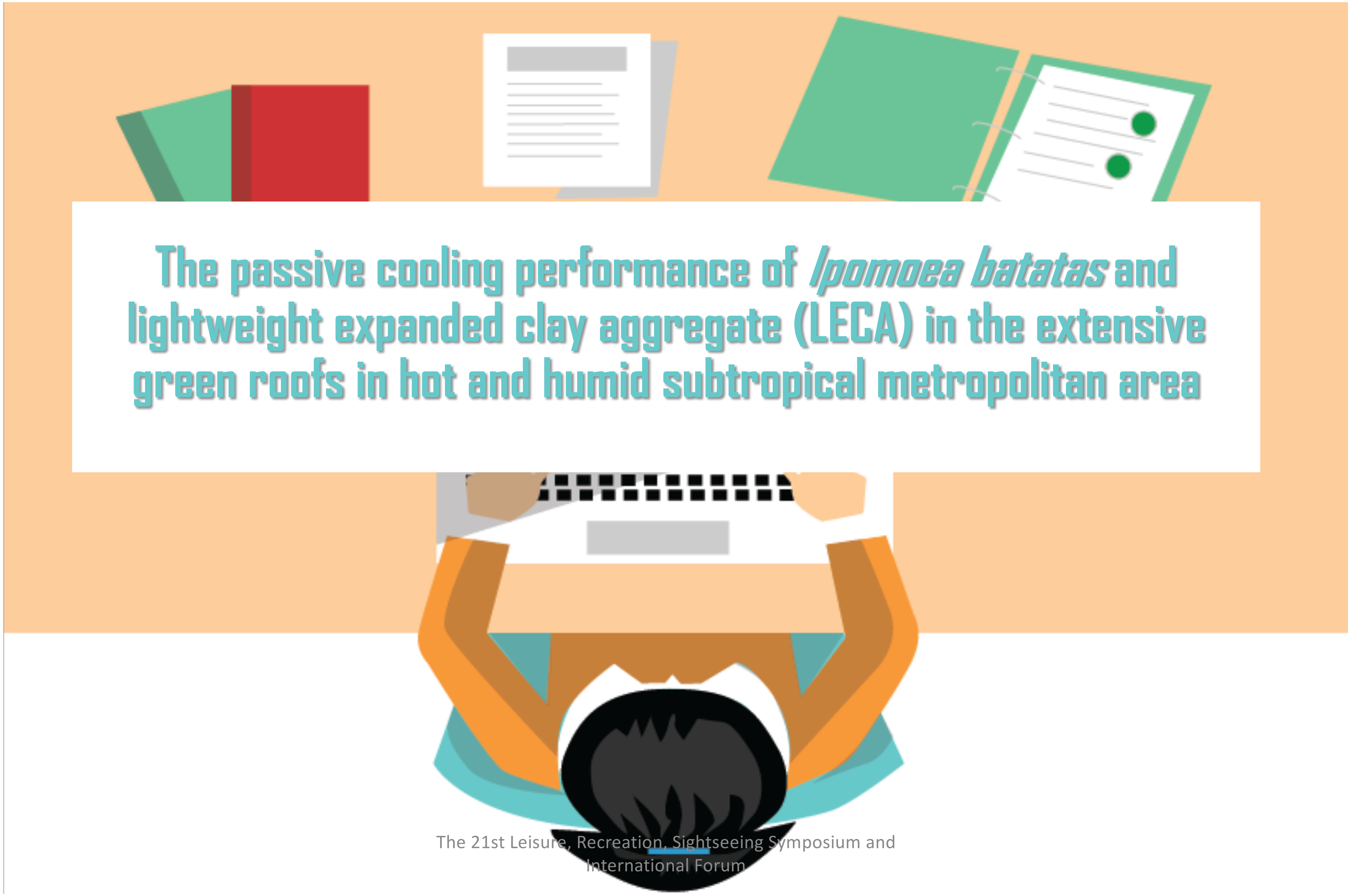

The passive cooling performance of *Ipomoea batatas* and lightweight expanded clay aggregate (LECA) in the extensive green roofs in hot and humid subtropical metropolitan area

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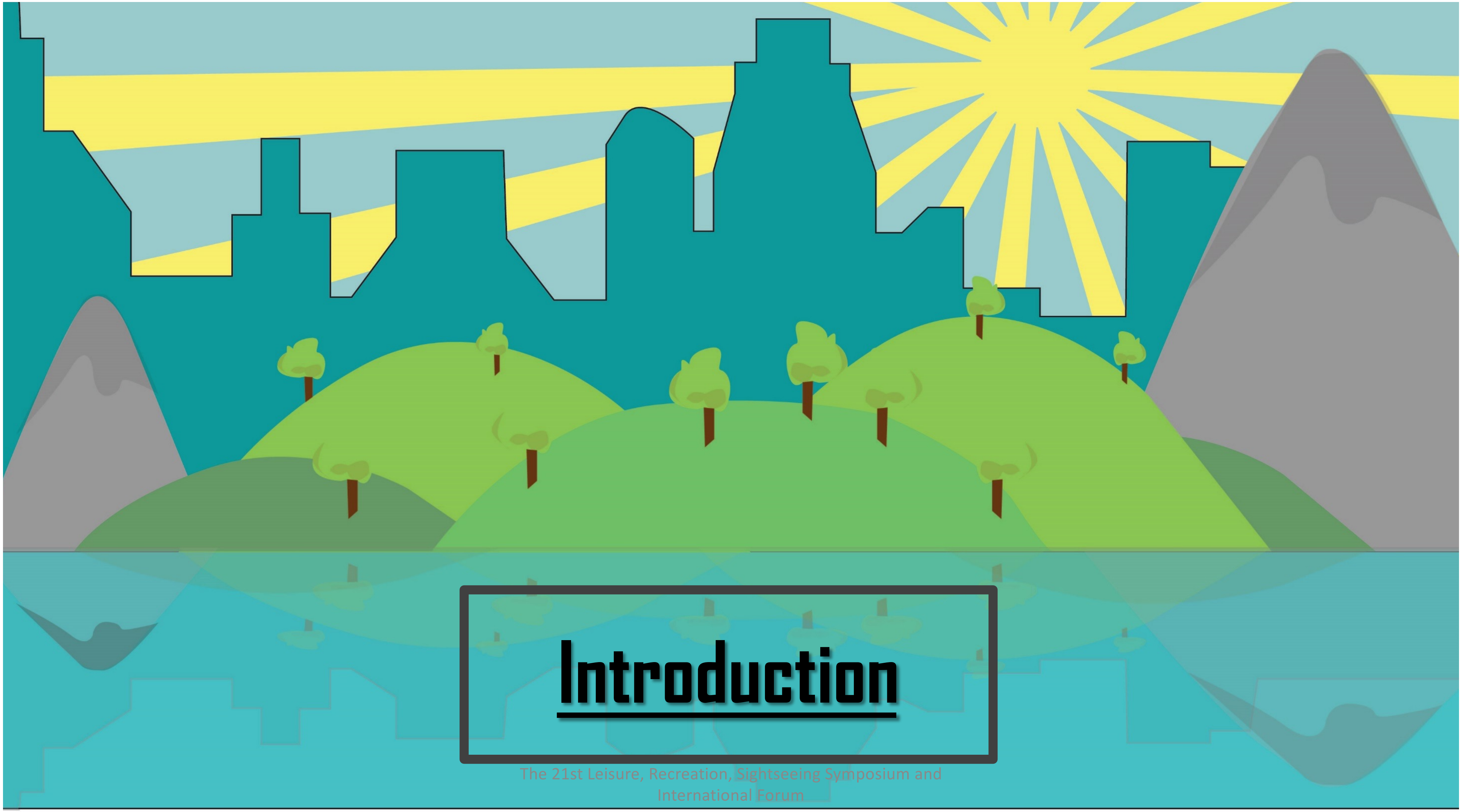
Introduction
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Why green roofing?

As land continues to be replaced with impervious surfaces due to population growth and urbanization, the necessity to recover green space is becoming increasingly critical to maintain environmental quality. Installing green roofs is one option that can reduce the negative impact of development while providing numerous environmental, economic, and social benefits

In modern urban societies, stressful lifestyles have increasingly driven humans to seek temporary stress relief, and stressful lifestyles are well known as the major causes for many physical and psychological illnesses, including anxiety, depression, insomnia, burnout syndrome, as well as gastroenterological, cardiovascular, neurological, and immunological diseases. Consequently, stress management should receive significant research attention in the interests of public health and green roof gardening could help achieve stress management.

Energy Conservation + Stress Management !!

What is green roof? Why it is important?

It is a roof of a building that is covered with vegetation and a growing medium. It also referred as eco-roof, living roof, and vegetated roof. There are two types of green roof, intensive (thicker) and extensive (thinner) roofs. This research studied the extensive roof.

- *Reduce rooftop temperature and reduce energy use*
- *Provide healing landscape and reduce people's stress*
- *Provide visually appealing landscape*
- *Reduce heat island effect*
- *Reduced air pollution and greenhouse gas emissions*
- *Enhanced storm water management*
- *Create a habitat for wildlife*

Why *Ipomoea batatas* (sweet potato)?

- High LAI
- Resistant to wind, sun, and drought
- Low maintenance
- Fast growing, high coverage
- Edibility, low carbon dioxide emissions
- Provision of horticultural activity

Formula for common lightweight growth medium

- Formula for common lightweight growth medium:

1. sandy loam (75%) +
2. organic matter (25%) → compost
3. lightweight growth medium (by stage) → LECA

+

+

What is LECA and why we used it?

Lightweight expanded clay aggregate (LECA) or expanded clay is a lightweight aggregate made by heating clay to around 1,200 °C (2,190 °F) in a rotary kiln. The yielding gases expand the clay by thousands of small bubbles forming during heating producing a honeycomb structure.

- Low conductivity of solar radiation
- Lightweight
- Porosity for holding water
- Well drainage for better root growth
- PH around 7
- Inexpensive
- Widely available
- Recyclable
- Won’t rot, good for supporting plant root

Research Purpose

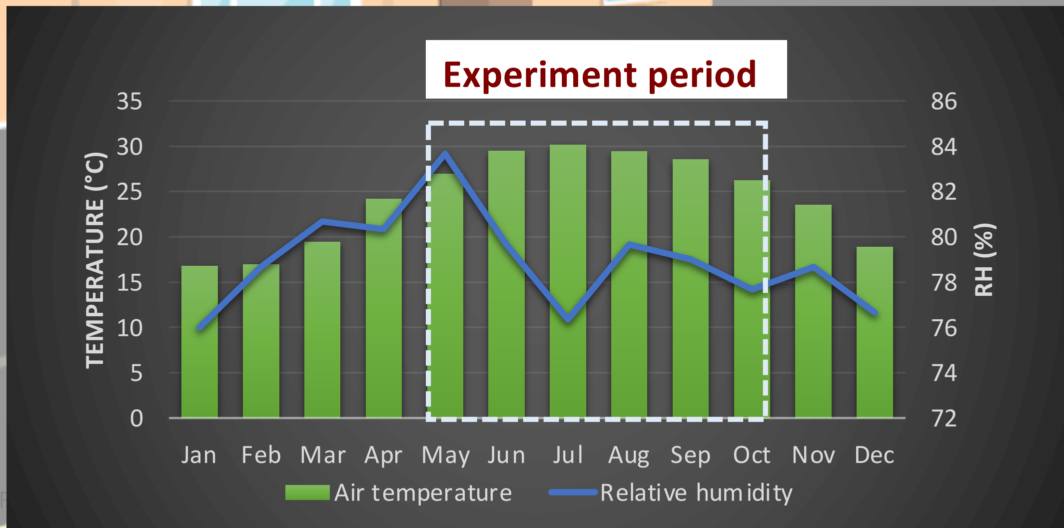
1. Investigate the depth of the growth medium;
2. Investigate the proportion of LECA in the growth medium;
3. Investigate the proportion & placement of LECA in the growth medium;
4. Investigate how adding *Ipomoea batatas* affects the thermal performance of extensive green roofs.
5. Conduct a weight-reduction-and-cost analysis of extensive LECA roofs.

Experimental site and period

Experimental Site: Rooftop of a 4-story student dormitory in Tunghai University

Climate zone: Hot and humid subtropical climate in summer

Weather: highest average temp. of 31°C and highest RH of 84%



Experimental setup

five 50x50x10 cm^3 cement boards capped with ceramic tiles were placed on a flat rooftop to simulate a flat bare roof. Styrofoam boards were placed under the cement boards to block heat conduction from the surrounding bare rooftop.

- Thermocouples were placed horizontally in close contact with the surface to measure the temperature accurately
- Air temperature, relative humidity, and solar radiation were measured at a point 2 m above the rooftop surface

Air temperature, relative humidity

Solar radiation

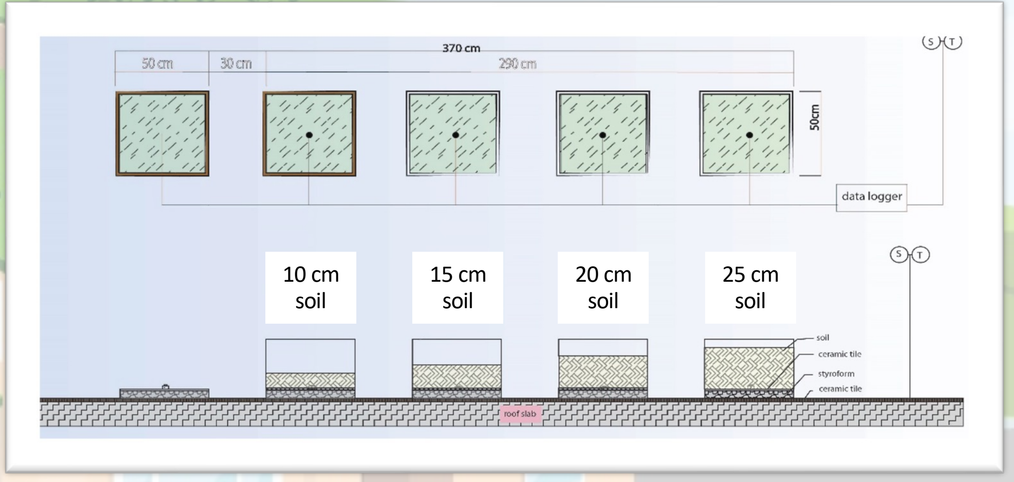
Tank temperature

Data logger

4 Experimental stages

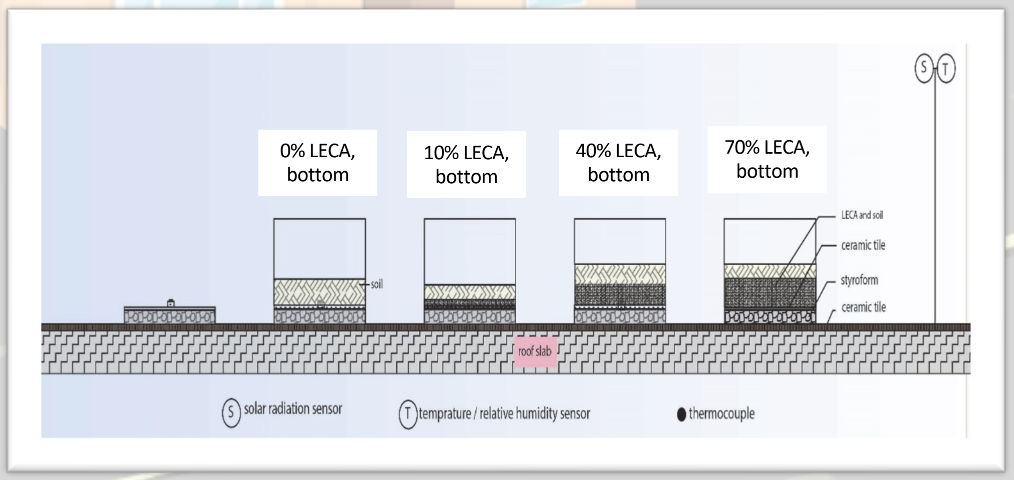
First stage-test soil depth

- Comparing the thermal performance of extensive green roof when four different depth of the conventional garden soil were employed without plants
- 14 – 15 May



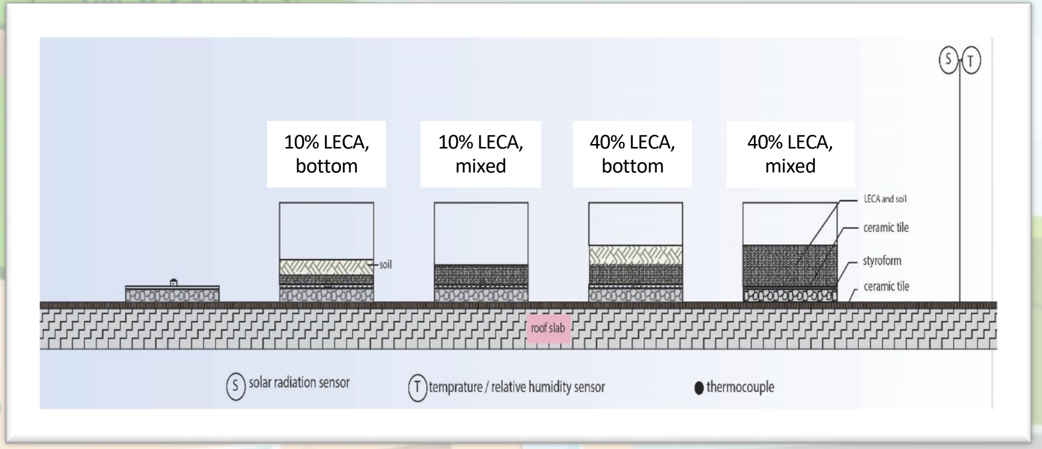
Second stage-test LECA %

- investigating the thermal performance of the extensive roof when different proportion LECA laid at bottom of the tanks without plants
- 25 – 26 July



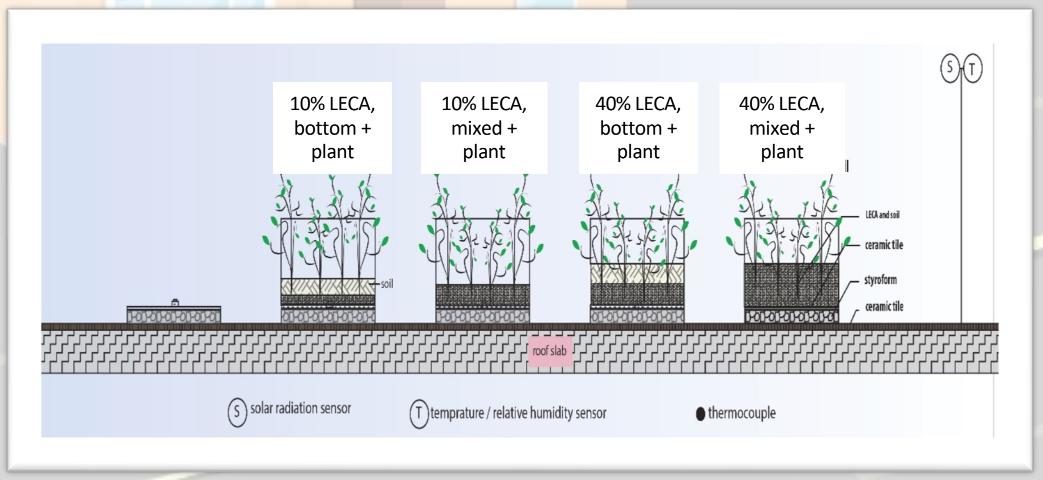
Third stage-test LECA% & placement

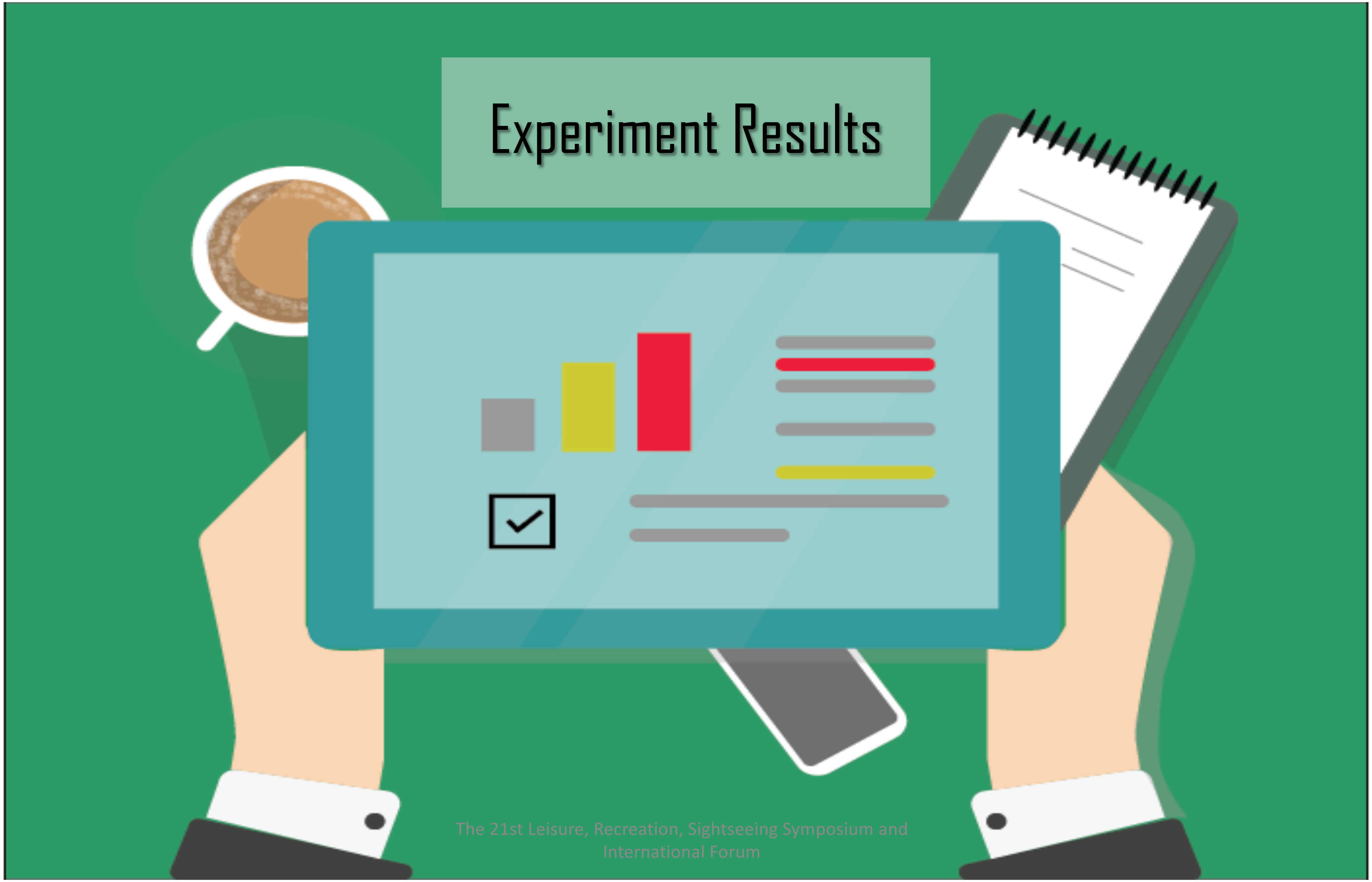
- investigating the thermal performance of the extensive roofs with 10% or 40% LECA laid at the bottom or mixed well with the conventional soil without plants
- 24 – 25 September



Fourth stage-test sweet potato

- investigating the thermal performance of the extensive roofs with 10% or 40% LECA laid at the bottom or mixed well with the conventional soil and with plants
- 01 – 02 October




Experiment Results
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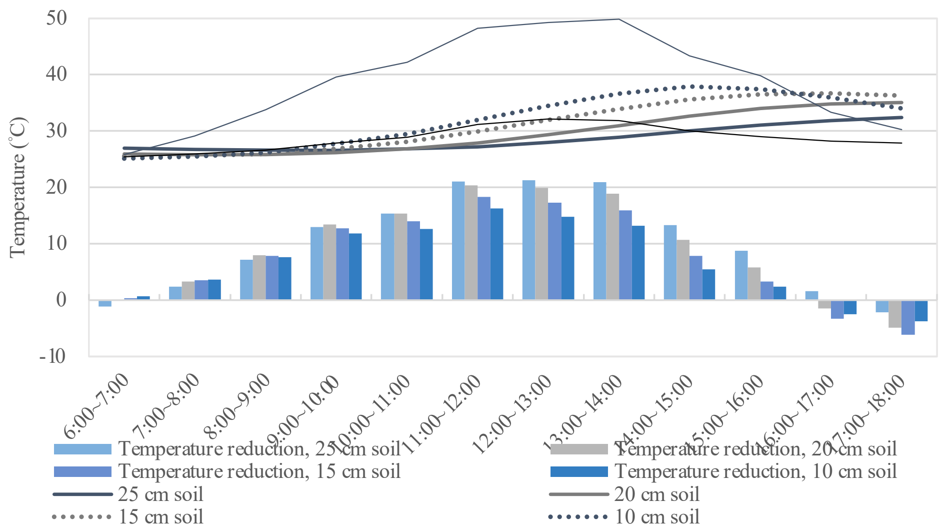
Stage 1: soil depth

- depths of conventional garden soil resulted in the insulation, absorption, and evaporation effects, the thicker the growth medium, the greater the temperature reduction
- decline in the marginal temperature reduction with increasing soil depth, suggesting that the roof with 10-cm deep of soil was most efficient



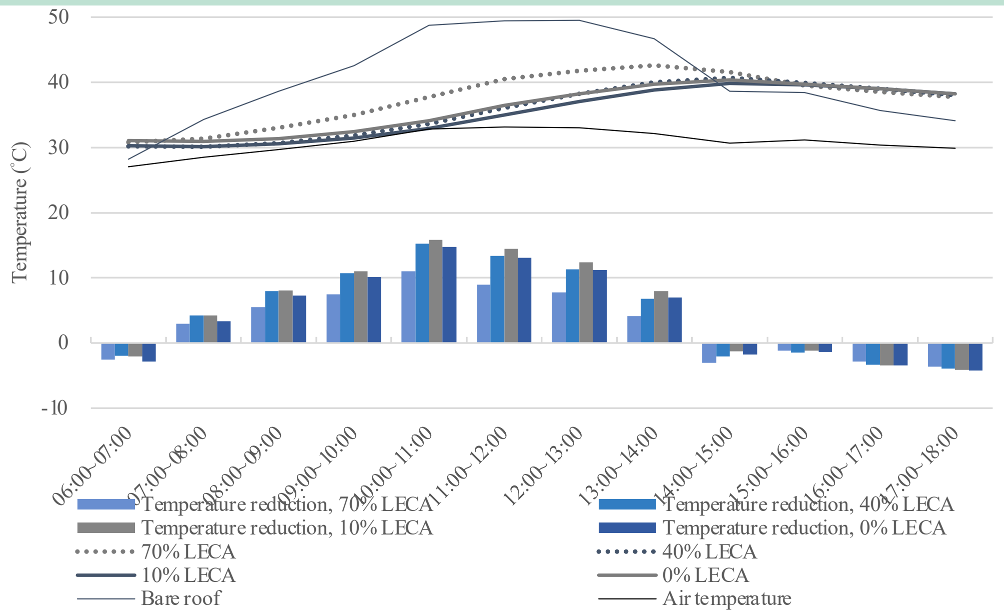
Temperatures and temperature reductions in the cases of 10, 15, 20, and 25 cm garden-soil roofs without plants (2017/05/14 05:59:44 to 2017/05/14 17:49:44).

10 cm soil
Most efficient

Thermocouple position	Avg. temp(°C)	Avg. temp reduction (°C)	Additional temp reduction due to increased soil depth(°C)	Marginal temp reduction (°C)
In the air	29.18	-	-	-
Bare rooftop	41.72	-	-	-
10 cm soil, no plants	30.28	11.45	11.45	1.15
15 cm soil, no plants	28.91	12.82	1.37	0.27
20 cm soil, no plants	27.54	14.19	1.37	0.27
25cmsoil, no plants	27.26	14.46	0.28	0.06

Stage 2: LECA %, bottom

- Proportions of LECA exhibited different insulation, absorption and evaporation
- Roofs with 10% and 40% LECA showed slightly greater temperature reduction (10-11°C) than of the 0% and 70% by 0.5-1°C.
- Roof with 70% LECA showed least temperature reduction performance.
- However, 0% LECA roof had highest heat amplitude reduction (63%).

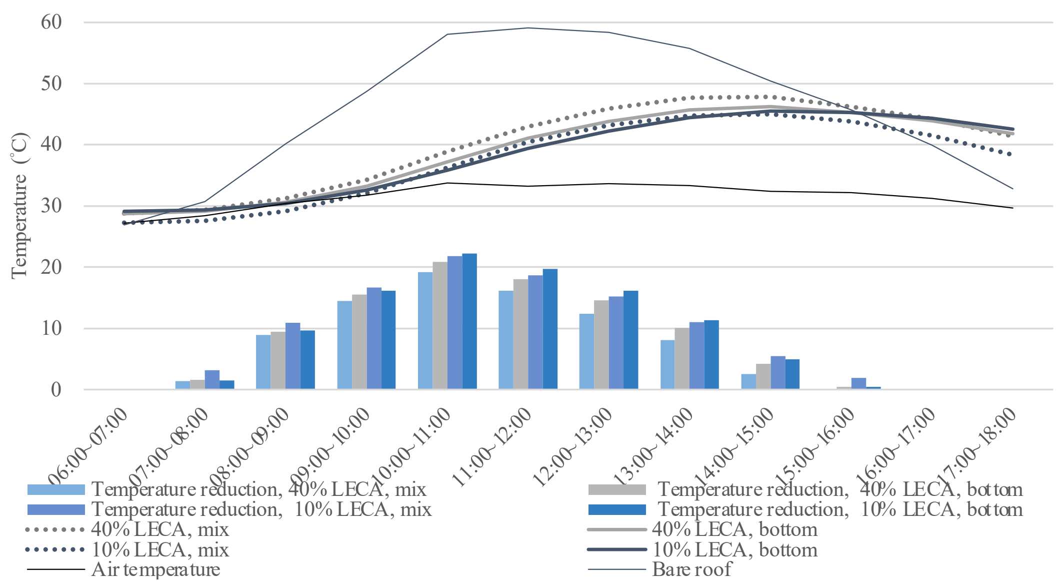


Temperatures and temp reductions in the cases of the roofs with 0%, 10%, 40%, and 70% LECA laid at the bottom without plants (2017/07/25 06:00:09 to 2017/07/25 17:50:09)

Thermocouple position	Average temp. reduction (°C)	Average temp. (°C)	Difference in temp. (°C)	Heat amplitude reduction
In the air	-	29.13	7.61	-
Bare rooftop	-	34.35	25.86	-
0% LECA, no plants	9.54	35.13	9.56	63.03%
10% LECA, no plants	10.57	34.46	9.85	61.91%
40% LECA, no plants	9.94	34.55	10.74	58.47%
70% LECA, no plants	6.84	35.56	12.05	53.40%

Stage 3: LECA % & Placement

- The extensive roofs with 10% LECA and without plants demonstrated superior passive cooling (about 14°C) compared with the extensive roofs with 40% LECA and without plants by about 1-2.5°C.
- 10% LECA laid at bottom without plants had highest heat amplitude reduction (55%).

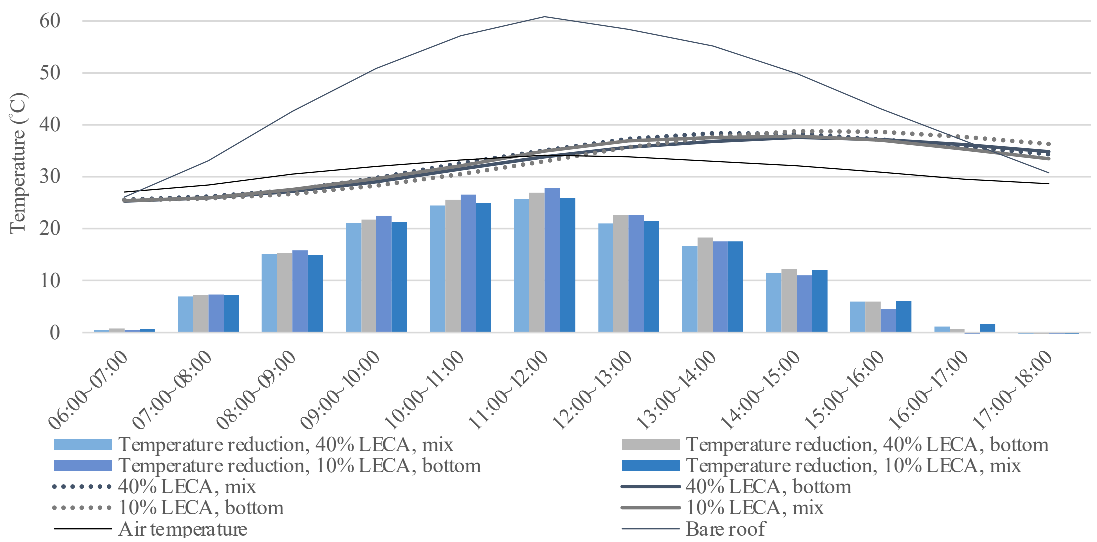


Temperatures and temperature reductions in the cases of the roofs with 10% and 40% LECA laid at the bottom without plants, and of 10% and 40% LECA mixed with the soil without plants (2017/09/24 06:08:41 to 2017/09/24 17:58:41).

Thermocouple position	Average temp. reduction (°C)	Average temp. (°C)	Difference in temp. (°C)	Heat amplitude reduction
In the air	-	29.86	8.26	-
Bare rooftop	-	36.11	36.72	-
10% LECA, bottom, no plants	13.82	35.79	16.53	54.98%
10% LECA, mix, no plants	13.92	33.89	18.00	50.98%
40% LECA, bottom, no plants	12.99	35.96	17.67	51.88%
40% LECA, mix, no plants	11.51	36.23	19.35	47.30%

Stage 4-sweet potato

- The addition of the sweet potato layer caused additional evapotranspiration cooling, as well as absorption, shielding and shading effects.
- Sweet potato help significantly reduce the rooftop temperature by about 1.4 times (14°C >> 20°C).
- Sweet potato help significantly reduce heat amplitude by about 1.2-1.3 times (54% >> 67%).
- With sweet potato, 40% LECA roof can easily outperform 10% LECA roof.



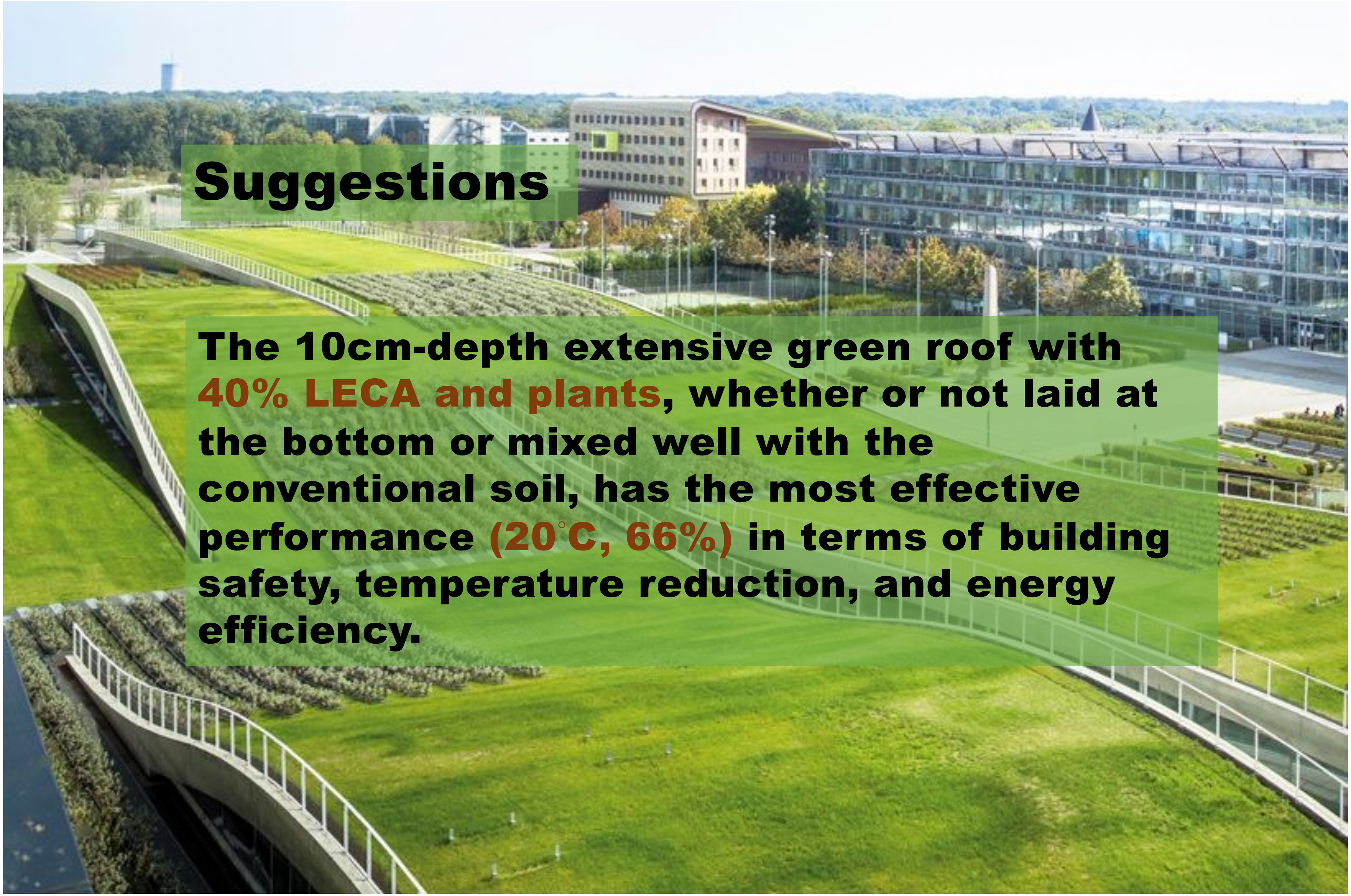
Temperatures and temperature reductions in the cases of the roofs with 10% and 40% LECA laid at the bottom with *Ipomoea batatas*, and of 10% and 40% LECA mixed with the soil with *Ipomoea batatas* (2017/10/01 06:07:57~2017/10/01 17:57:57).

Thermocouple position	Average temp. reduction (°C)	Average temp. (°C)	Difference in temp. (°C)	Heat amplitude reduction
In the air	-	29.30	8.15	-
Bare rooftop	-	35.77	37.61	-
10% LECA, bottom, with plants	19.73	30.89	13.42	64.32%
10% LECA, mix, with plants	18.73	30.36	12.51	66.74%
40% LECA, bottom, with plants	**19.36**	30.51	12.37	67.11%
40% LECA, mix, with plants	**18.44**	30.81	13.09	65.20%

Cost benefit analysis of LECA extensive roofs

The roofs with LECA laid at the bottom and with plants	Unit weight of medium after irrigation	Total weight after irrigation per unit building	Estimated unit cost (NT dollar/m^2)	Estimated total cost of growth medium per unit building (NT dollar)	Average rooftop temperature reduction (°C)	Heat amplitude reduction (%)
0% LECA roof (benchmark)	136 kg/m^2	5,710 kg	$ 650 /m^2	$ 27,300	—	—
10% LECA roof (preferred)	126 kg/m^2	5,308 kg (cut by 402 kg, 7%, **7 adults**)	$ 690 /m^2	$ 29,070 ($ 1,770 more)	19-20 °C	64-67%
40% LECA roof (most preferred)	98 kg/m^2	4,103 kg (cut by 1,607 kg, 28%, **27 adults**)	$ 820 /m^2	$ 34,290 ($7,044 more)	18-19 °C	65-67%
70% LECA roof (not preferred)	69 kg/m^2	2,898 kg	$ 940 /m^2	$ 39,600	—	—

When compared with 0% LECA roof, although the additional thermal reduction in the bare rooftop in the roofs with 10%-40% LECA was not as high as one might expect, the greatest contribution of the LECA roofs was the increase in building safety resulting from the alleviation of the constant weight load (the weight of 7-27 adults) to which building structure is subjected.



Suggestions

The 10cm-depth extensive green roof with **40% LECA and plants**, whether or not laid at the bottom or mixed well with the conventional soil, has the most effective performance **(20°C, 66%)** in terms of building safety, temperature reduction, and energy efficiency.


Thank you
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