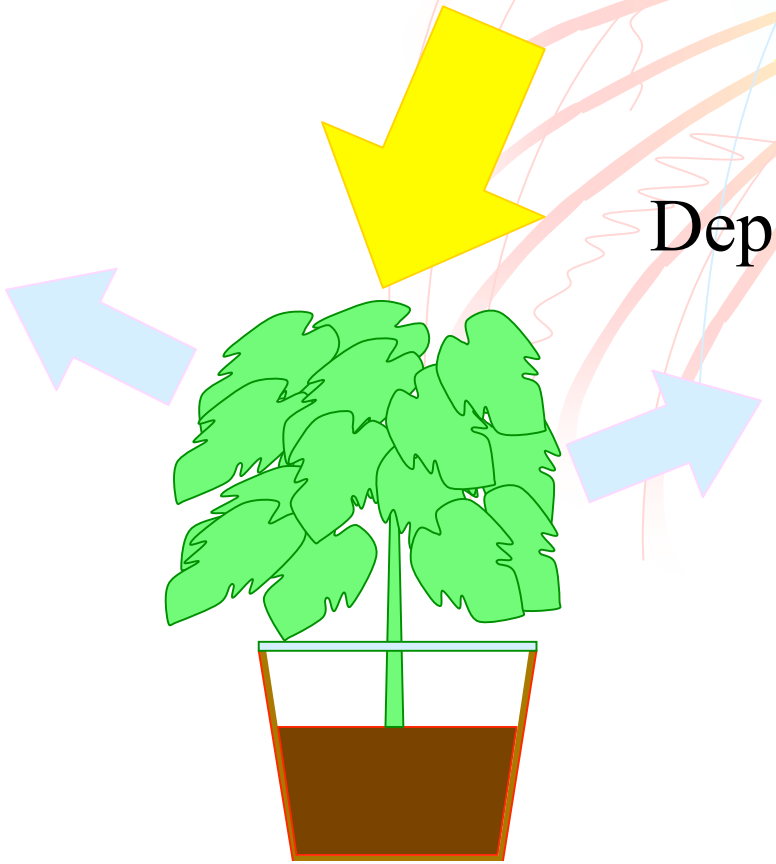
Field Measurement on Energy Budget of an Isolated Plant Unit



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Outline

Background

Energy Balance of Potted Plant

Energy Balance of Isolated Single Tree

Prediction of transpiration rate of single leaf

Model of radiation balance and transpiration of single tree

Results and Discussion

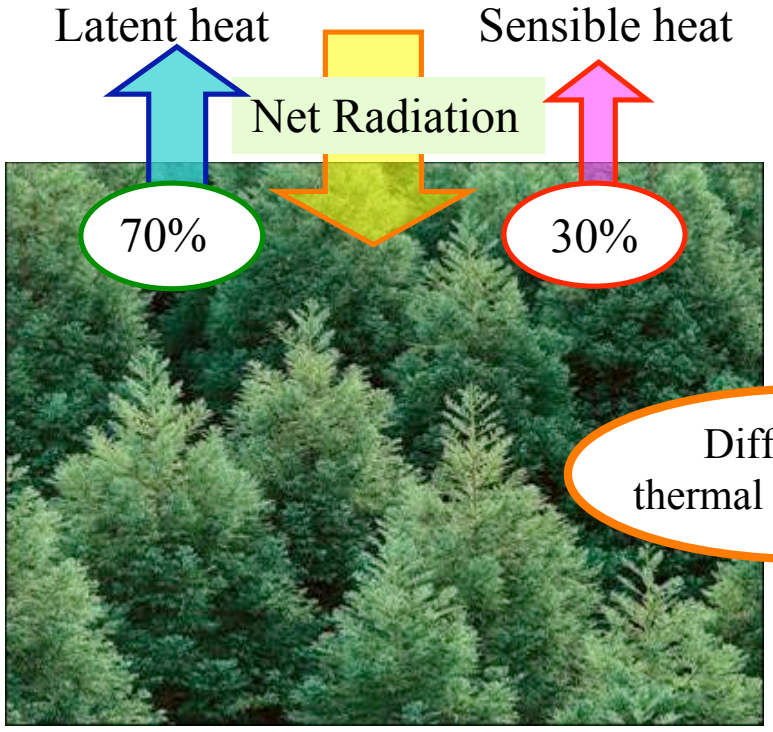
- ◆Latent heat transfer / Sensible heat transfer
- ◆Evaporation efficiency
- ◆Heat transfer coefficient

Conclusion

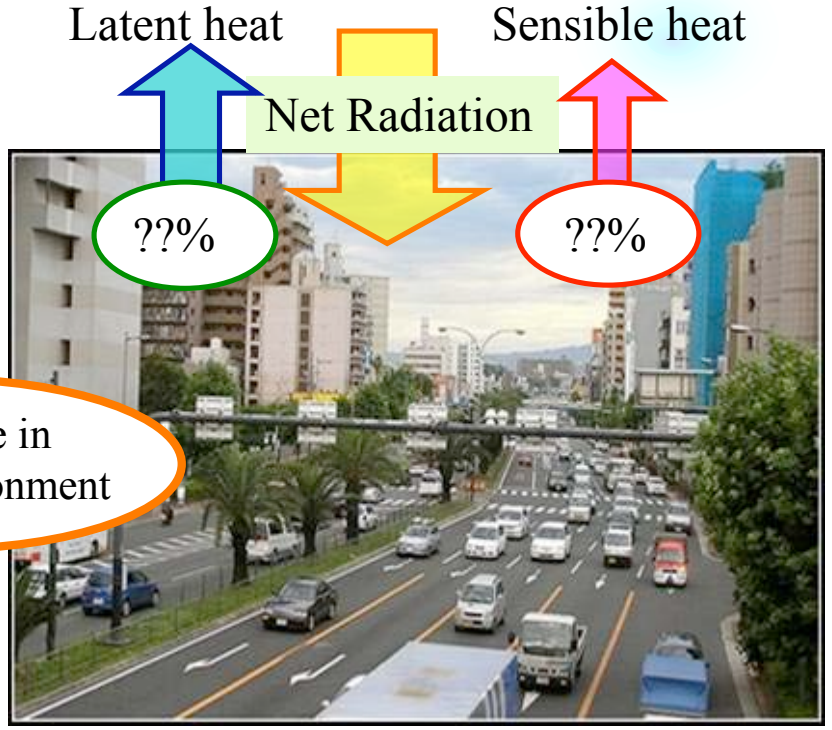
Background

The thermal environment in urban area keeps deteriorating by the heat island phenomenon. To solve such a problem, the role of a plant is assessed.

Energy budget of a forest



Energy budget of an isolated plant



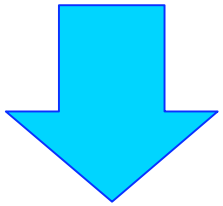
Difference in thermal environment

Comparison of thermal environment between being in a forest and an urban space

In urban spacess, plants are subjected to stress

- High temperature
- Lack of water in soil … etc

Many plants are isolated.



Amount of reflected solar radiation

Physiological action (Transpiration)

It is difficult to evaluate energy balance exactly in urban spaces on the basis of evaluated value of energy budget in a large scale forest.

Energy Balance of Potted Plant

Measurement method

The diameter of potted hibiscus used is about 55cm.

Water was given enough to the pot on the morning of the measurement day.
The soil side had been covered with a vinyl film.
The potted hibiscus was weighed with an electronic balance every 30 minutes, and the transpiration rate of the plant was obtained.

The leaf area index (LAI) is 1.71.

Measurement item and instrument

Air temperature Relative humidity	Thermo-hygrometer
Leaf and ground temperature	Thermocouple
Radiation flux	Net radiometer
Wind velocity	Super sonic anemometer
Weight	Electrical balance

Procedure

Net radiation

$$Rn = Rn_{up} + Rn_{down}$$

Rn_{up} Upper side

Rn_{down} Lower side

Energy Budget of Plant

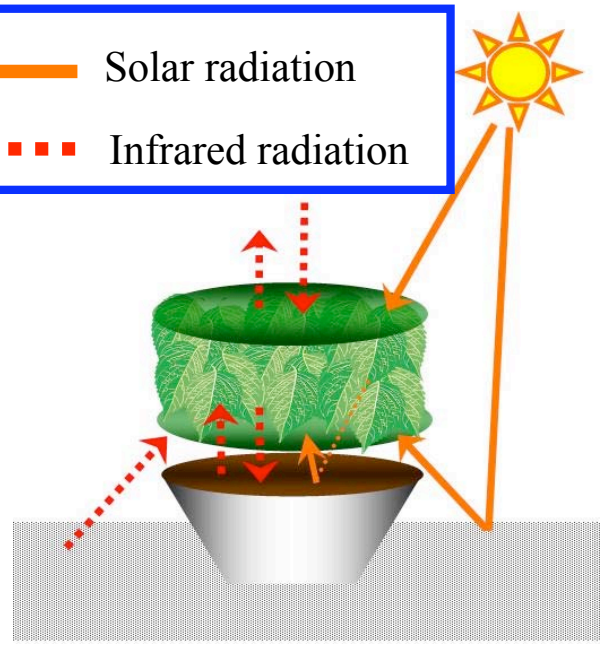
$$Rn = H + lE + G$$

Rn Net radiation [W/m^2]

H Sensible heat flux

lE Latent heat flux

G Conductive heat flux

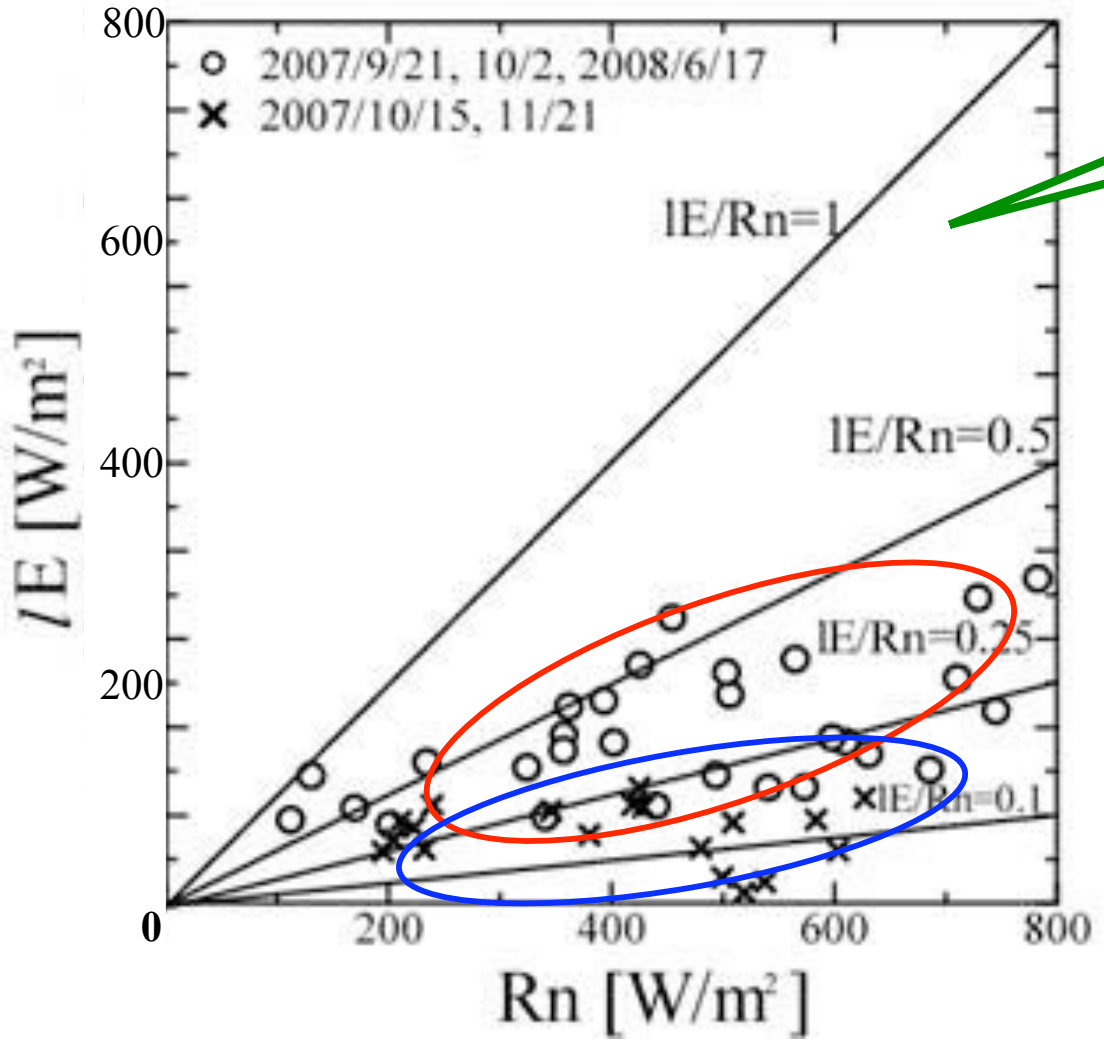


$$Rn = H + LE + G \sim H + LE$$

Conductive heat transfer in the plant canopy was thought to be zero.

L Latent heat of vaporization , E Transpiration rate

Result



Latent Heat / Net Radiation

summer (26~33deg.C)

fall (13～22deg.C)

$\frac{lE}{Rn}$ <0.5

***H* >50%**

The ratio of the latent heat transfer in the potted plant was obviously smaller than that in the forest.

Energy Balance of Isolated Single Tree

Measured transpiration rate

The latent heat flux of a camphor tree is obtained using the transpiration rate.

The measured transpiration rate of each leaf Jp_{obs} [g/cm^2/s] and stomata conductance were obtained by using the diffusion-type polometer.

diffusion-type polometer

Predicted transpiration value

Predicted value is generally expressed by the following equation.

$$Jp = \frac{g_b g_s (\rho_l - \rho_c)}{g_b + g_s}$$

g_b conductance of boundary layer on leaf side

g_s stomata conductance

ρ_l water vapor concentration on leaf side

ρ_c water vapor concentration of surrounding atmosphere

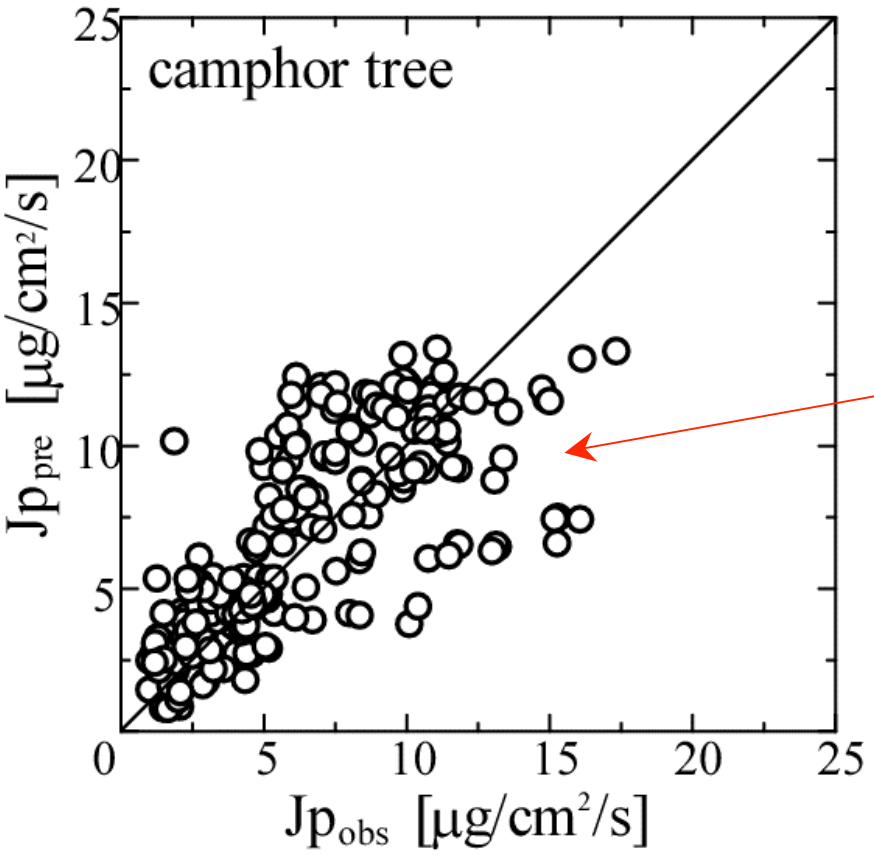
Jarvis's model

$$g_s = g_{smax} f_1(Q) f_2(D) f_3(T_l)$$

Q photon number
D vapor-pressure deficit
T_l leaf temperature

The values of g_{smax} and the parameters in each function are decided to suit the measured data most, according to the nonlinear least square method.

Comparison between prediction and measured transpiration rate



Jp_{pre} Prediction transpiration rate of each leaf

Jp_{obs} Measured transpiration rate of each leaf

Correlation coefficient is 0.7

The prediction is said to be almost possible according to the surrounding weather conditions.

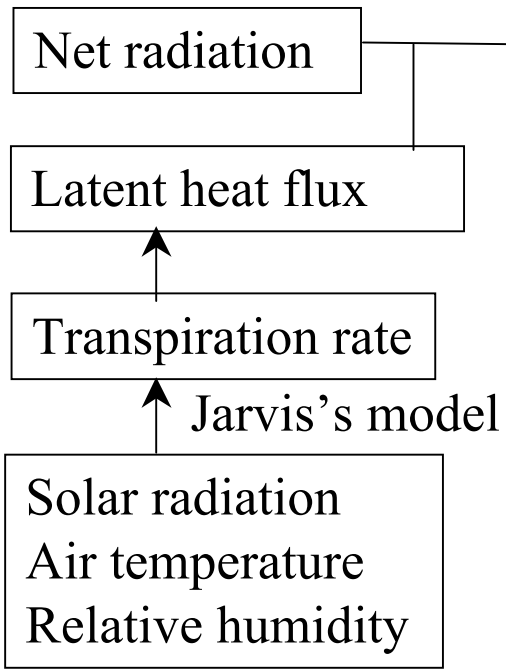
Model of radiation balance and transpiration of single tree

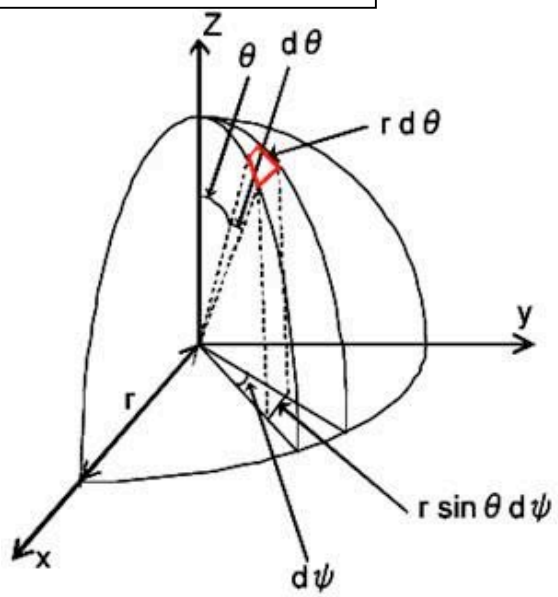
Configuration of leaves was assumed to be a globe.

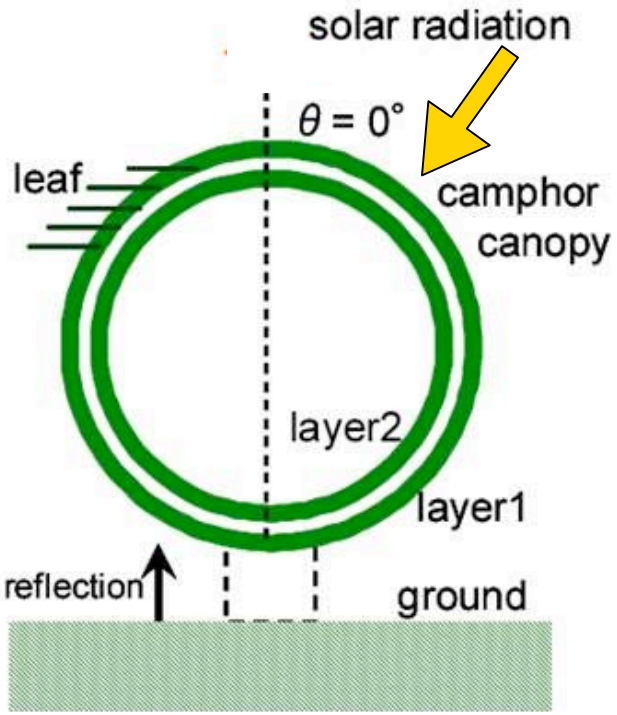
A double layer of the spherical shell was adopted as a group of leaves.
The leaf area index (LAI) was given 8.0.

All leaf elements are assumed to be attached in parallel to ground, and not to interfere mutually.

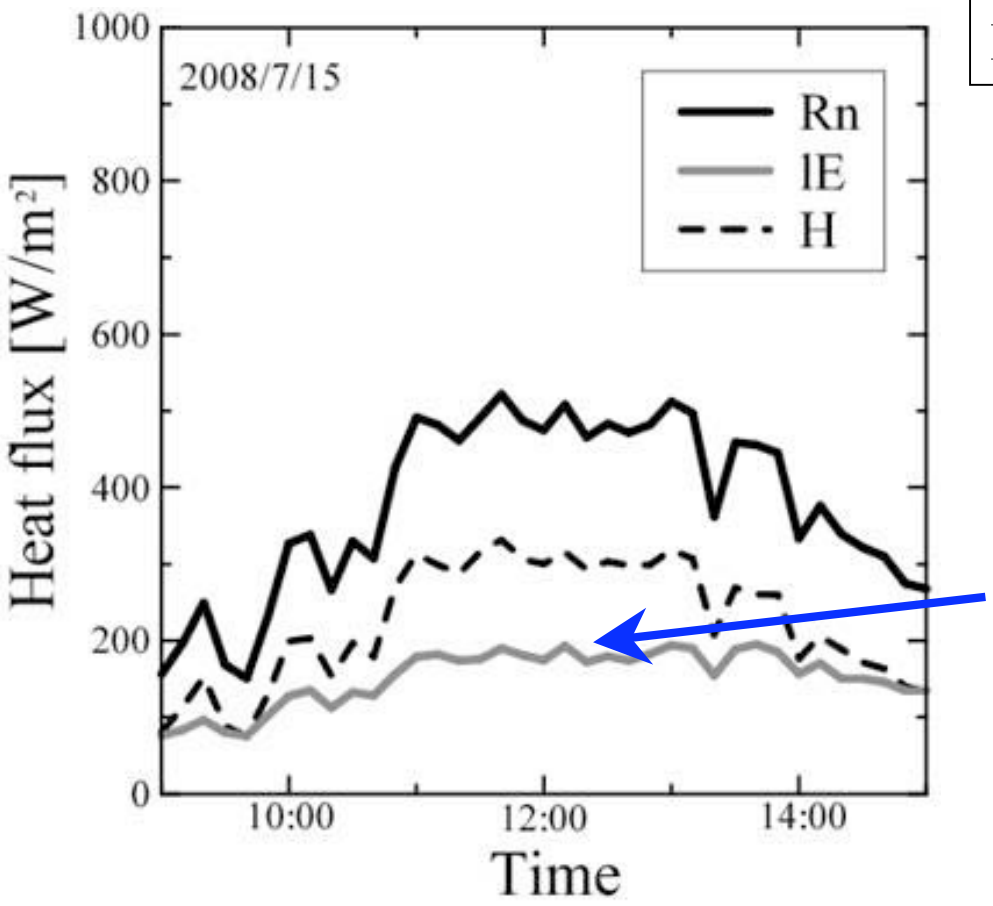
It is assumed that direct solar radiation is equally received in the hemisphere in the incident direction.







Result



Rn	Net radiation
lE	Latent heat flux
H	Sensible heat flux

The energy budget was estimated by using the meteorological data on July 15, 2008 between 9:00AM-3:00PM at intervals of ten minutes.

The estimated latent heat transfer became about 35-50 percent of the net radiation.

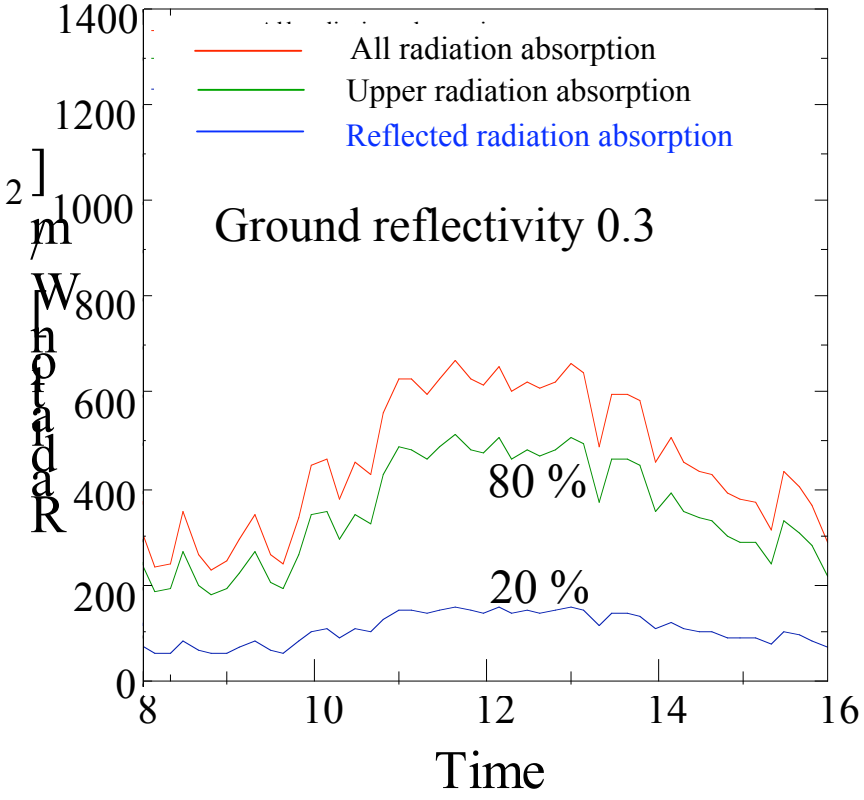
It has been understood that the ratio to the net radiation of the latent heat transfer is almost similar to the potted plant.

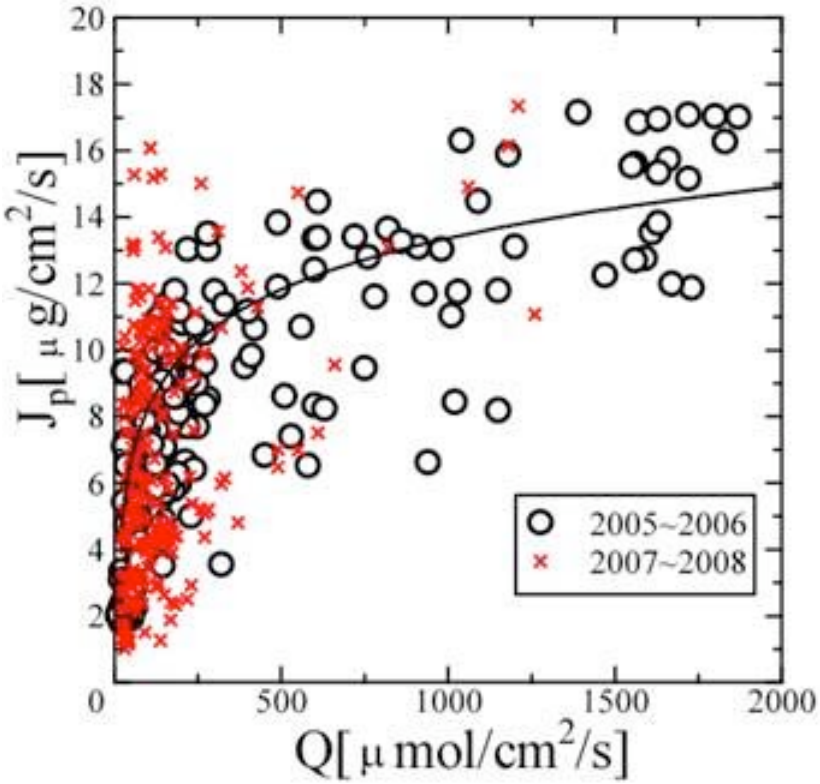
Discussion

The latent heat transfer of isolated tree and potted plant occupied 50 percent at most to the radiation transfer.

In urban space, net radiation absorbed by tree becomes large.

The transpiration rate has the tendency to reach the ceiling for the solar radiation on account of the physiological trait of the plant.





Evaporation efficiency

actual transpiration rate / evaporation rate on water surface

$$\kappa = \frac{\alpha}{C_p L_e}$$

$$\beta = \frac{E}{\kappa(X_s - X_a)}$$

α : heat transfer coeeficient

κ : mass transfer coefficient

Cp : specific heat of air

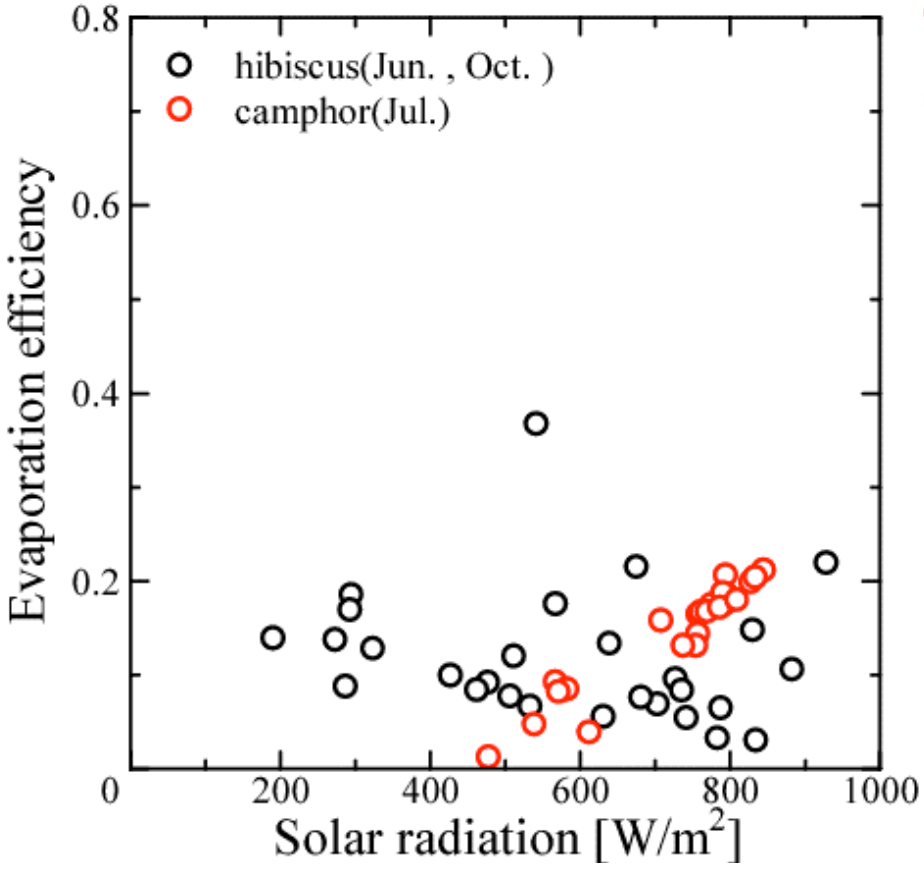
Le : Lewes number (= 0.83)

β : evaporation efficiency

E : actual evaporation rate

Xs : saturated absolute humidity at surface temperature

Xa : absolute humidity of air



According to the previous study,

Natural lawn of watering enough	0.7
Trees of Japanese cherry and zelkova	0.1-0.2

Heat transfer coefficient

hibiscus & artificial plant

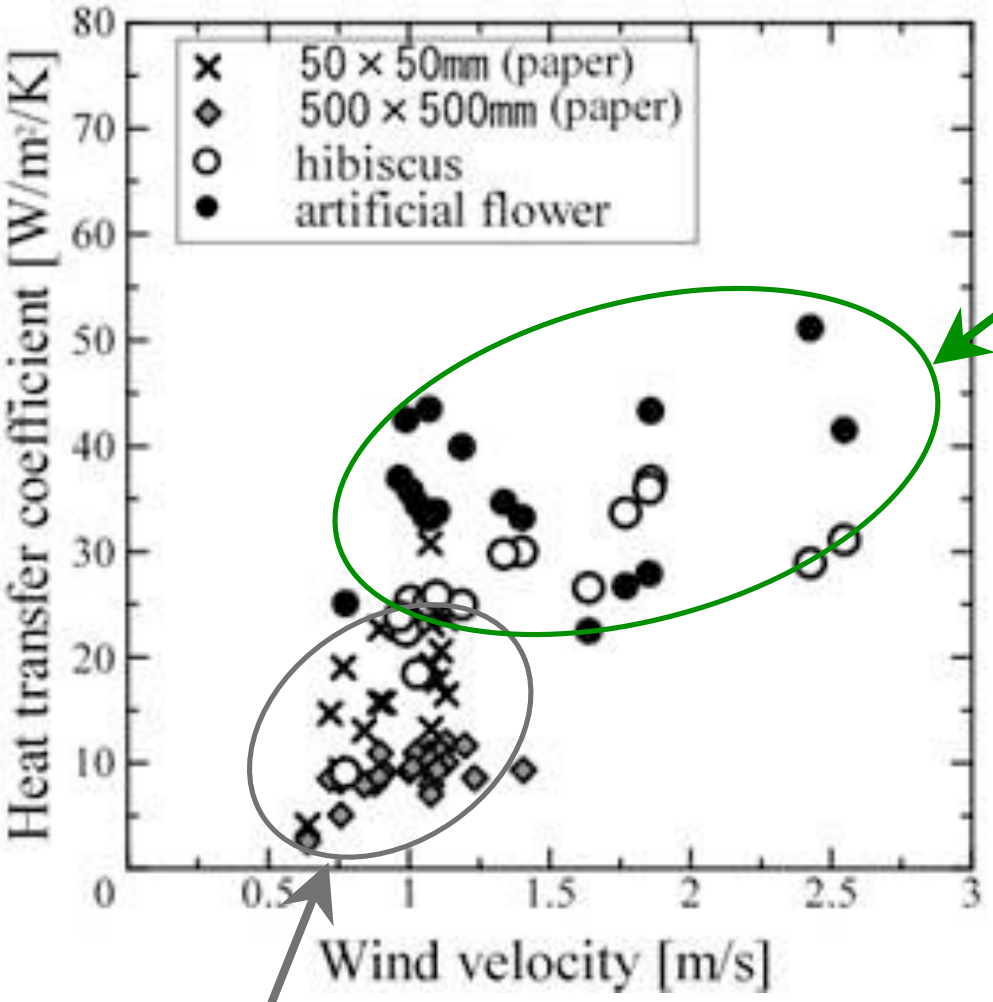
Leaf side $\alpha = \dfrac{H}{\Delta T \text{ x } LAI \text{ x } 2}$

- Size
- Distribution
- Swing etc…?

- Check of size effect

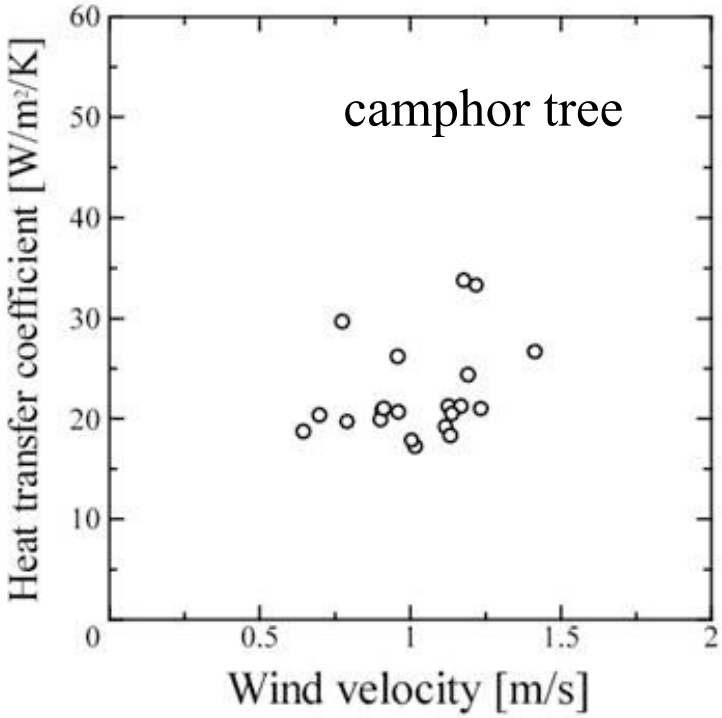
(1568 x 2160mm)

(500 x 500mm, 300 x 300mm,
100 x 100mm, 50 x 50mm)



hibiscus
& artificial plant

> large size of paper



paper

- **small size > large size**
- **small size of paper**
  ~ hibiscus

Conclusion

The latent heat transfer of isolated tree and potted plant occupied 50 percent at most to the radiation transfer, and then the sensible heat transfer took an important role in viewpoint of the energy balance of plant.

The evaporation efficiency of tree was smaller than that of natural lawn including the evaporation from the soil, but did not change greatly regardless of the solar irradiation.

It was found out that the heat transfer coefficient on the leaf side was larger than that on the semi-infinite flat plate. One of the main causes was guessed to be small size of leaf on the basis of the theory of boundary layer.

Solar cell

in future

Fractal configuration

Thank you for your kind attention.