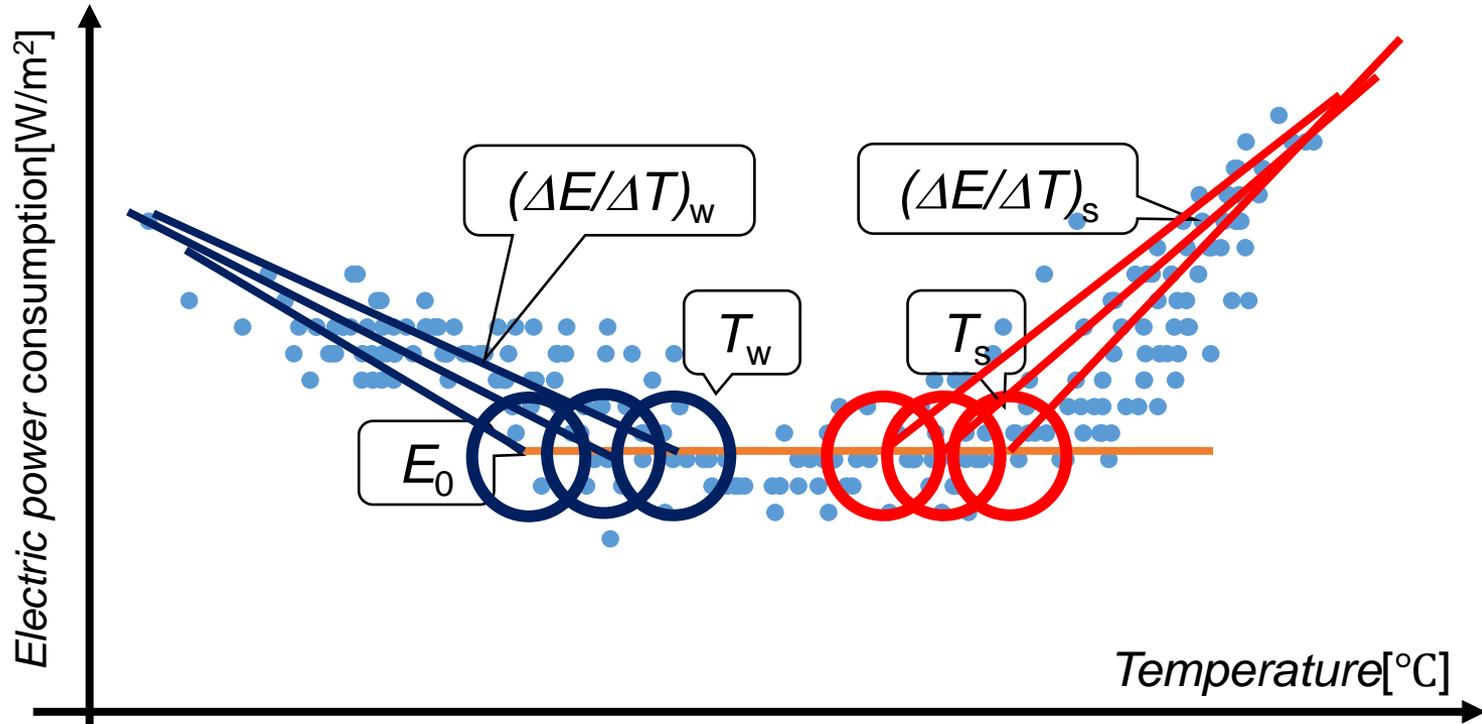
事務所

Source by JIS Z 9110



Algorithm of this model

Source by Japan meteorological agency



$$E_{\text{cal.}} = E_0 + \underbrace{\left(\frac{dE}{dT}\right)_w (T - T_w)}_{T < T_w} + \underbrace{\left(\frac{dE}{dT}\right)_s (T - T_s)}_{T > T_s} + \underbrace{\left(\frac{dE}{dQ}\right)_s (Q - Q_s)}_{Q > Q_s}$$