World Forum on Urban Forests
Mantova 2018

*PS 1.4 Changing Environment*

# Analysis of Heat Mitigation Strategies of Zen Gardens to Extremely Hot Weather Conditions in Kyoto, Japan

Lihua Cui
Kyoto University
lihua.cui.36x@st.kyoto-u.ac.jp

World Forum on Urban Forests
Mantova 2018

# OUTLINE

Background

Research Purpose

Methodology

Result

Discussion

Lihua Cui
Kyoto University
lihua.cui.36x@st.kyoto-u.ac.jp

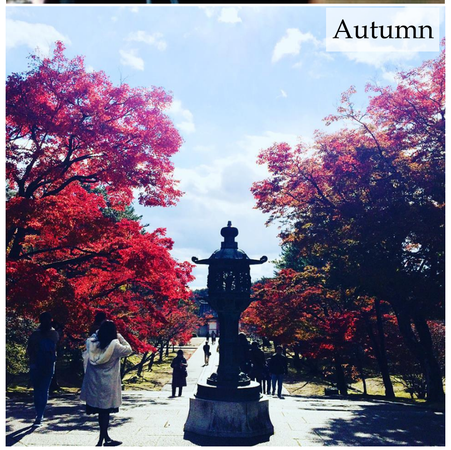
Background

**Greatest Concentration of Treasures**

- 17 World Heritage Sites,
- 90 gardens,
- 140 museums and galleries,
- 177 festivals,
- 471 notable temples and shrines…

A long history (14~19th century)
↓
Accumulation of knowledge and technology







Flourish nature + Climate

**Climate:**
Uncomfortable climate caused by its topography.
Blisteringly hot and humid in summer;
Savagely Cold in winter.

# Japanese Gardens

Lihua Cui
Kyoto University
lihua.cui.36x@st.kyoto-u.ac.jp

# Research Questions:

1. Characteristics of the microclimate in Zen gardens?
2. How the gardens function on mitigating summer heat?
3. How to apply the heat mitigation strategies of Zen gardens to urban open spaces?

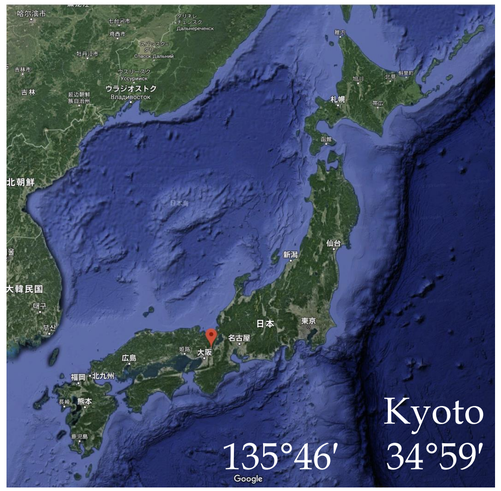


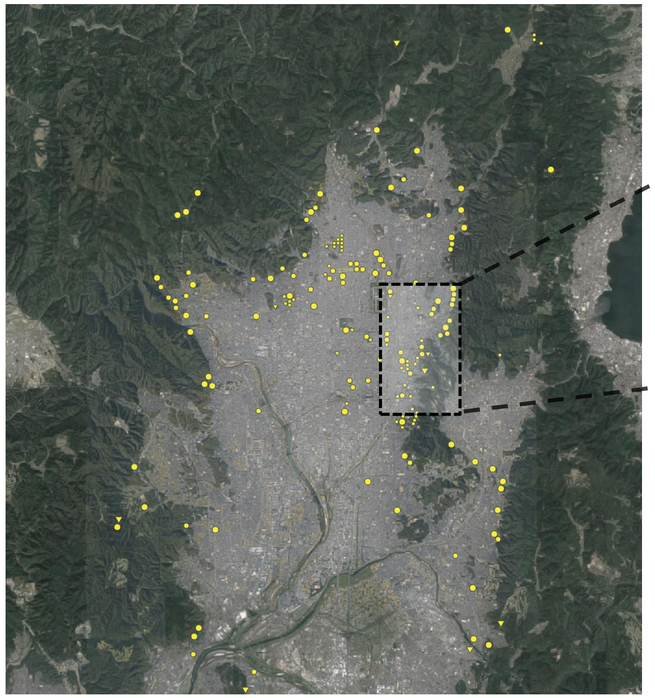
Lihua Cui
Kyoto University
lihua.cui.36x@st.kyoto-u.ac.jp

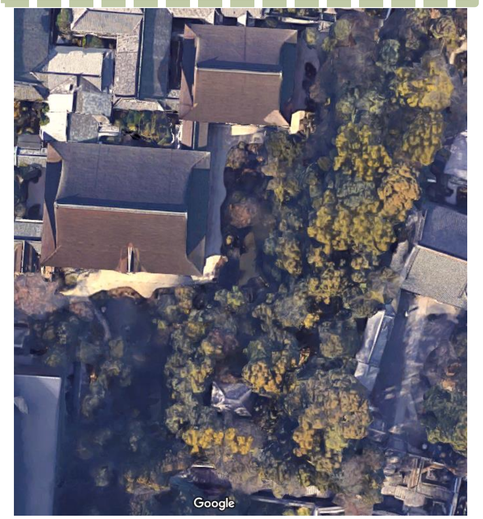
World Forum on Urban Forests
Mantova 2018

# Location of the research objects

Methodology



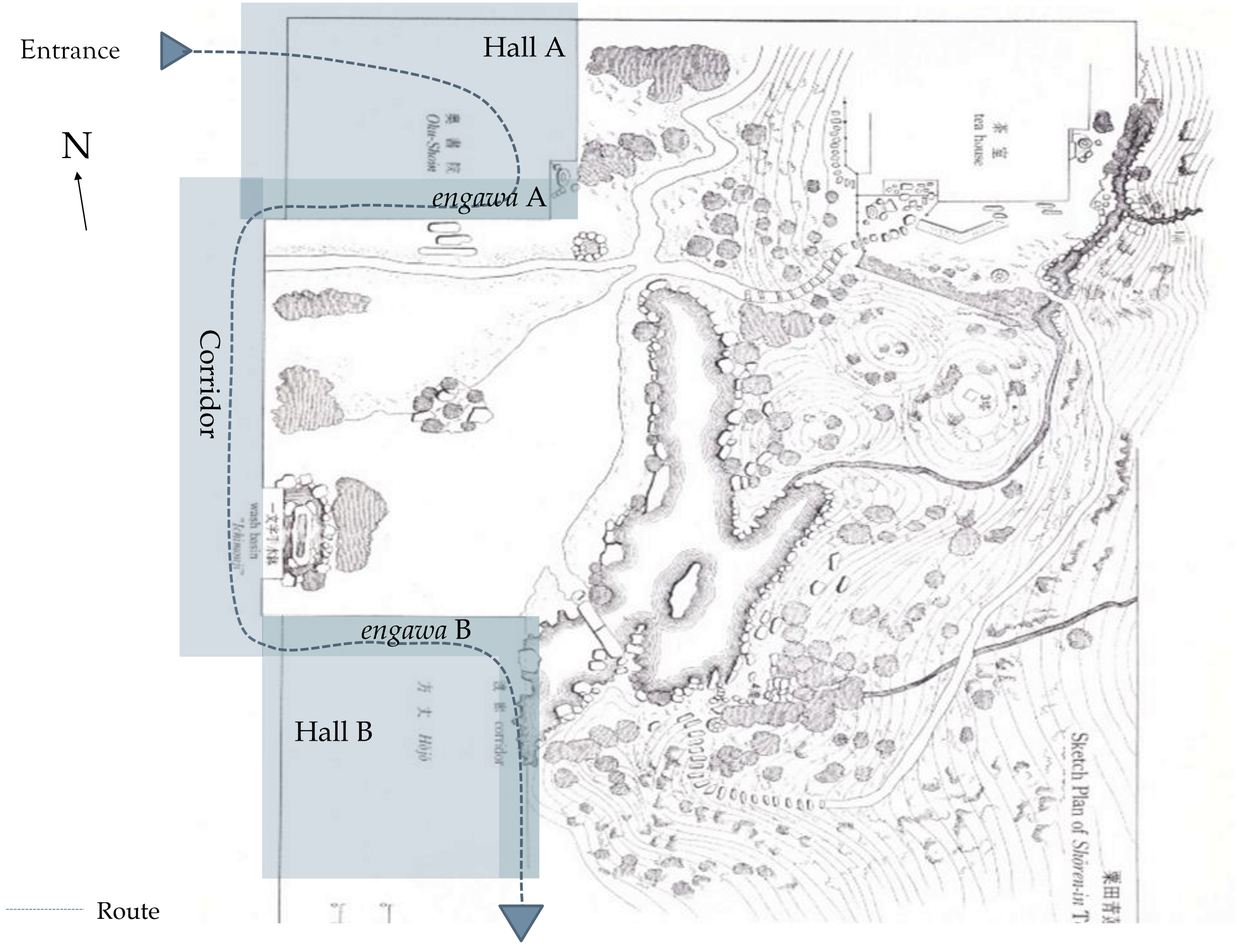


Lihua Cui
Kyoto University
lihua.cui.36x@st.kyoto-u.ac.jp

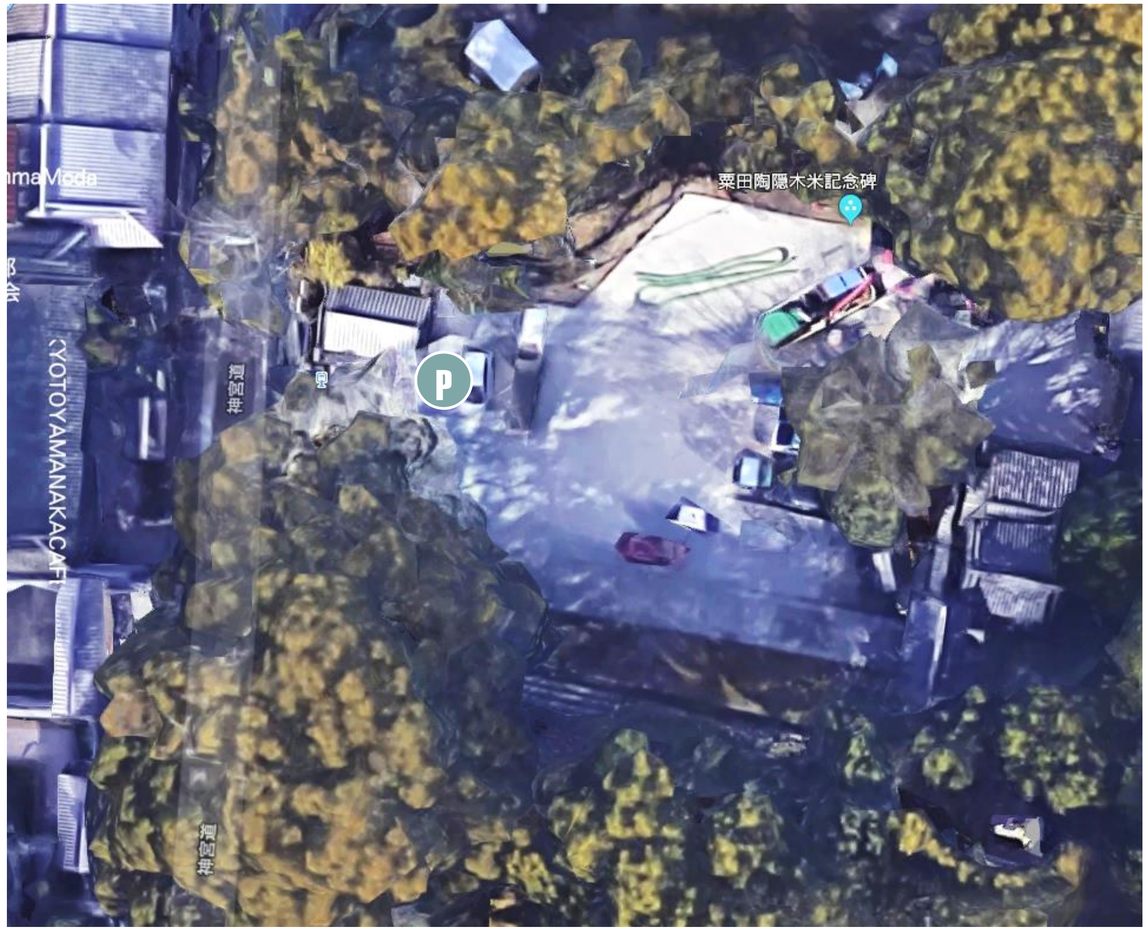
# Research Site



## | Plan of Shoren-in Temple Garden




## | Parking Area

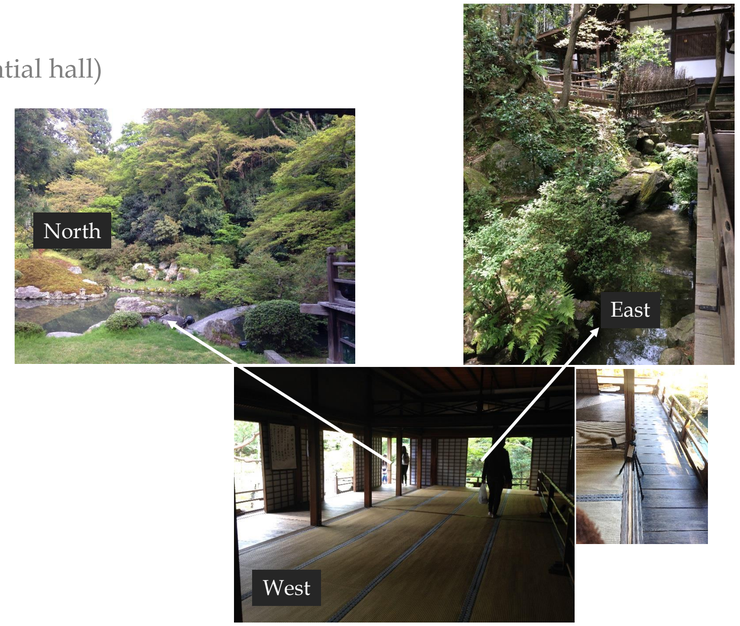

Lihua Cui
Kyoto University
lihua.cui.36x@st.kyoto-u.ac.jp

World Forum on Urban Forests
Mantova 2018

Methodology


## | A (main hall/reception hall)


## | B (residential hall)




# | What we did

Kestrel 5400
Air temperature,
Globe temperature,
Relative humidity,
Wind speed,
Wind direction,
Etc.

NS9200 Thermography Camera
Surface temperature

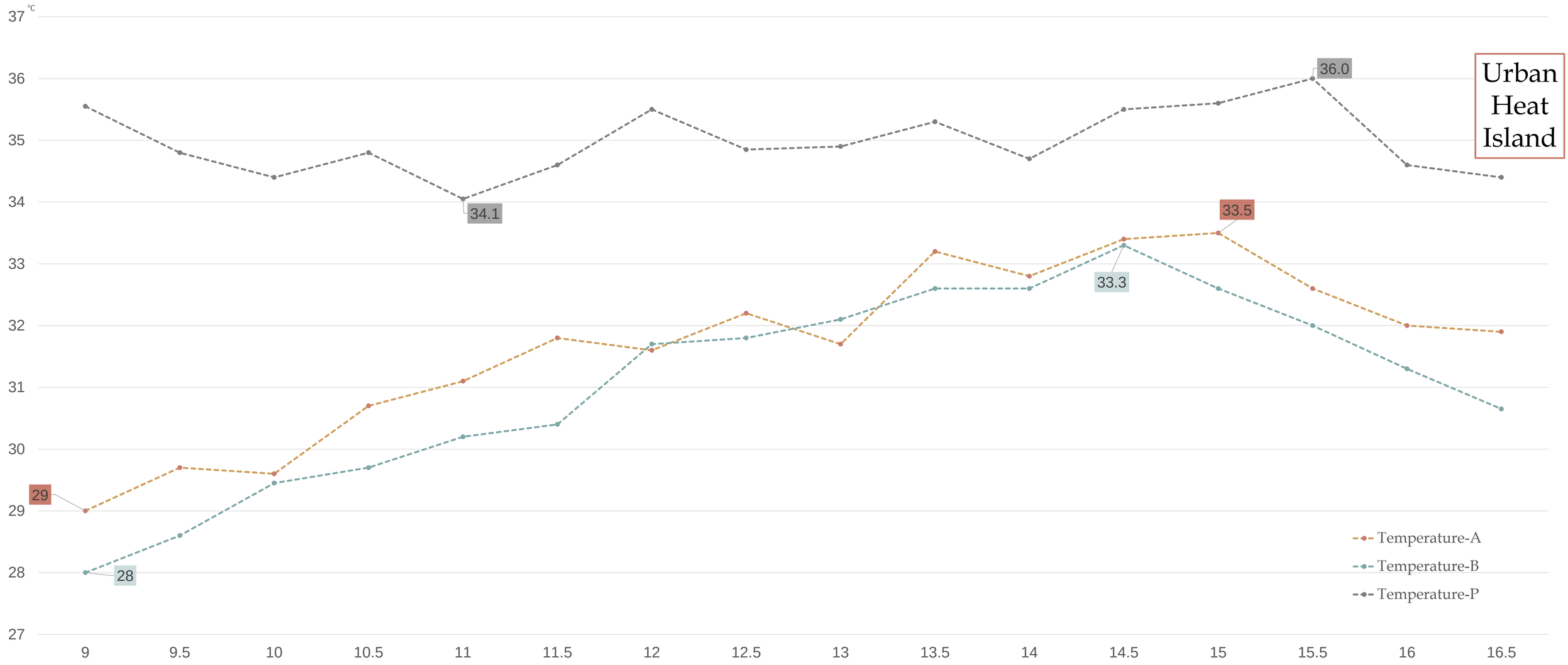
Record length of stay of visitors at A and B,

Including: Time , gender, age range, Japanese or foreigners, visiting alone or with others, and activities.

Lihua Cui
Kyoto University
lihua.cui.36x@st.kyoto-u.ac.jp

# Microclimate | Temperature (A&B&P)

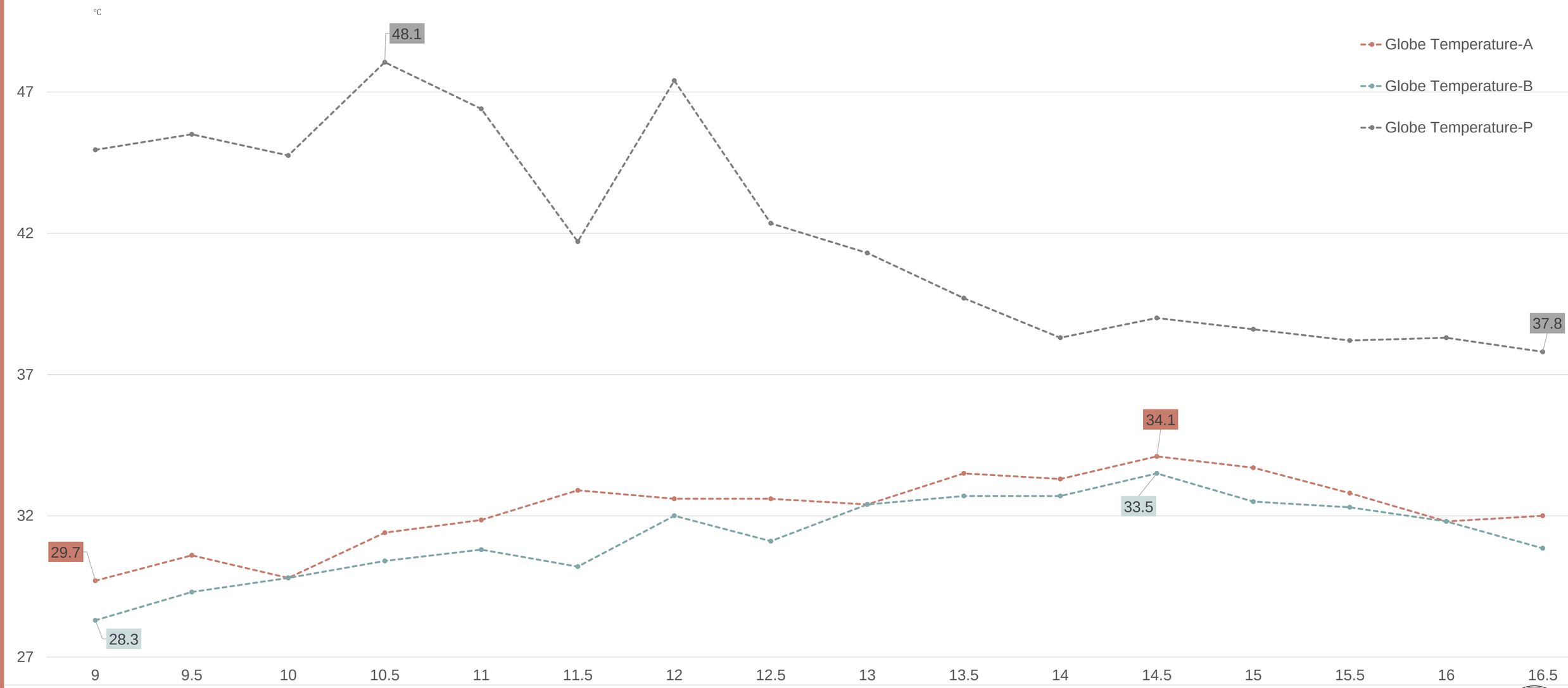
Result




Lihua Cui
Kyoto University
lihua.cui.36x@st.kyoto-u.ac.jp

# Microclimate | Globe Temperature (A&B&P)

Result

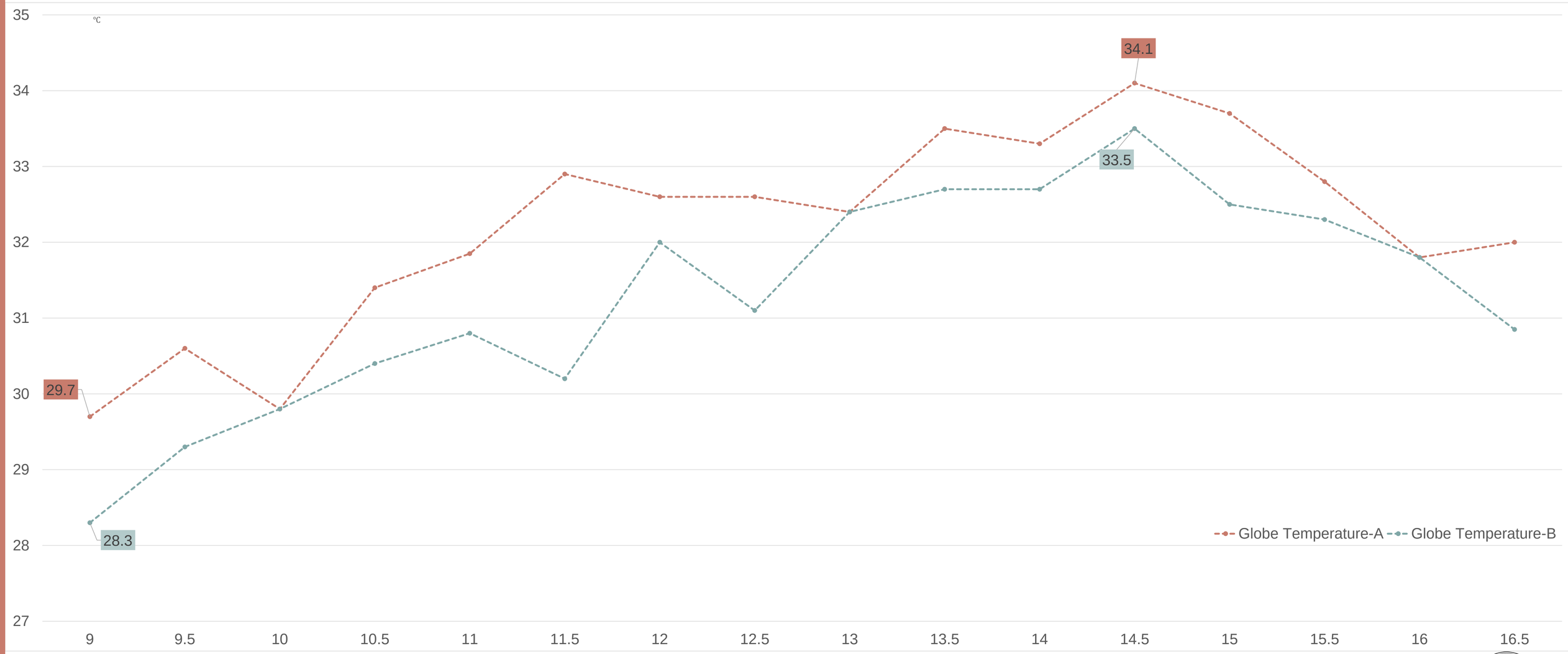



Lihua Cui
Kyoto University
lihua.cui.36x@st.kyoto-u.ac.jp

World Forum on Urban Forests
Mantova 2018

# Microclimate | Globe Temperature (A&B)

Result

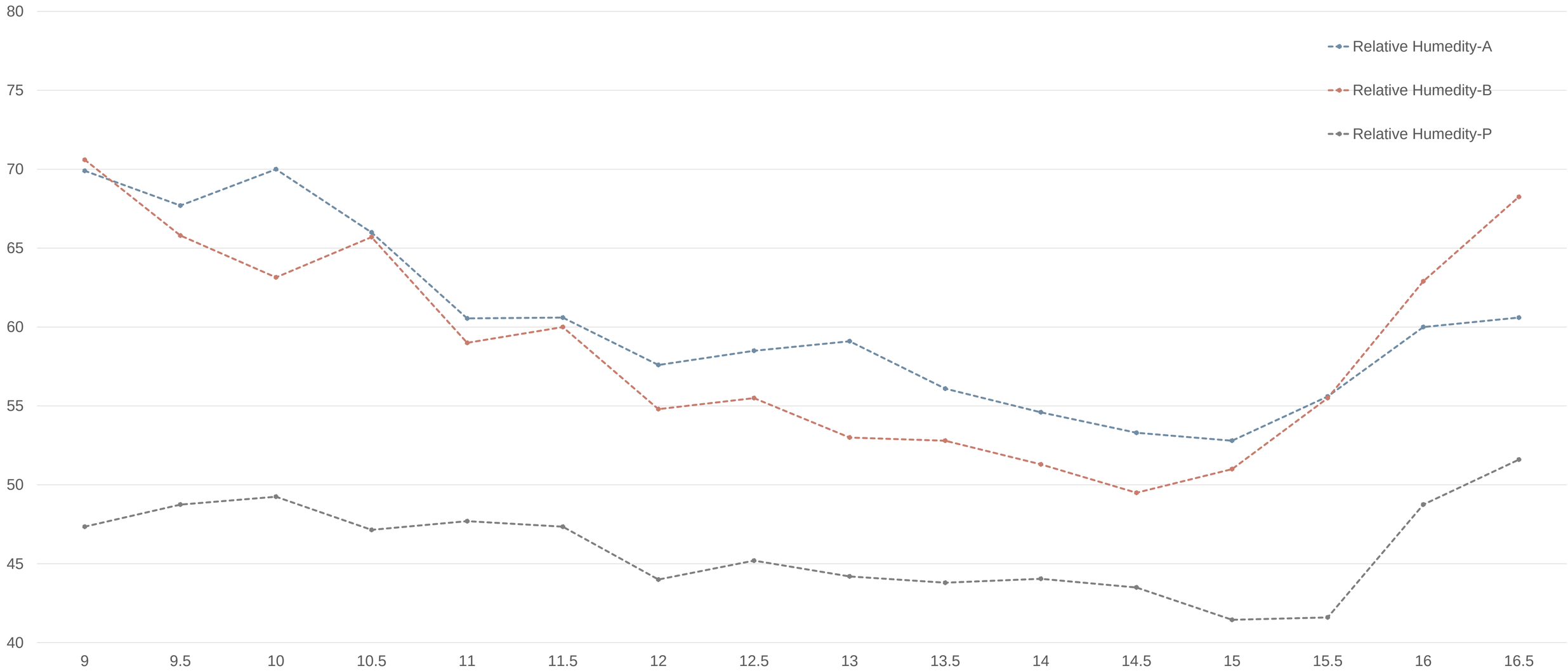



Lihua Cui
Kyoto University
lihua.cui.36x@st.kyoto-u.ac.jp

World Forum on Urban Forests
Mantova 2018

# Microclimate | Relative Humidity (A&B&P)

Result




Lihua Cui
Kyoto University
lihua.cui.36x@st.kyoto-u.ac.jp

World Forum on Urban Forests
Mantova 2018

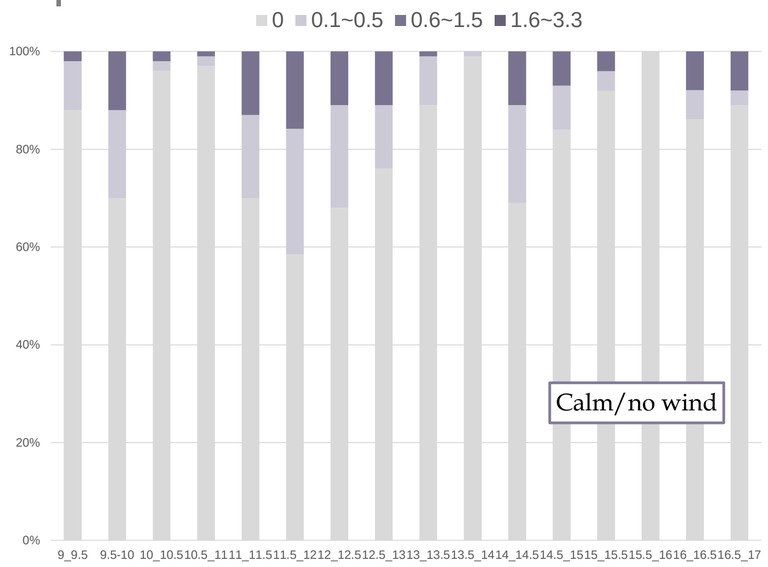
# Microclimate | Wind Speed

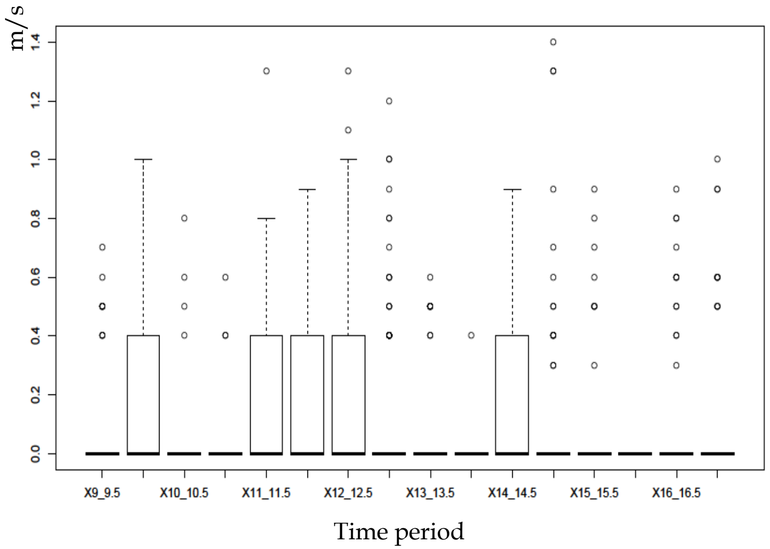
Result

**Beaufort Wind Scale**

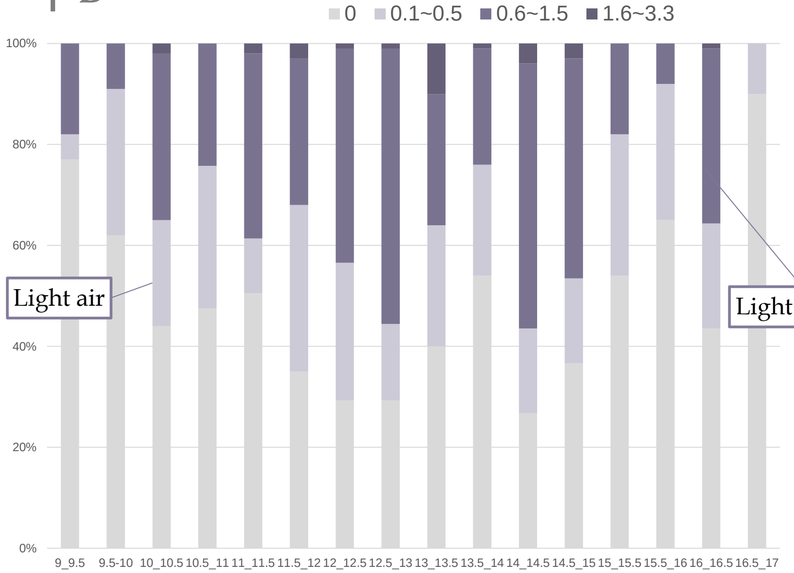
| | |
|---|---|
| 1.6~3.3m/s | Gentle breeze |
| 0.6~1.5m/s | Light breeze |
| 0.1~0.5m/s | Light air |
| 0m/s | Calm |

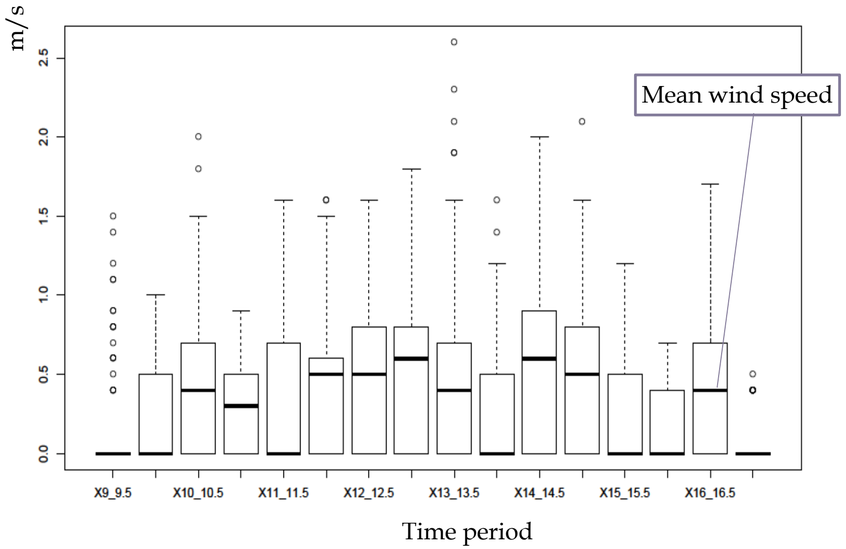
## | A



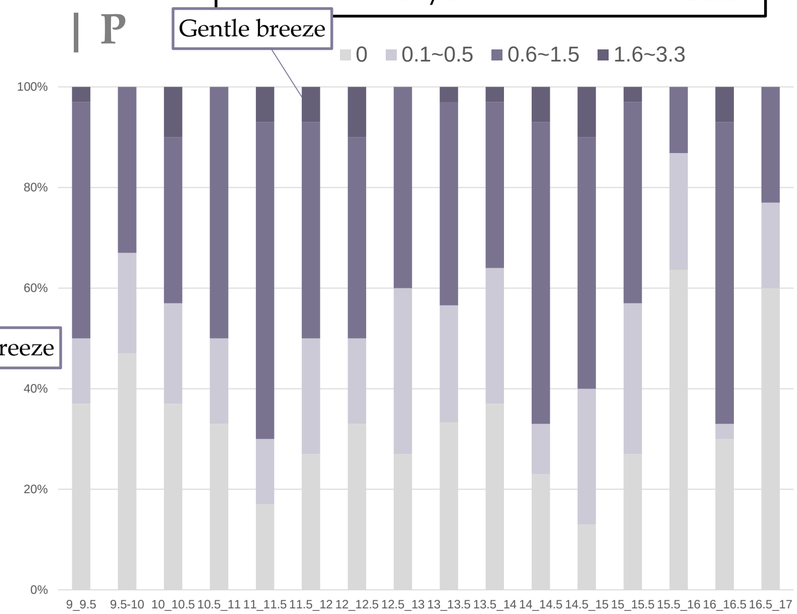



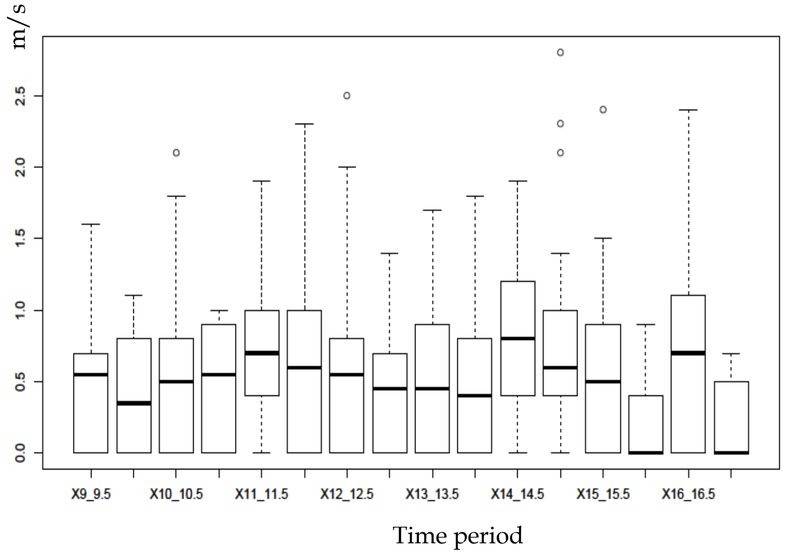

## | B



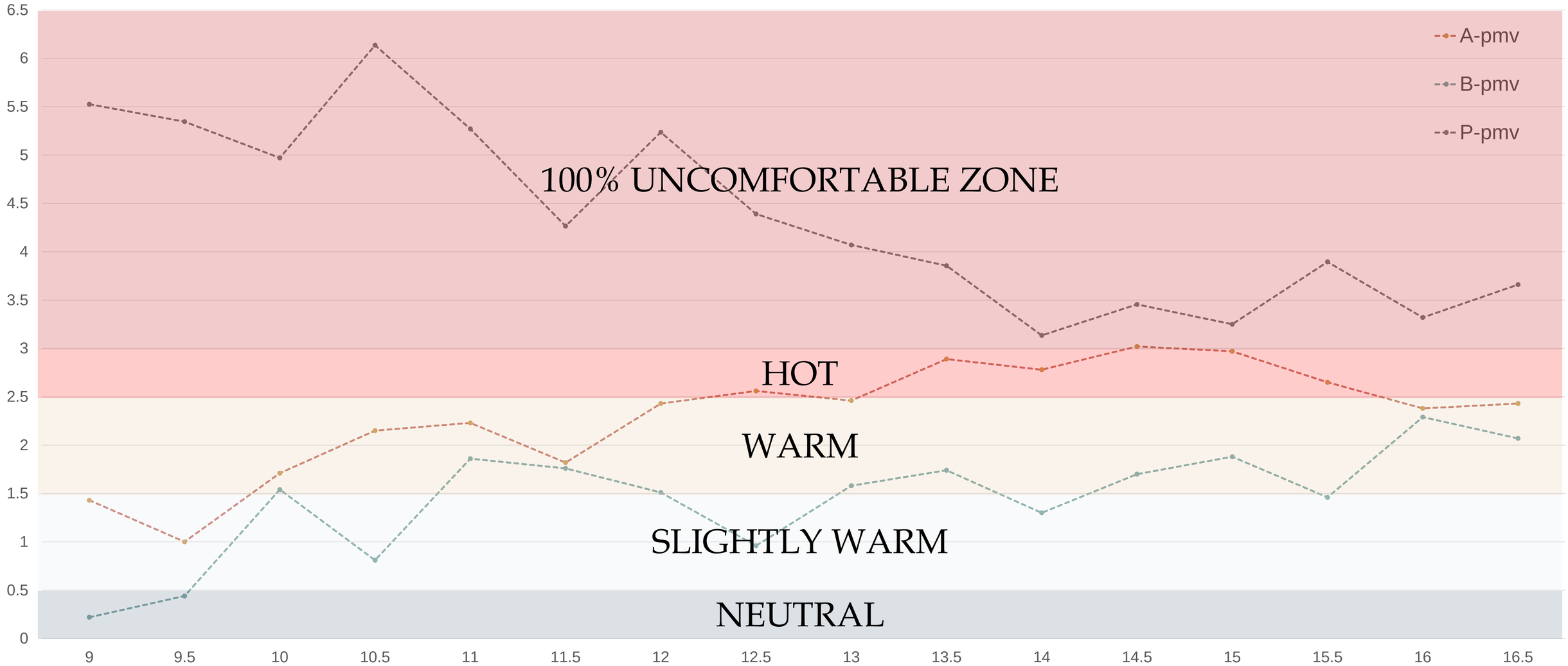

## | P



# PMV (Predicted Mean Vote)

PMV is calculated with air temperature, mean radiant temperature, relative humidity, air speed, metabolic rate, and clothing insulation.
Metabolic rate: 1 met (=sitting)  Clothing insulation: 0.5clo (=typical summer clothes)




Result

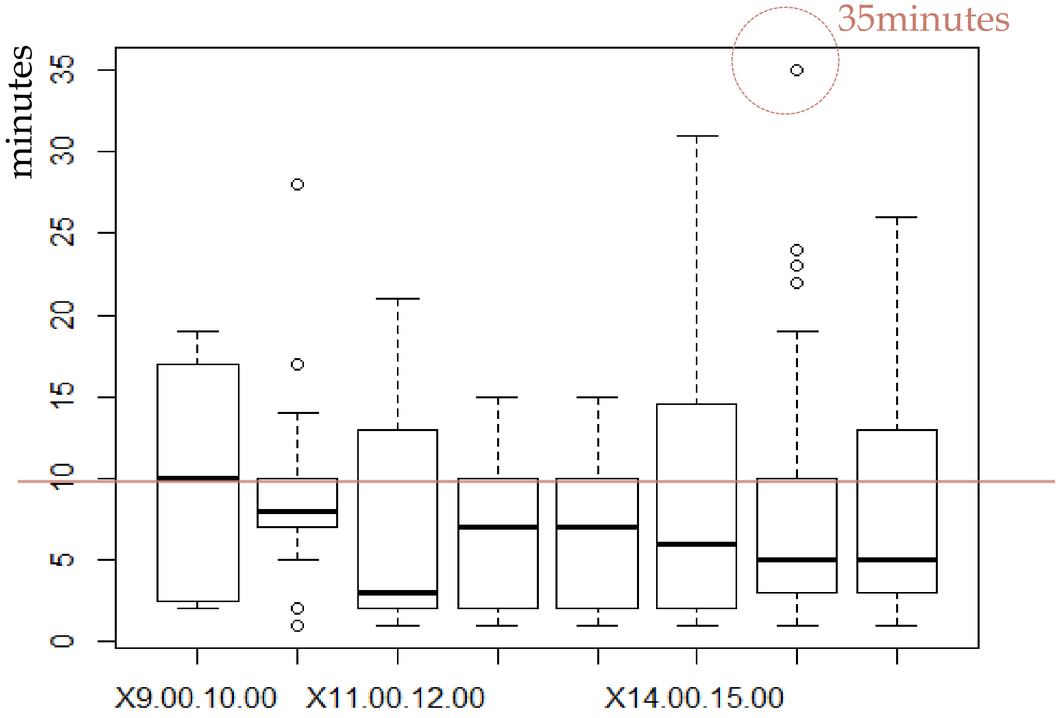


Lihua Cui
Kyoto University
lihua.cui.36x@st.kyoto-u.ac.jp

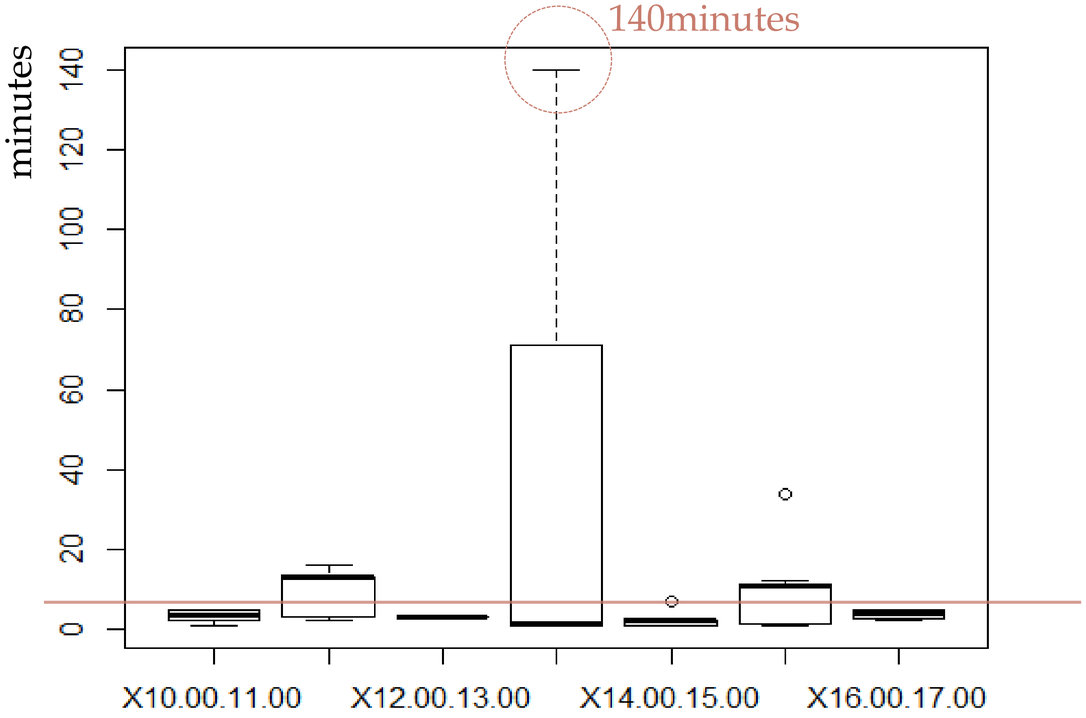
# Length of stay of visitors

Result

A




B



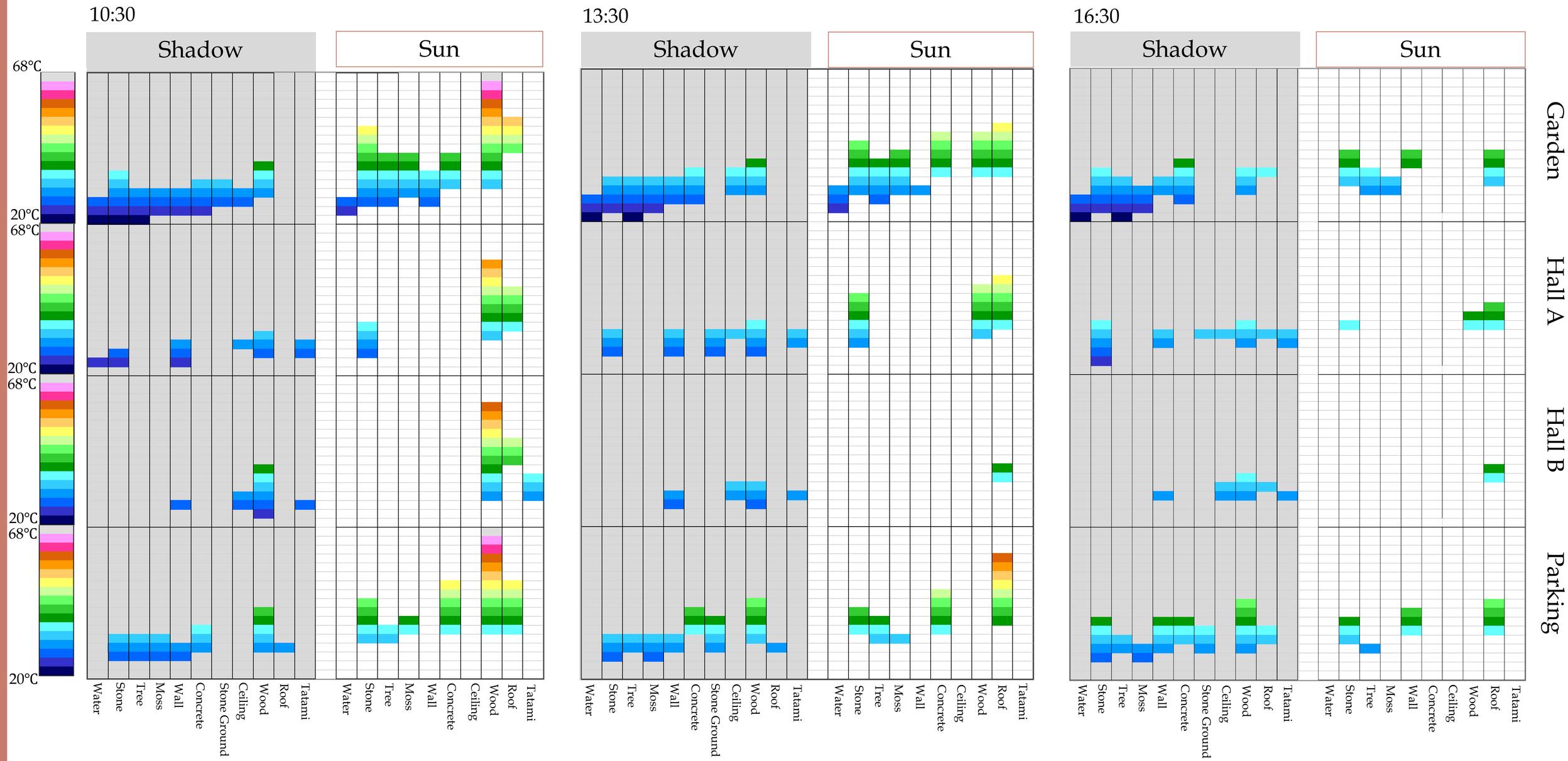



Lihua Cui
Kyoto University
lihua.cui.36x@st.kyoto-u.ac.jp

World Forum on Urban Forests
Mantova 2018

# Surface Temperature of objects at Hall A, Hall B and Parking Area

Result



Discussion

## 1. Characteristics of the microclimate in Zen gardens?

- Temperature

The temperature of the garden is different from regular urban spaces, no urban heat island effect was found in the garden. Air temperature in the garden is low in the morning and evening, higher in the noon and afternoon.

- Globe Temperature

Significant difference is detected between the parking area and the garden. Roof of the halls prevent solar radiation, hence globe temperature in the Hall A and Hall B is low. → Sunshade is critical for the comfortable microclimate in the summer.

The difference in globe temperature between A and B shows different terrestrial radiation environment at Hall A and Hall B.

- Wind

Hall A is calm during the day, however, wind at Hall B and parking area was frequent. There were more Gentle Breeze at parking area than at Hall B, which is reasonable owing to the broad space of parking area.

- PMV

The parking area is uncomfortable (even dangerous) to stay for a long time.

△ ***Engawa* B is the most comfortable microclimate in the summer in Shoren-in Temple garden.**

△ **We suppose the frequent wind and low globe temperature contributed to the comfortable microclimate at Hall B.**

Lihua Cui
Kyoto University
lihua.cui.36x@st.kyoto-u.ac.jp

## 2. How the gardens function on mitigating summer heat?

> **Water has the lowest surface temperature among the objects in the garden and the parking area.** The garden has a large area of pond, we assume the pond with the dense forest skirts it plays as a cooler in the garden.

> **The objects which were under the sun in the morning became hidden in the shadow as time went on.** Fewer objects were under the sun at noon and few of the objects were under the sun in the afternoon. Particularly, Hall B is completely hidden in the shadow from the noon, no object is exposed to the sun except the roof. This phenomena explains the lowest globe temperature at Hall B among the three points we have investigated.

> Compared to Hall B, Hall A has several objects nearby with higher surface temperature, such as stones and woods, hence people sitting at Hall A would receive more terrestrial radiation than at Hall B. **In summary, with more wind but less terrestrial radiation at Hall B, people would feel more comfortable at Hall B compared to at Hall A.**

> In the parking area, there was no object with surface temperature lower than 26℃, the surface temperature range of majority of the objects were between 30℃ to 40℃. With such a condition, we assume it is hard to create a cool zone to cool down the area. Contrary, the large area of concrete and stone pavement, which absorb substantial amount of radiation and emit it back to the space, acts as a heater and make the environment uncomfortable.

## 3. How to apply the heat mitigation strategies of Zen gardens to urban open spaces?

Will be considered on the further studies...

Lihua Cui
Kyoto University
lihua.cui.36x@st.kyoto-u.ac.jp

World Forum on
Urban Forests
Mantova 2018




Lihua Cui
Kyoto University
lihua.cui.36x@st.kyoto-u.ac.jp