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Can LECA be Used to Improve the Thermal Performance of an Extensive Green Roof ?

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INTRODUCTION

Research Motivation

The structure loads of most buildings in Taiwan always merely meet the minimum legal requirement to minimize the construction costs.

According to the architectural regulation, the live load of buildings is only 200 kilogram/m^2. Given that, using the traditional garden soil, the total weight load can easily exceed the designed live load if an adult is introduced to an extensive green roof system with growth medium exceeding 10 cm in depth after irrigation.

Research Motivation

The thermal properties of a medium vary significantly as a function of medium design, and the pores and air holes in the medium can play crucial roles in reducing the medium's thermal conductivity.

Growth medium containing material such as porous silica-based aggregate or expanded vermiculite can effectively reduce the thermal conductivity of growth medium.

Research Motivation

Consequently, in this study we attempted to develop a lighter green roof with lower conductive capability than the traditional green roof using lightweight expanded clay aggregate (LECA).

LECA is appropriate because it is a lightweight growth medium containing numerous air holes which can reduce thermal conductivity of the growth medium.

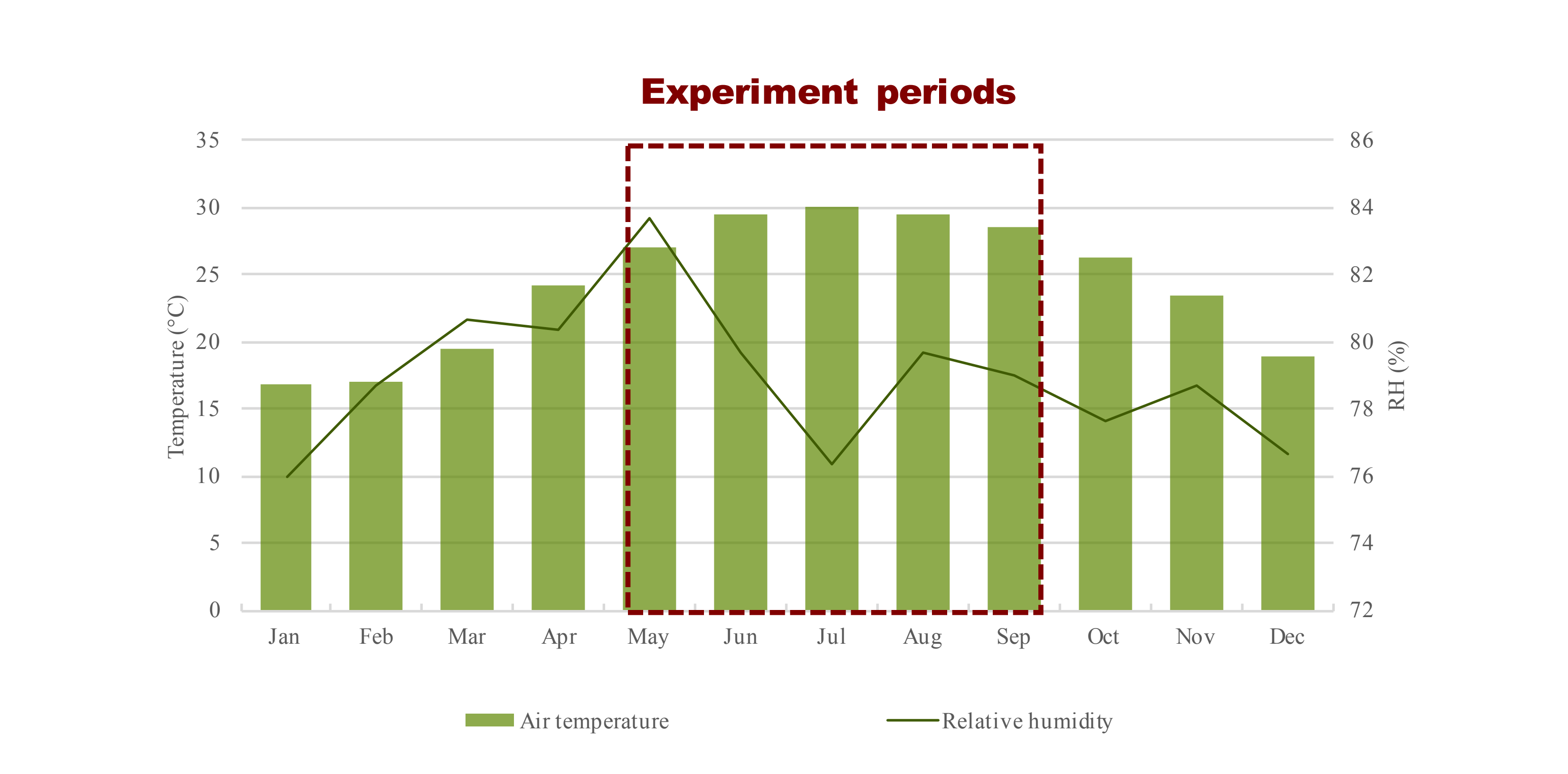
Research Purpose

- To investigate the depth of the growth medium that elicits the most efficient thermal performance;
- To explore the proportion of LECA providing highest effect on temperature reduction of the rooftop;
- To compare the placement methods of LECA that results in higher thermal performance;
- To conduct a cost–benefit analysis of the LECA-containing roofs.

STUDY DESIGN

Experiment site & Experiment periods

- In the metropolitan area
- Warm oceanic climate/humid subtropical climate
- Hottest months of the year: May ~ Sept.
- Relative humidity: 76.0% ~ 83.7%



LECA Features

1. A lightweight aggregate produced by baking a mixture of clay powder and saw dust.

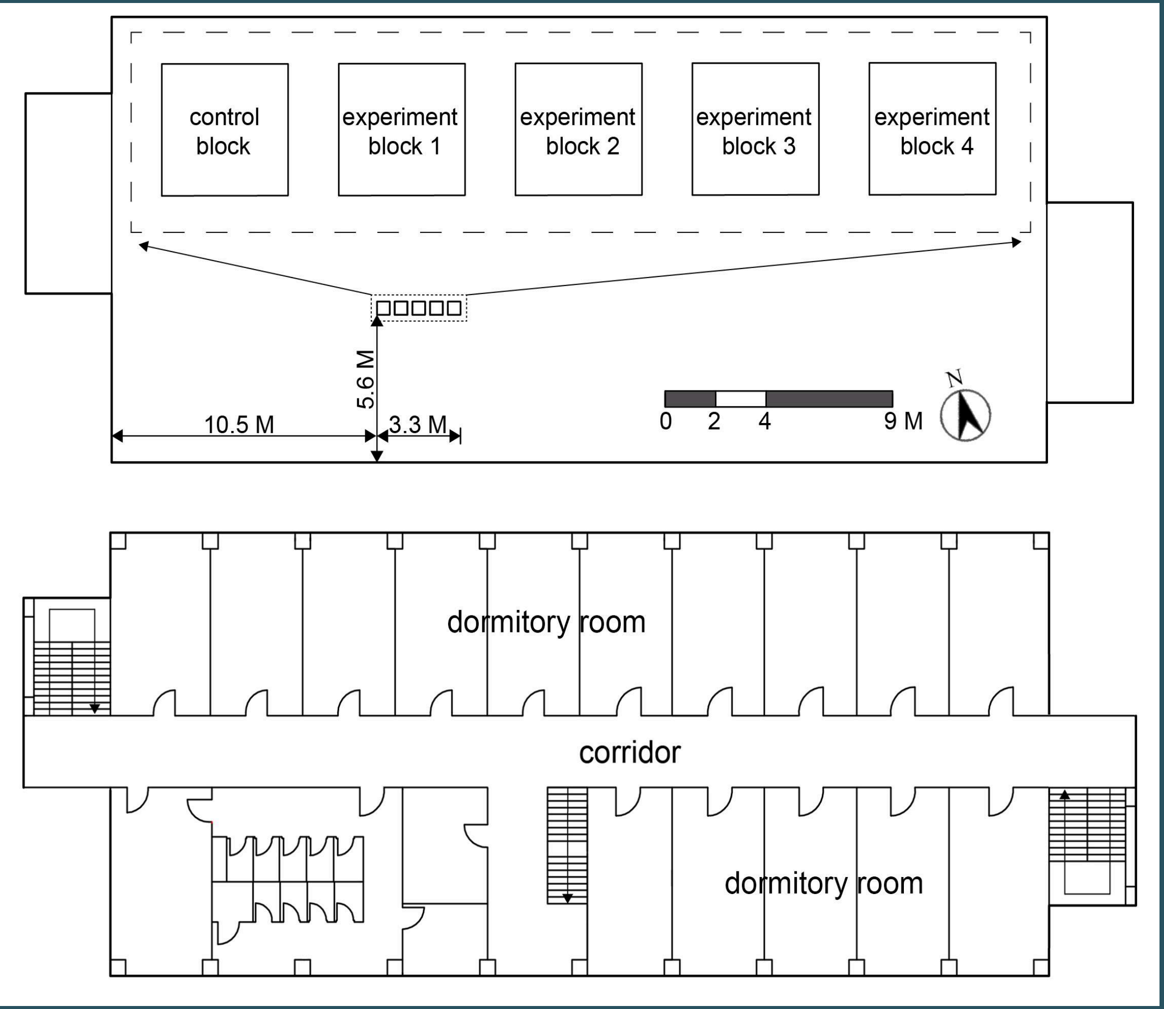
2 .With a hard ceramic shall and a porous core.

3. Recyclable, durable, stable, nontoxic, and environmental friendly.

7. Lighten the structure weight load and for thermal insulation in buildings.

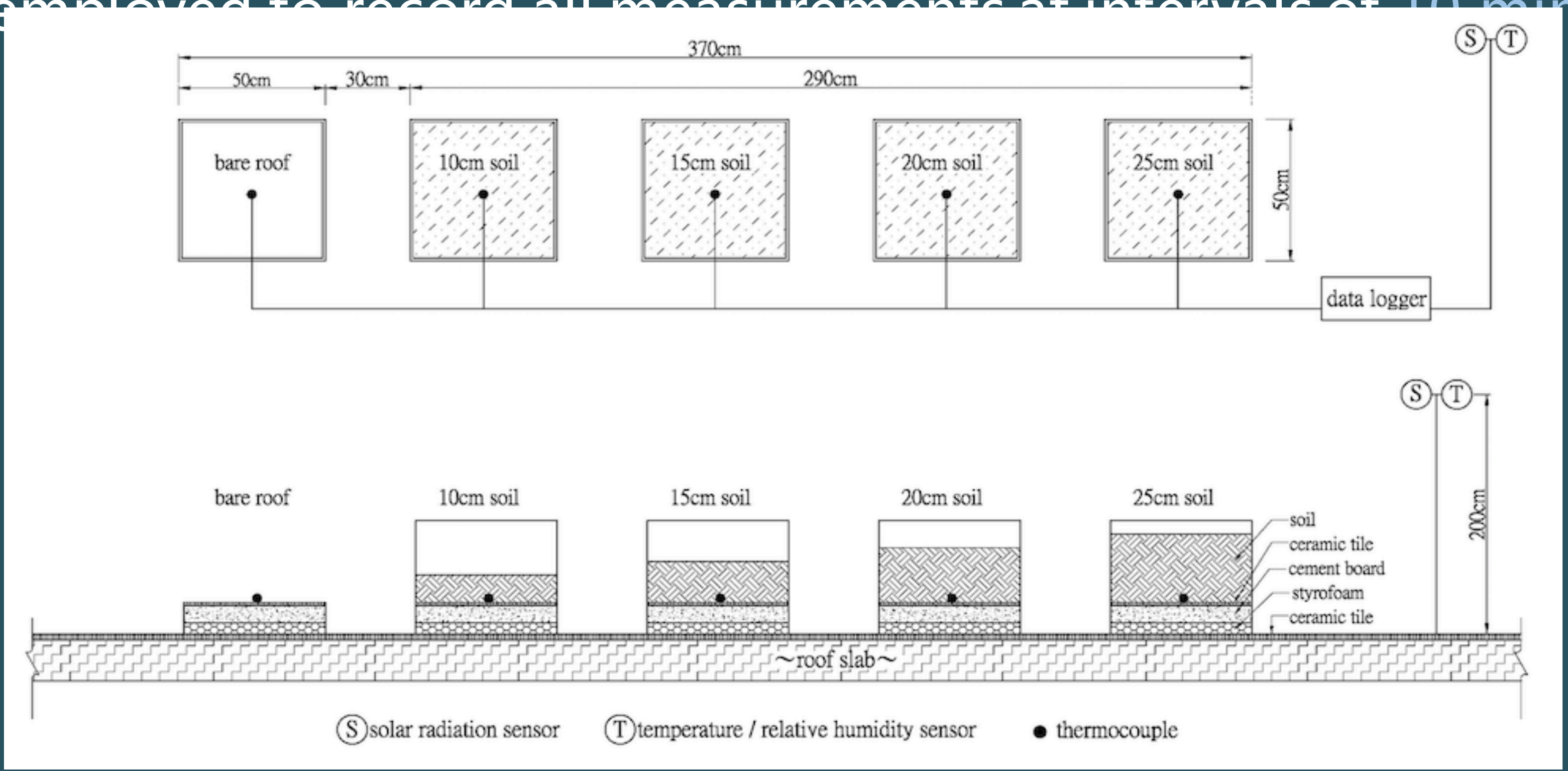
Experimental Location

The floor plans of the fourth and fifth floors



Experimental Setup

- 5 measurement points were placed at the bottom center of the extensive roof and at the center of the simulated bare roof.
- A thermal monitoring system comprising 3 data loggers was employed to record all measurements at intervals of 10 min.



Experimental Setup

4 experimental blocks

1 control block

Instruments and Parameters

Parameters	Equipment Used
Solar radiation	Solar radiation smart sensor
Air temperature & Relative humidity	12-bit Temperature/Relative humidity smart sensor
Temperature	12-bit Temperature smart sensor
-	Hobo micro station data logger

Solar radiation

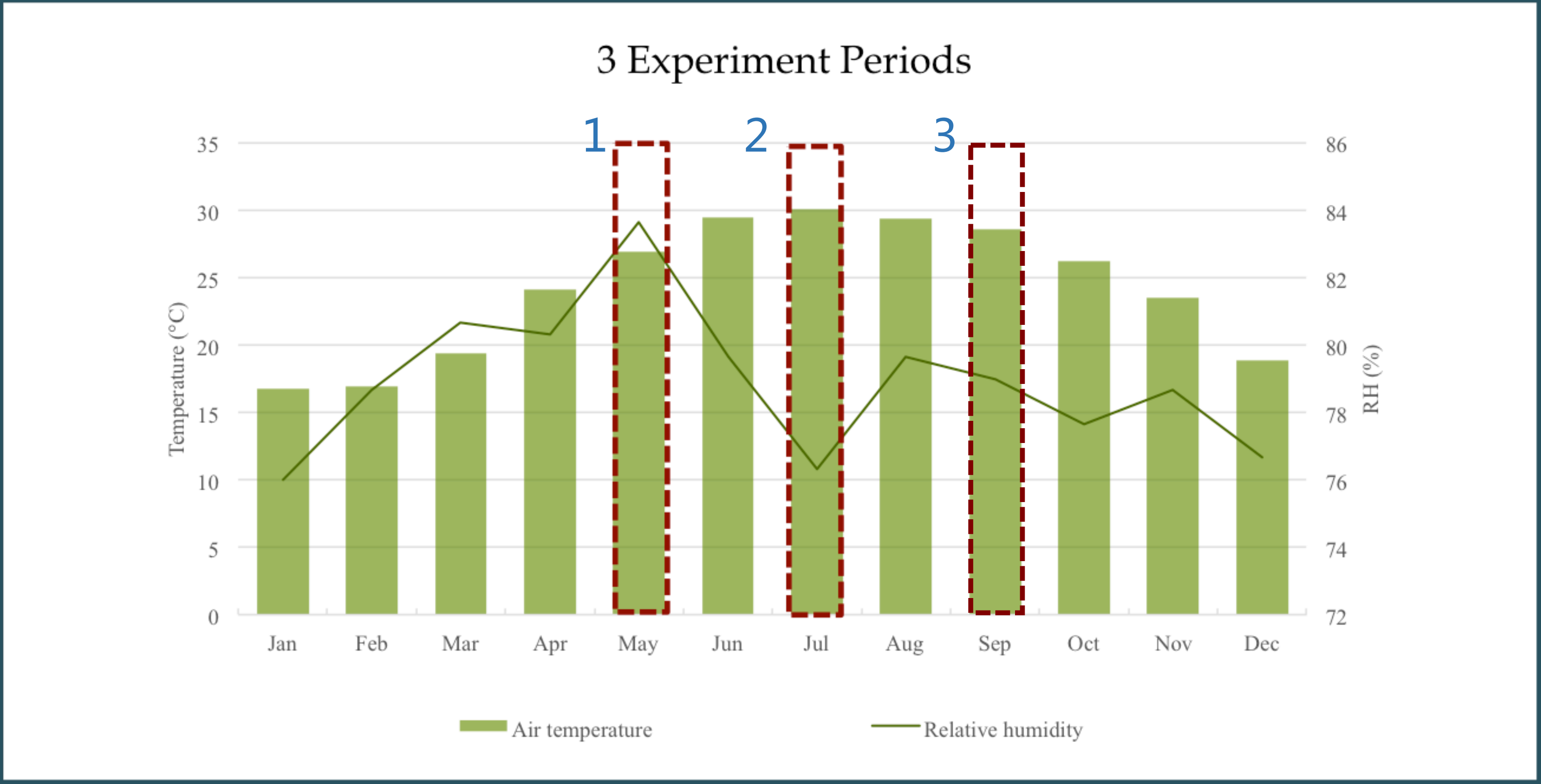
Air temperature & Relative humidity

Temperature

Data logger

Three Experiment Periods

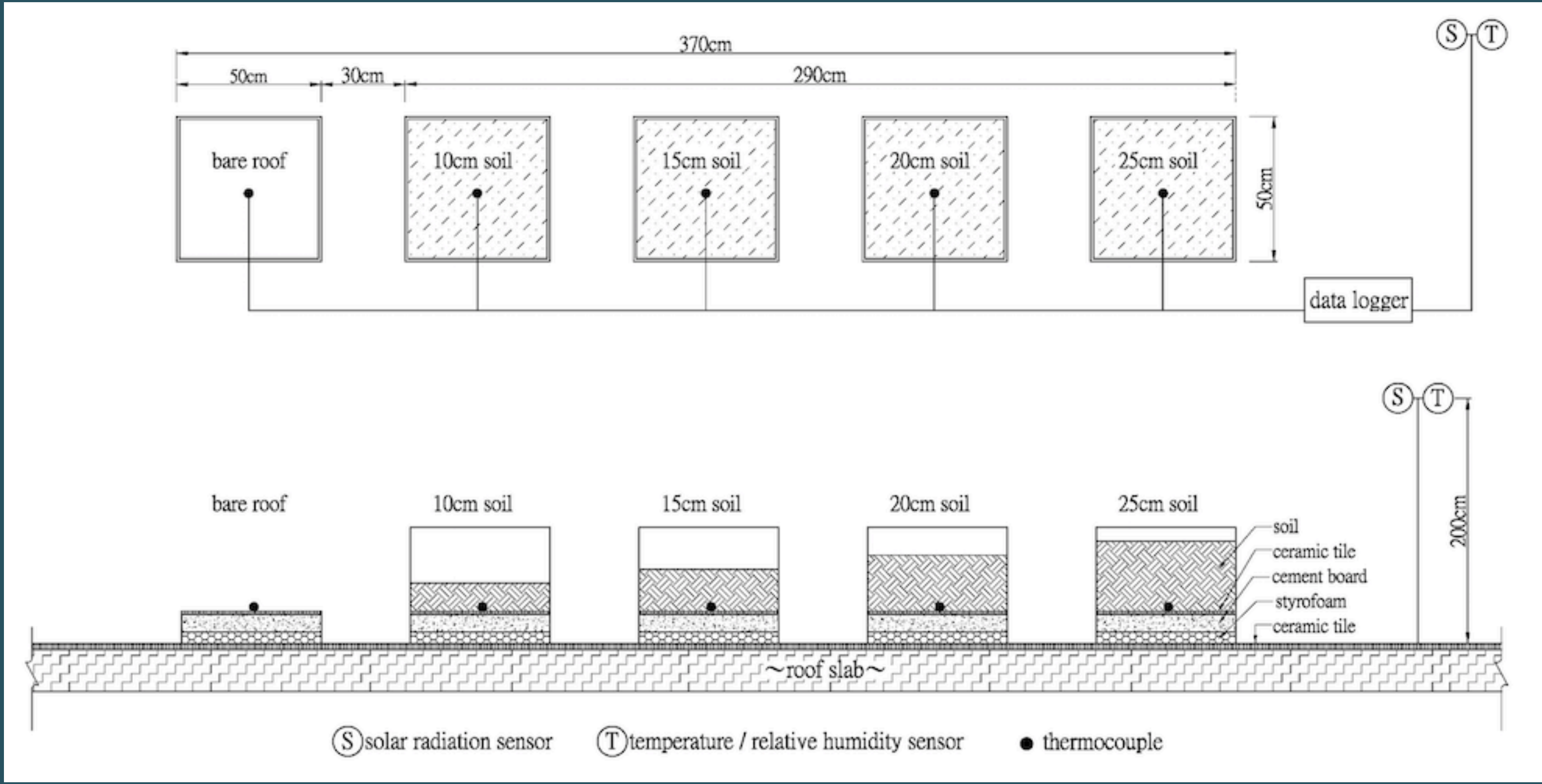
- Stage 1: May 13-23, 2017
- Stage 2: July 14-26, 2017
- Stage 3: Sept. 20-27, 2017



RESULTS & DISCUSSION

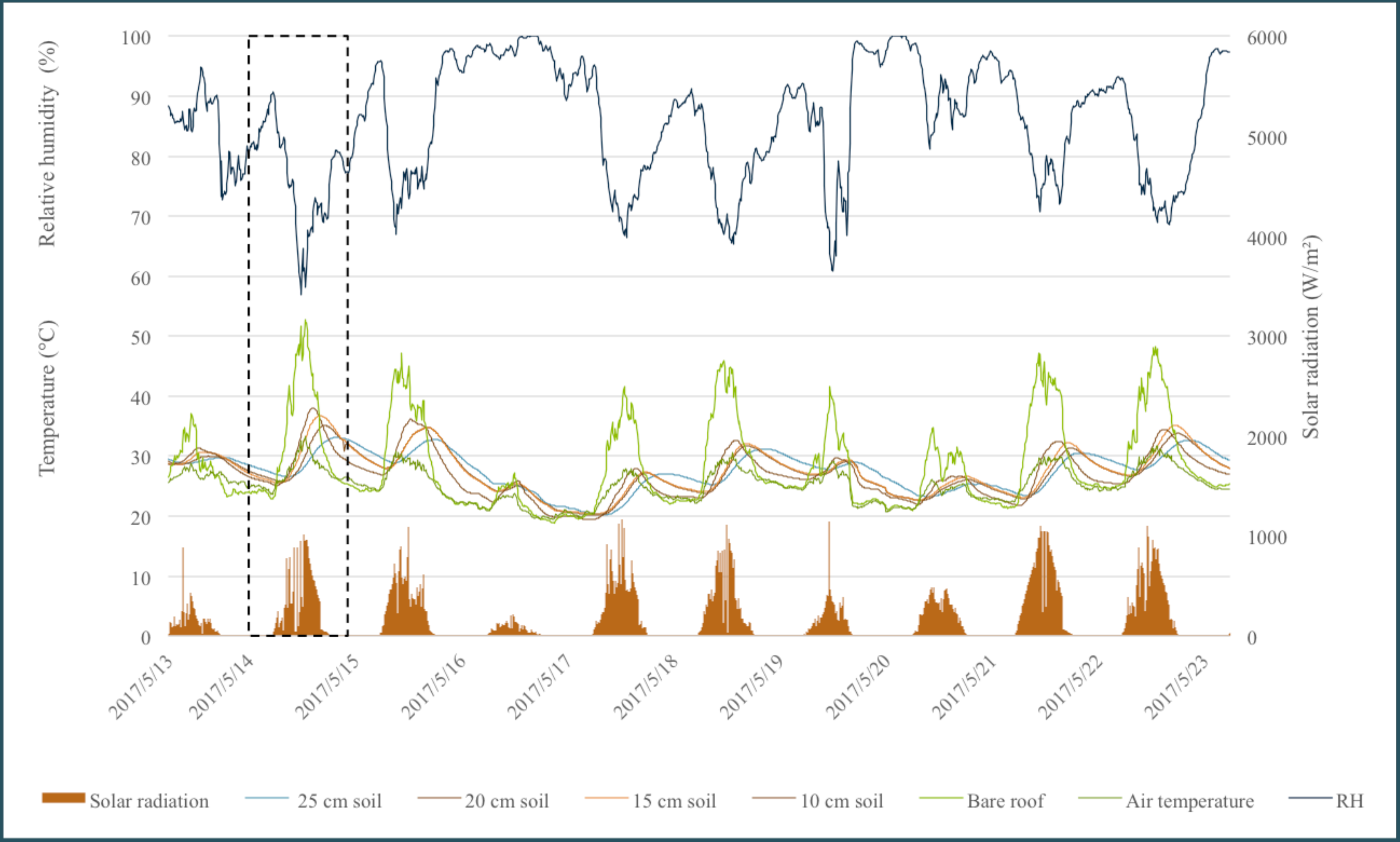
The First Stage

Comparing the thermal performance of extensive roofs with four different depths of growth medium: 10, 15, 20, and 25cm



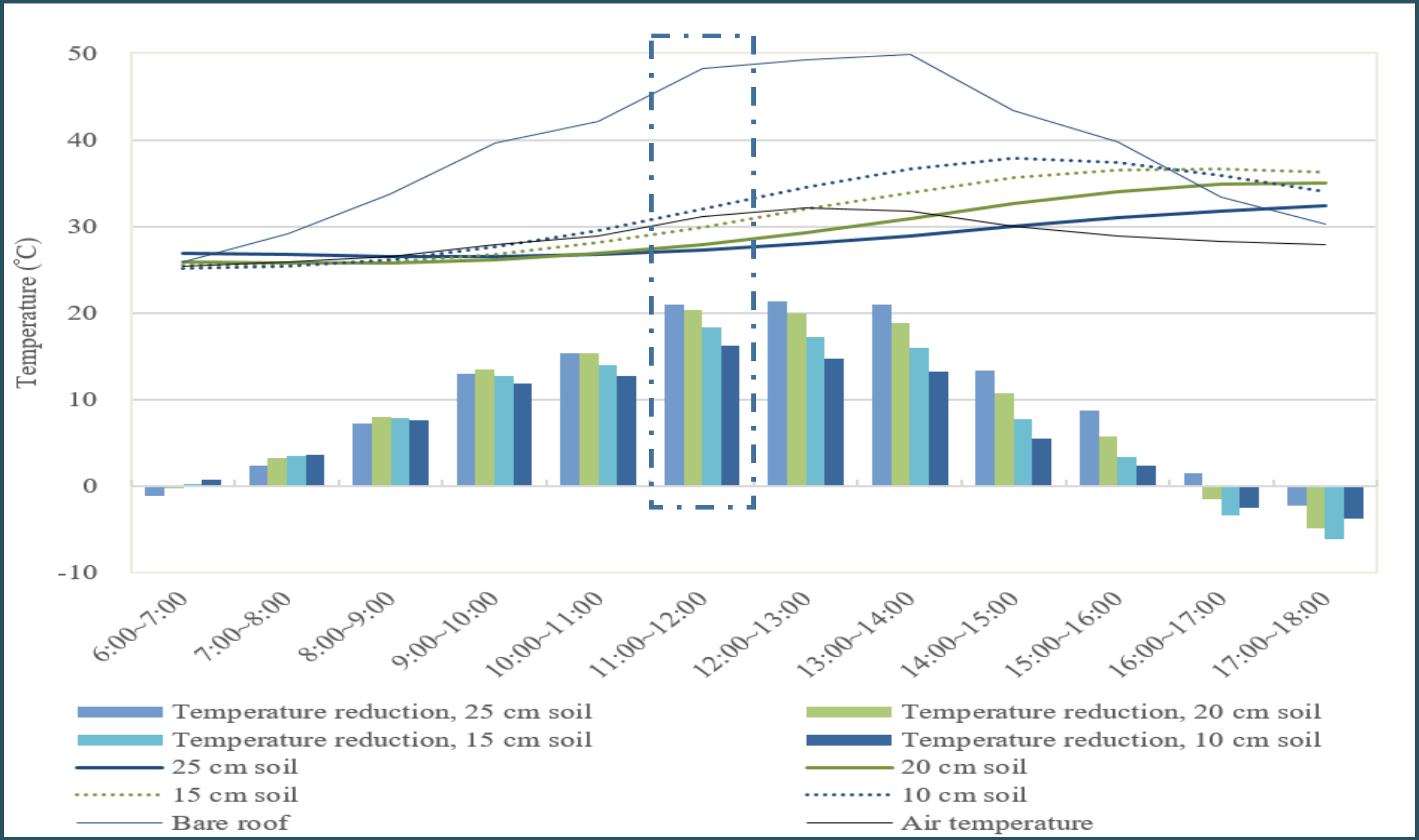
The First Stage

2017/05/14–15



The First Stage

2017/05/14–15



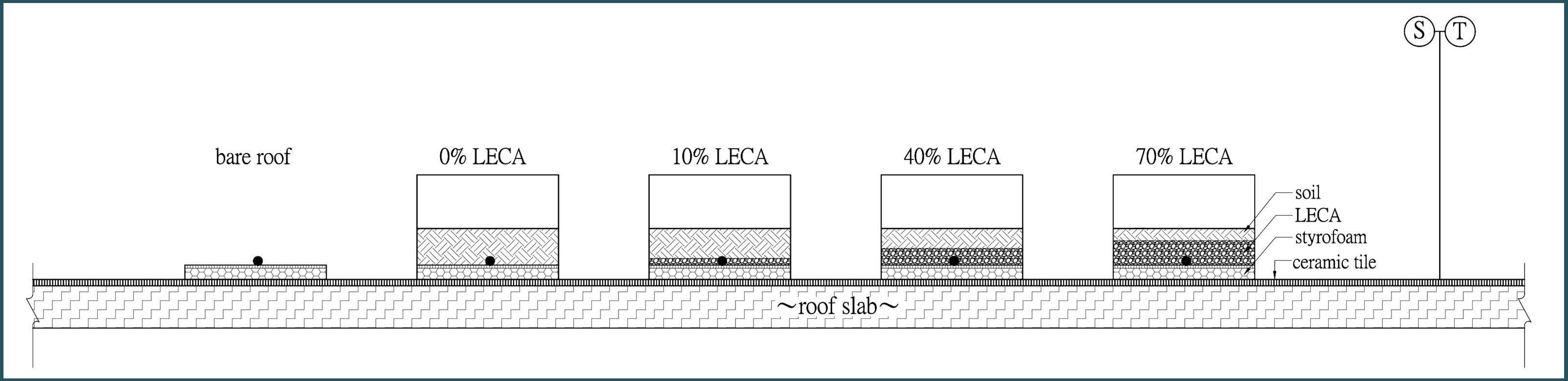
The First Stage

2017/05/14–15

Marginal temperature reduction in the cases of 10, 15, 20, and 25 cm pure-soil roofs (11:00 - 12:00)				
Thermocouple position	Temperature (°C)	Total temperature reduction (°C)	Increased soil depth (cm)	Marginal temperature reduction per cm depth of soil (°C)
Air temperature	31.14	-	-	-
Bare rooftop surface	48.26	-	-	-
At the bottom				
10 cm soil	32.02	16.24	10	**1.62**
15 cm soil	29.90	2.12	5	**0.42**
20 cm soil	27.88	2.02	5	**0.40**
25 cm soil	27.24	0.64	5	**0.13**

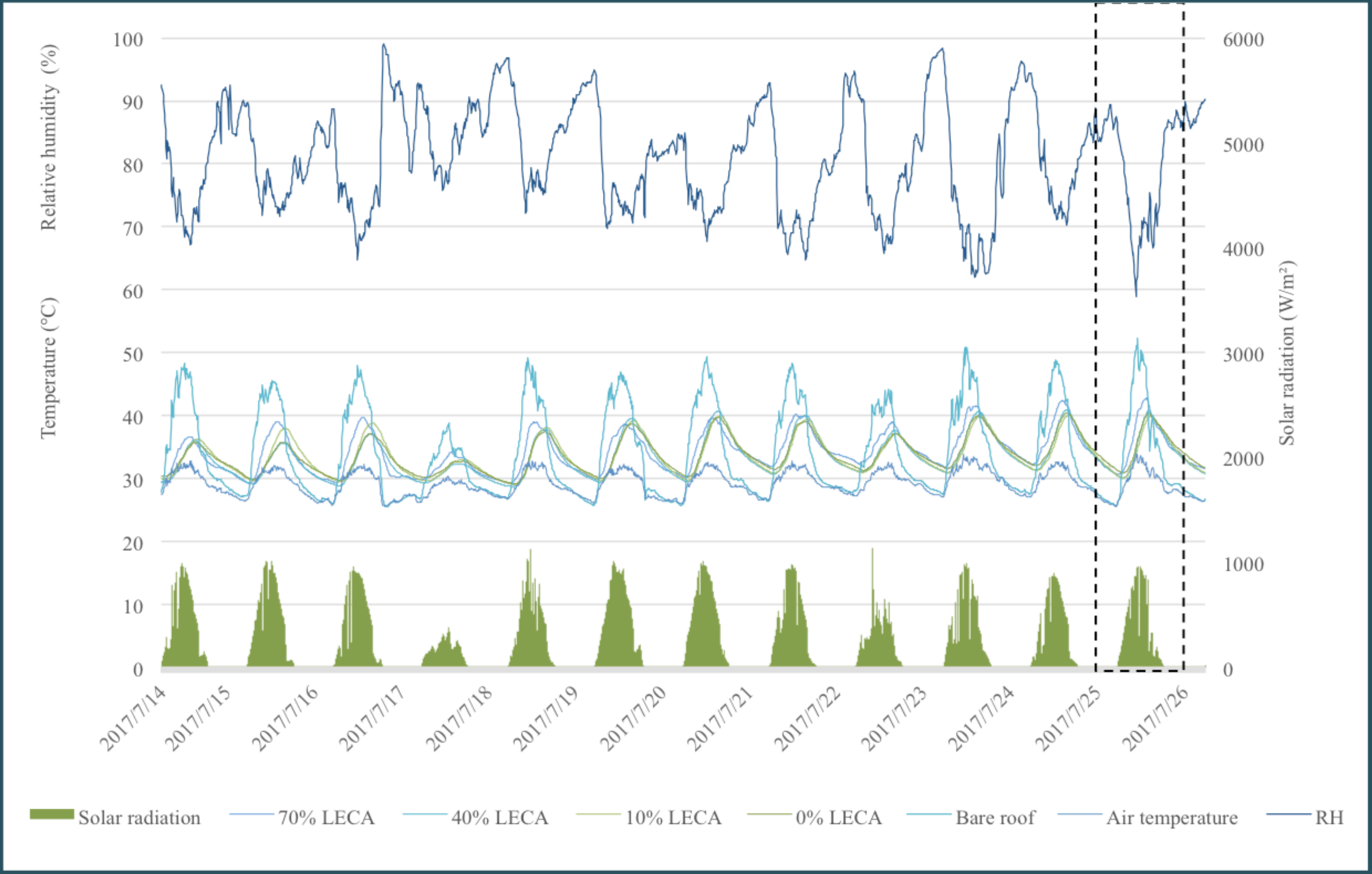
The Second Stage

Investigate the reductions in temperature and heat amplitude of the extensive roof on the bare rooftop when different proportions of LECA were laid at the bottom of the tanks.



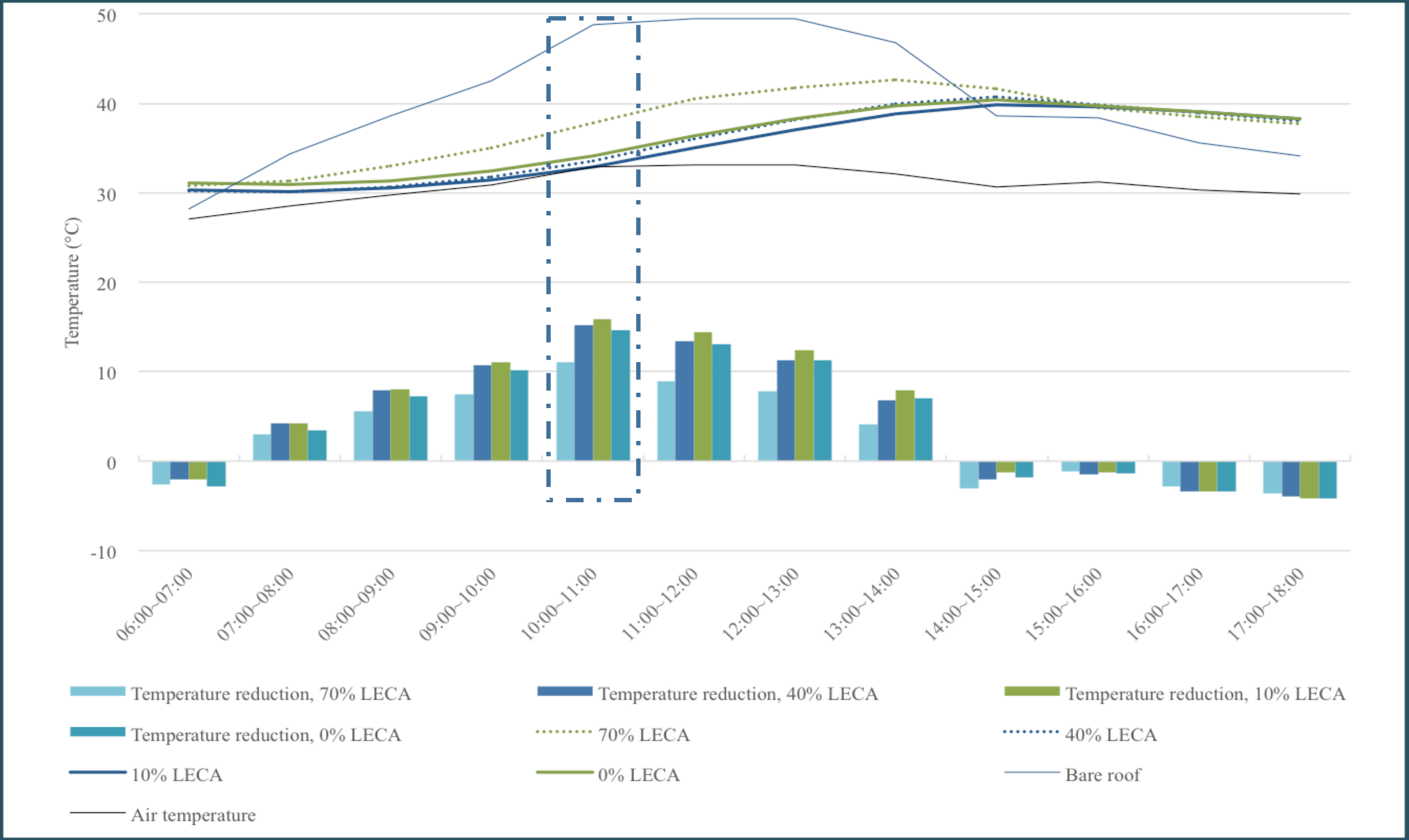
The Second Stage

2017/07/25-26



The Second Stage

2017/07/25-26



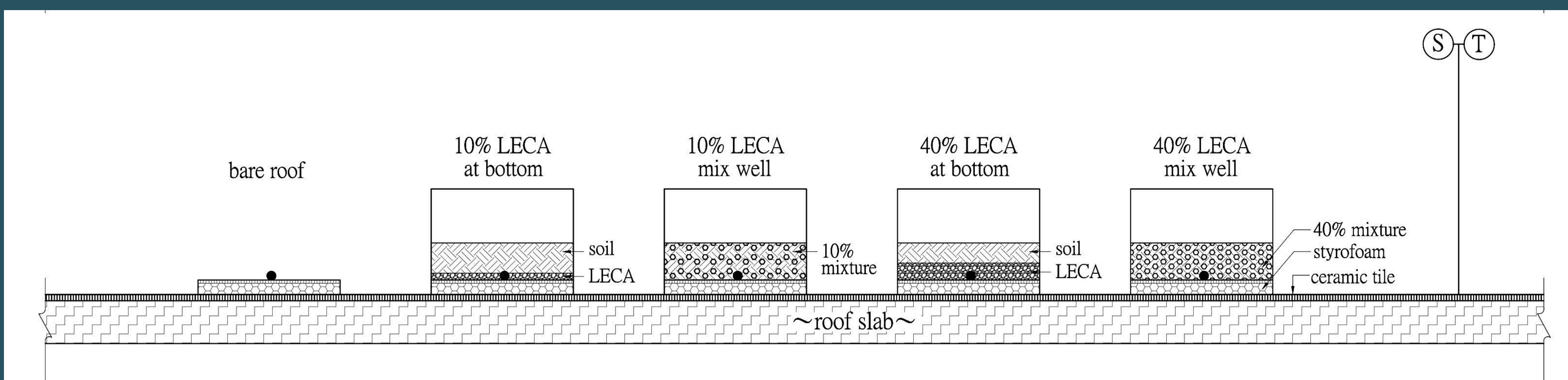
The Second Stage

2017/07/25-26

Thermalcouple Position	Type of extensive roof	Average temperature (°C)	Range of temperature (°C)	Difference in temperature (°C)	Heat amplitude reduction
In the air		29.13	26.33–33.94	7.61	-
Bare rooftop surface		34.35	26.38–52.24	25.86	-
At the bottom	0% LECA	35.13	30.90–40.46	9.56	**63.03%**
	10% LECA	34.46	30.09–39.94	9.85	**61.91%**
	40% LECA	34.55	30.04–40.78	10.74	**58.47%**
	70% LECA	35.56	30.72–42.77	12.05	**53.40%**

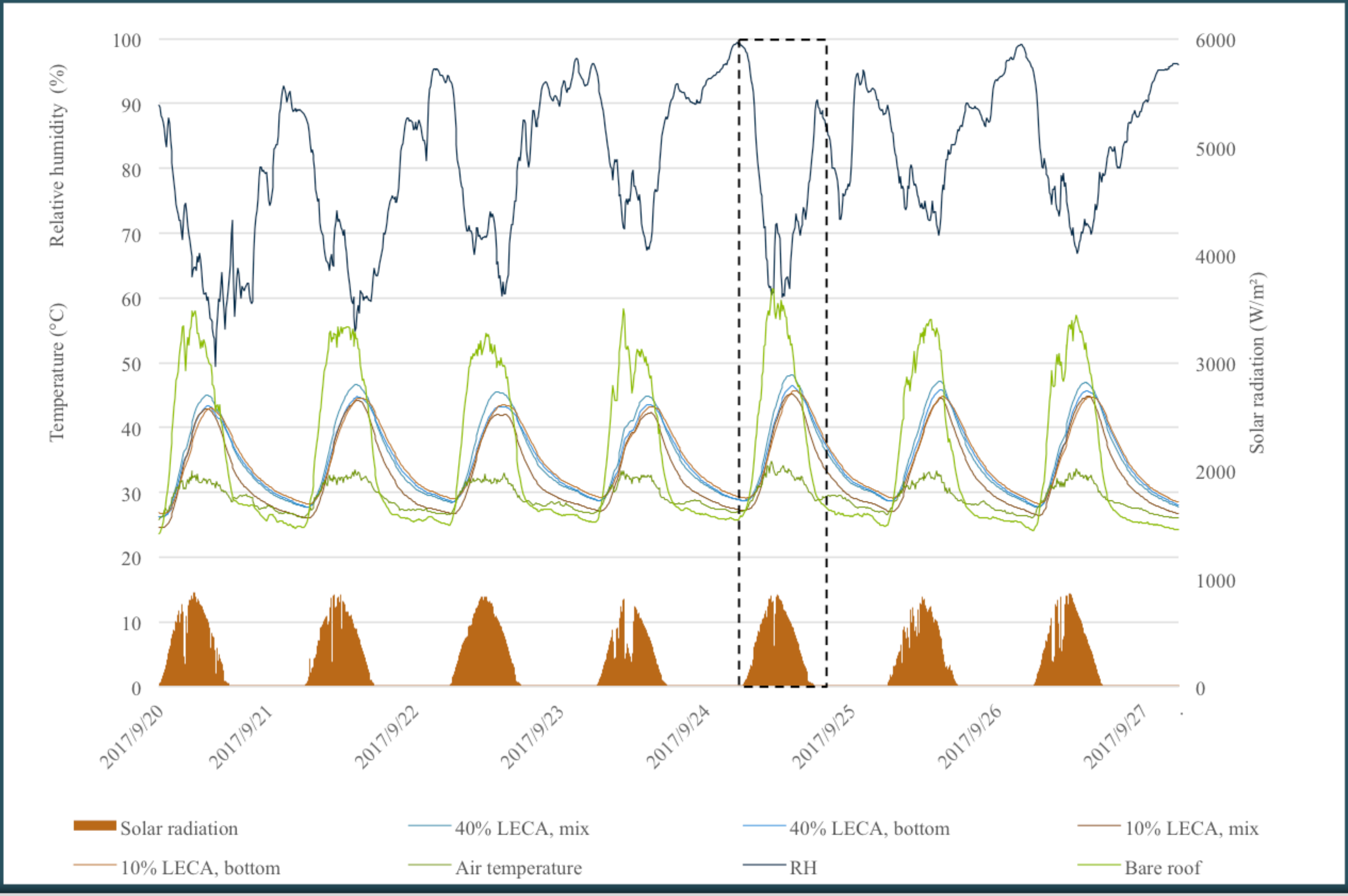
The Third Stage

Investigate the reductions in temperature and heat amplitude of the bare rooftop owing to the extensive roofs with 10% and 40% LECA laid at the bottom or well mixed with the soil.



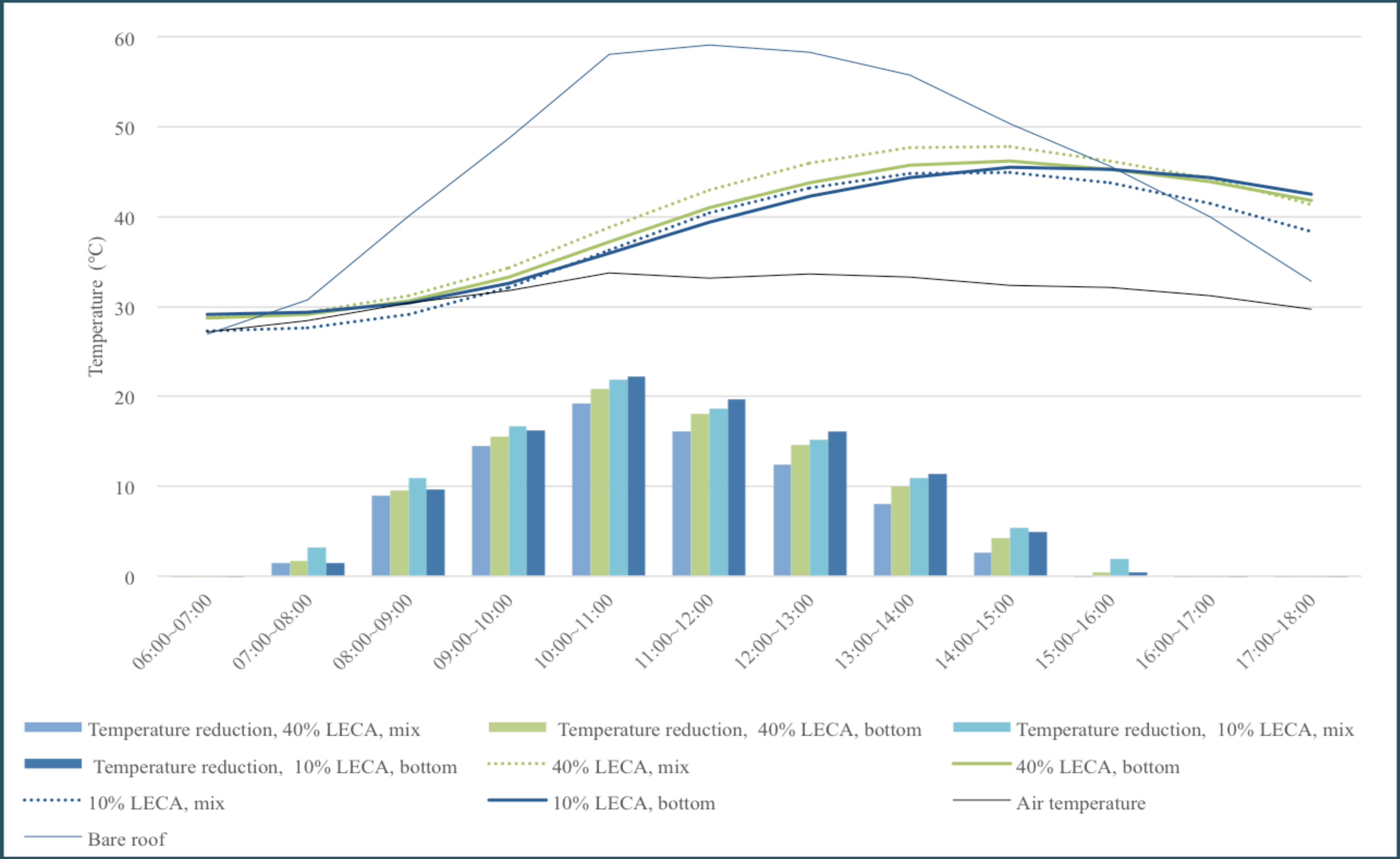
The Third Stage

2017/09/24-25



The Third Stage

2017/09/24-25



The Third Stage

2017/09/24-25

Thermalcouple position	Type of extensive roof	Average temperature (°C)	Range of temperature (°C)	Difference in temperature (°C)	Heat amplitude reduction (°C)
In the air		29.86	26.50–34.76	8.26	-
Bare rooftop surface		36.11	24.77–61.49	36.72	-
At the bottom	10% LECA, bottom	35.79	29.09–45.62	16.53	**54.98%**
	10% LECA, mix	33.89	27.19–45.19	18.00	**50.98%**
	40% LECA, bottom	35.96	28.72–46.39	17.67	**51.88%**
	40% LECA, mix	36.23	28.72–48.07	19.35	**47.30%**

Cost–benefit analysis of the LECA-containing green roof

The roofs with LECA laid at the bottom (recommendation)	Unit weight of growth medium before irrigation (kg/m^2)	Unit weight of growth medium after irrigation (kg/m^2)	Total weight **before irrigation** (per building unit, green roof area 42 m^2)	Total weight **after irrigation** (per building unit, green roof area 42 m^2)	Estimated total cost ($US dollar)	Maximum temperature reduction (°C)
0% LECA roof, benchmark	81.27	135.95	3,413.34	5,709.90	910.14	14.70
10% LECA roof (preferred)	76.71	126.38	3,221.82 (cut by **191.52 kg, 3 adults**)	5,307.96 (cut by **401.94 kg, 7 adults**)	968.94 (US$58.8 more)	**15.87**
40% LECA roof (preferred)	63.02	97.69	2,646.84 (cut by **766.50 kg, 13 adults**)	4,102.98 (cut by **1,606.92 kg, 27 adults**)	1,144.92 (US$234.8 more)	**15.21**
70% LECA roof (not preferred)	49.32	69.00	2,071.44	2,898.00	1,320.48	11.01

CONCLUSIONS

Conclusions

1. 10 cm depth of growth medium was most efficient for reducing the temperature of the bare rooftop.

2. The roofs with 10% and 40% LECA laid at the bottom lead to larger temperature reductions of the bare rooftop compared with the roof with 0% LECA roof.

3. The roof with LECA laid at the bottom yielded larger reductions in temperature and heat amplitude of the bare rooftop compared with the roof with LECA well mixed with the soil.

4. Compared with the roof with 0% LECA, the roofs with 10% and 40% LECA laid at the bottom not only achieved superior cooling of the bare rooftop but also significantly reduced the weight load on the building structure.