ICGRSA 2022: 23th International Conference on Green Roof Systems and Applications

Thermal Performance of the Extensive Wetland Green Roofs in Winter in Humid Subtropical Climate?

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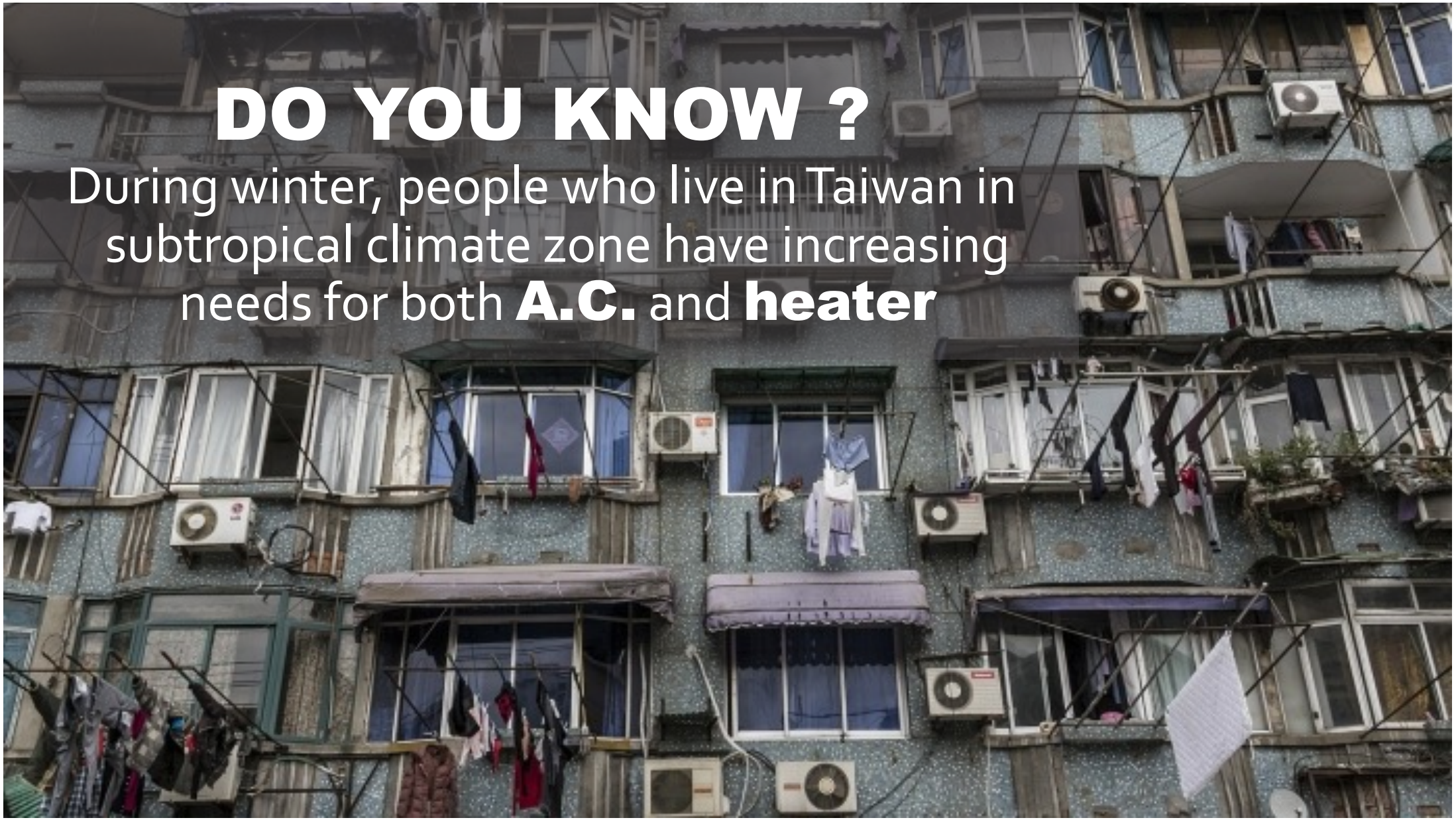
Human thermal comfort: how a green roof can help the cause of climate change and contribute towards human thermal comfort ?


DO YOU KNOW ?
During winter, people who live in Taiwan in subtropical climate zone have increasing needs for both A.C. and heater

DO YOU KNOW ?

Regarding how to keep the building warm during winter, the innovative extensive wetland green roof can **outperform** the traditional extensive terrestrial green roof to save energy bills for air conditioning and heating needs.

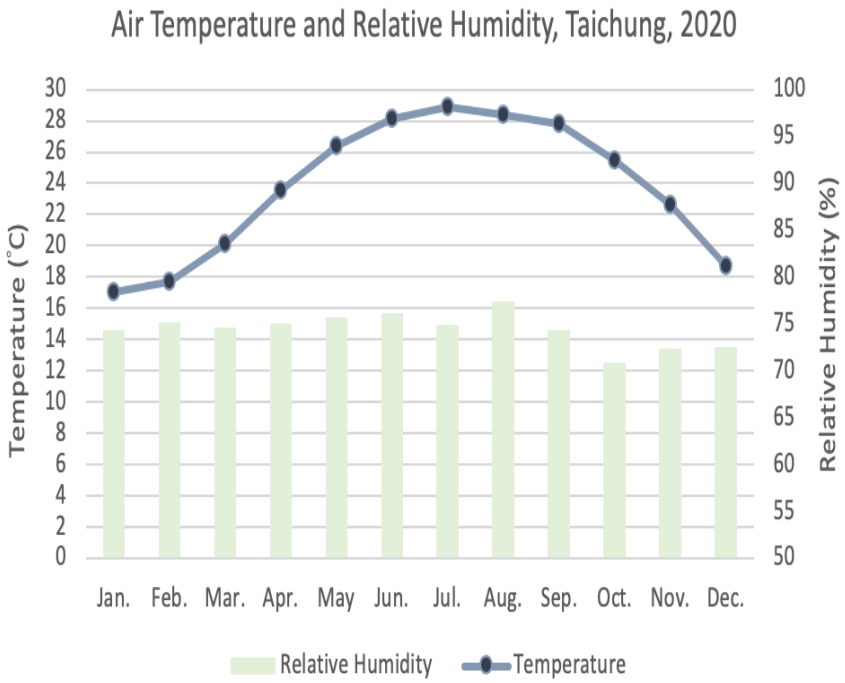
Why Wetland green roof?

	Advantage	Disadvantage	Example
Terrestrial green roof	+ Traditional practice + Higher passive cooling (not good in winter) + Higher thermal insulation (not good in summer)	- High maintenance (weed, irrigation, change soil from time to time) - High installation cost (more soil material needed, more labor needed for shipping)	
Pure water green roof	+ Low maintenance (no weed, no daily irritation needed, easy fertilization, no need to change soil from time to time) + Low installation cost (just open tap water)	- Lower passive cooling (too transparent) - Lower thermal insulation (too transparent)	
Wetland green roof	+ Improved passive cooling + Improved thermal insulation + Low maintenance + Low installation cost		

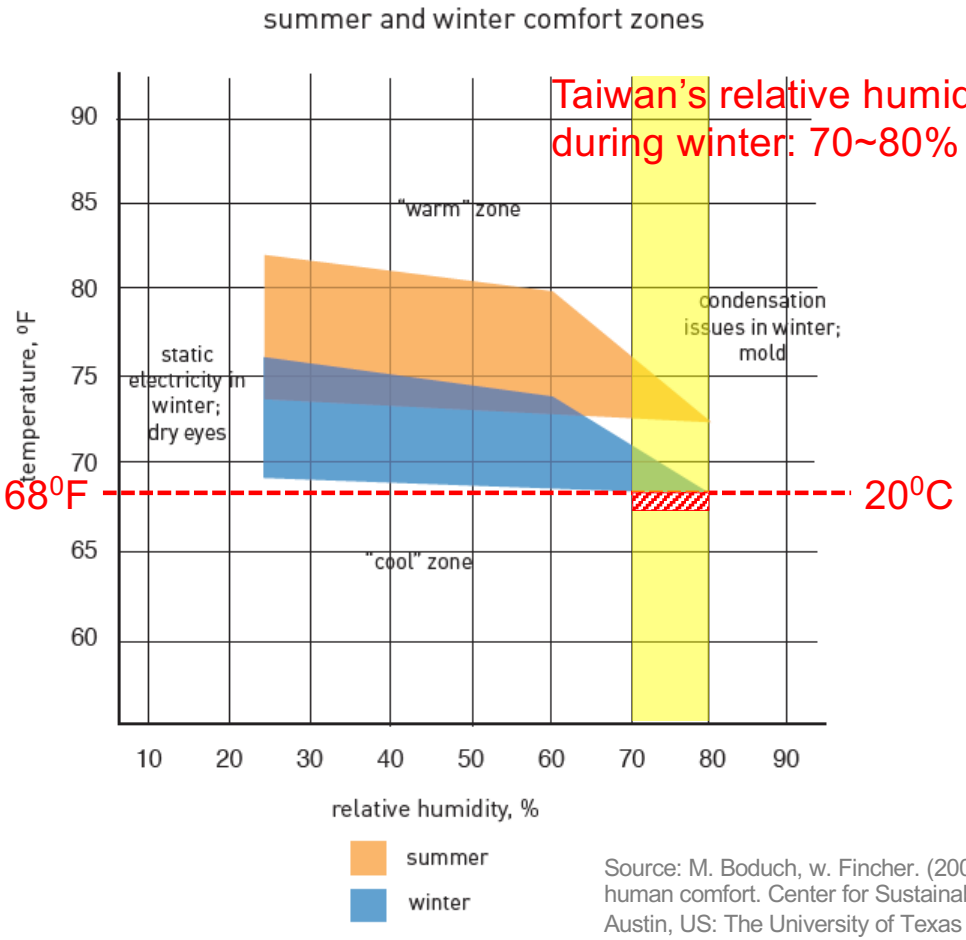
Why Wetland green roof?

	Advantage	Disadvantage	Example
Terrestrial green roof	+ Traditional practice + Higher passive cooling (no good in winter) + Higher thermal insulation (no good in summer)	- High maintenance (weeding, frequent irrigation, change soil from time to time) - High installation & dismantle costs (more soil material needed, more labor needed for shipping)	
Pure water green roof	+ Low maintenance (weed-free, no daily irrigation needed, easy fertilization, no need to change soil from time to time) + Low installation & dismantle costs (open tap water, drainage)	- Lower passive cooling (too transparent) - Lower thermal insulation (too transparent)	
Wetland green roof	+ Improved passive cooling + Improved thermal insulation + Low maintenance + Low installation cost		

Why set 20 ℃ as the benchmark for Winter?



Since the average relative humidity is 74.5% and fairly stable through out the entire year in Taichung, the most comfortable temperature for human is 20^{0}C during winter, which will then become our benchmark.



Source: M. Boduch, w. Fincher. (2009). Standard of human comfort. Center for Sustainable Development. Austin, US: The University of Texas at Austin.

Research Purposes

1. To evaluate the impacts of different kind of wetland soils on thermal performance of the extensive wetland green roofs;
2. To evaluate the impact of different ratio of wetland soil mixture on thermal performance of the extensive wetland green roofs;
3. To evaluate the impact of different ratio of water in wetland soil mixture on thermal performance of the extensive wetland green roofs;
4. To evaluate the impact of different type of wetland plant on thermal performance of the extensive wetland green roofs;

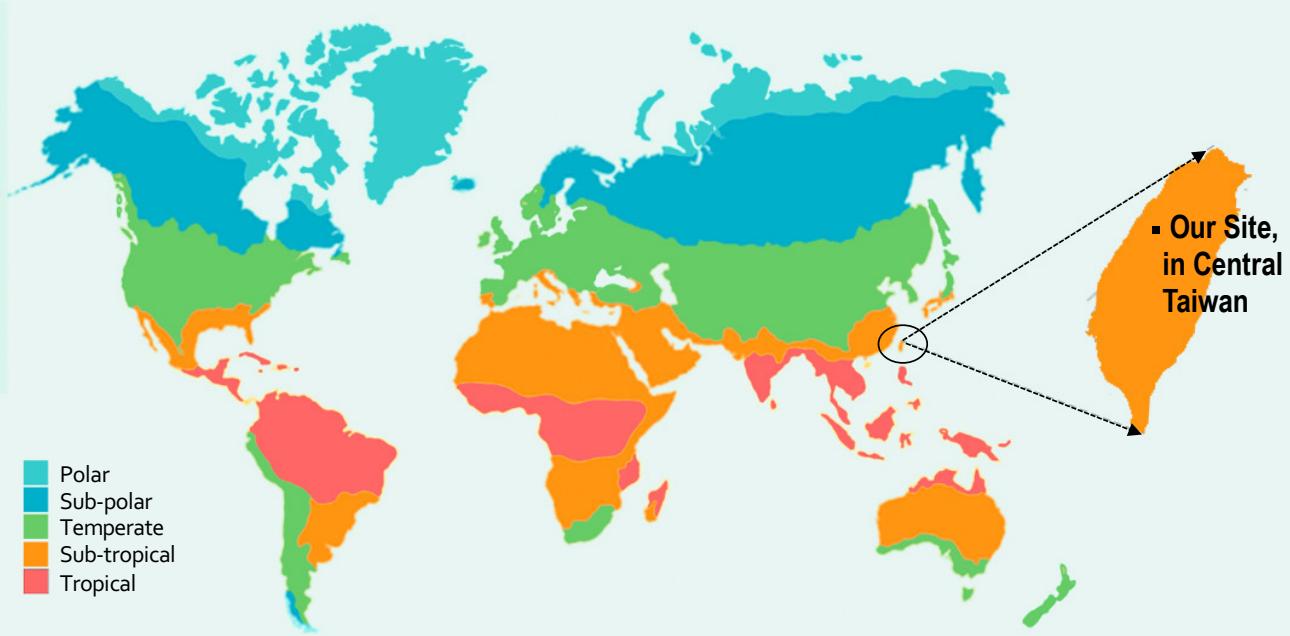
Easy maintenance

Reduce carbon

Energy saving

Methodology

Experimental Site



Sub-tropical Climate Zone →
Central Taiwan →
One student dormitory in Tunghai Univ.

. **Country:** Taiwan, one Southeast Asian country in the subtropical climate zone
. **Location:** on the bare rooftop of one student dormitory at Tunghai University in Taichung metropolitan area in Central Taiwan

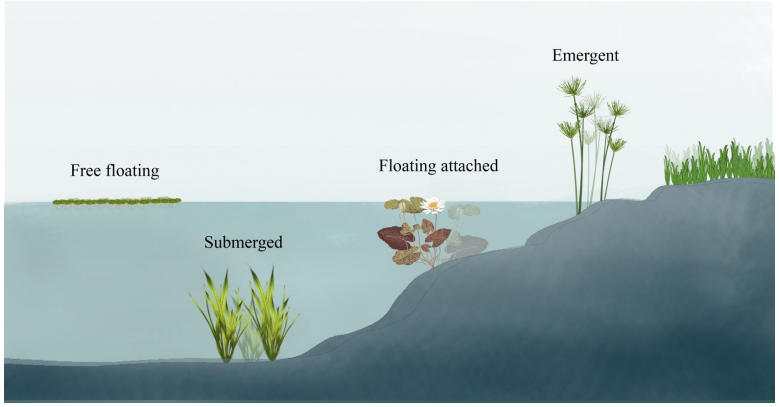
Experiment Period & Weather Condition

	Dec.	Jan.	Feb.	Mar.	Average
Period	Dec.13-31, 2019	Jan. 06-16, 2020	Jan.28-Feb.15, 2020	Feb.19-Mar.17, 2020	Winter, 4 months (Dec.12, 2019-Mar.17, 2020)
Air temp.	19.1 ℃ (13.7-28.4 ℃)	17.8 ℃ (12.7-26.7 ℃)	16.4 ℃ (8.7-29.1 ℃)	19.3 ℃ (10.7-30.3 ℃)	18.2 ℃ (8.7-30.3 ℃)
Bare roof temp.	23.4 ℃ (12.4-51.5 ℃)	22.7 ℃ (10.6-47.2 ℃)	20.6 ℃ (5.9-54.2 ℃)	24.3 ℃ (8.7-49.9 ℃)	22.8 ℃ (5.9-51.5 ℃)
Relative humidity	89.9 %	89.5%	83.6 %	86.8 %	Very humid 87.5 %
Max. temp. for representative	**23.6 ℃**	**24.4 ℃**	**24.2 ℃**	**23.4 ℃**	2-day periods (x4)
	Stage 1	**Stage 2**	**Stage 3**	**Stage 4**	Well controlled samples, fall within1 ℃ range (23.4-24.4 ℃)

. **Experiment Period:** 4 coldest months in winter; Dec., 2019-Mar., 2020
. **Cold-Mild winter weather:** air temp. 8.7 to 30.3°C; average 18.2°C
. **More dramatic temp. shift for bare rooftop: bare roof temp.** 5.9 to 51.5°C; average 22.8°C
. **Very high relative humidity:** average 87.5%
. **Well-controlled samples selected:** 4 representative dates; the hottest point temp. fall within 1°C range (23.4-24.4°C)

Type of Wetland Plants & Experiment Plant Materials

Type of Wetland Plants



. **4 types wetland plants:** free-floating, submerged, floating-attached, emergent plants

. **4 types of experiment plant materials:** Water hyacinth(free-floating); Ribbon weed (submerged); Water lily (floating-attached); Roundleaf rotala(emergent)

Experiment Plant Materials

Water hyacinth
(free-floating)

Ribbon weed
(submerged)

Water lily
(floating-attached)

Roundleaf rotala
(emergent)

Experiment Growth Medium

Control Tanks: Lightweight soil (Peat, Sandy loam, Vermiculite, Perlite), Pure water blocks

Lightweight Soil blocks

Peat | Sandy loam | Vermiculite | Perlite

Pure Water blocks

Pure water

Experiment Tanks: Akadama, Creek gravel, Pure water with various %

Wetland blocks

Akadama | Creek gravel | Pure water

. **Lightweight soil block:** Peat: Sandy loam: Vermiculite: Perlite = 1:2:1:1
. **Pure water block:** Pure water = 100%
. **Wetland blocks:** Akadama, Creek gravel, Pure water = various %

. Akadama is made from volcano ash, fits for cultivate wetland plants.
. Creek gravel is lightweight which can reduce building's weight bearing.

Experimental Setup, Instrument, Variables

. **Control blocks:** 3 blocks → bare roof, lightweight soil, pure water blocks

. **Experiment blocks:** 5 blocks

. **Block size & arrangement:** Seven 75x75x20cm^3 tanks above Styrofoam board (5cm thick), each block 50cm apart to avoid shadow interference

. **Instruments:** Solar radiation sensor; Temperature/Relative humidity sensor; Temperature sensor; Hobo station data logger

. **Field measurement:** Solar radiation; air and measured temperature, relative humidity

. **Factors:** Different "wetland soil," " % of soil mixture," " % of water," and "wetland plant species"

- Thermocouples were placed horizontally in close contact with the surface, and in the center of the tanks, to measure the temperature accurately.
- Air temperature, relative humidity, and solar radiation were measured at a point 2m above the rooftop surface, and 5.6m away from the parapet walls, for precise and interference-free measurement.

Temp./Relative humidity sensor

Solar radiation sensor

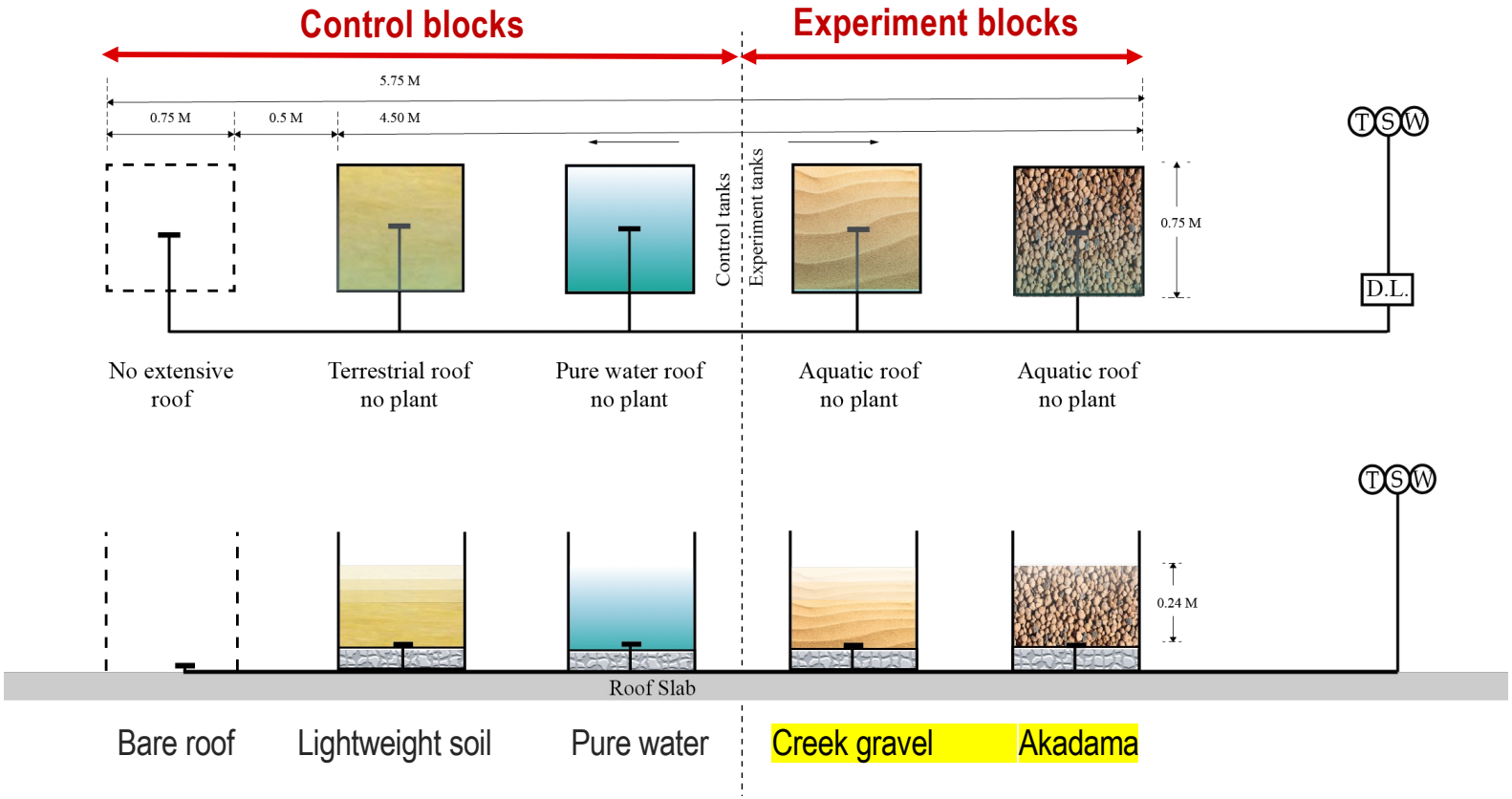
Temperature sensor

Hobo station

Experiment Stages

Stage 1

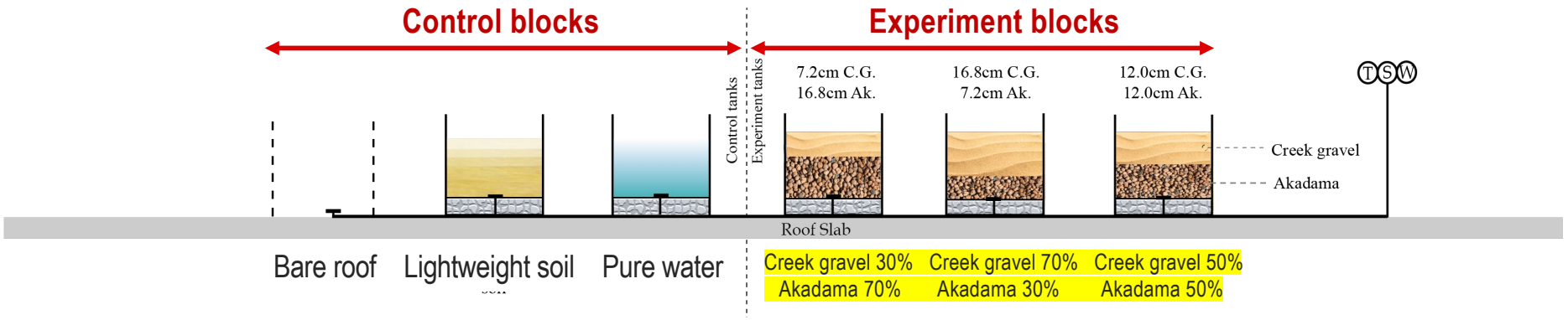
- **Factor:** different kind of wetland soil → exploring the optimal wetland soil



The drawing is mainly to convey the concept, not to the actual size.

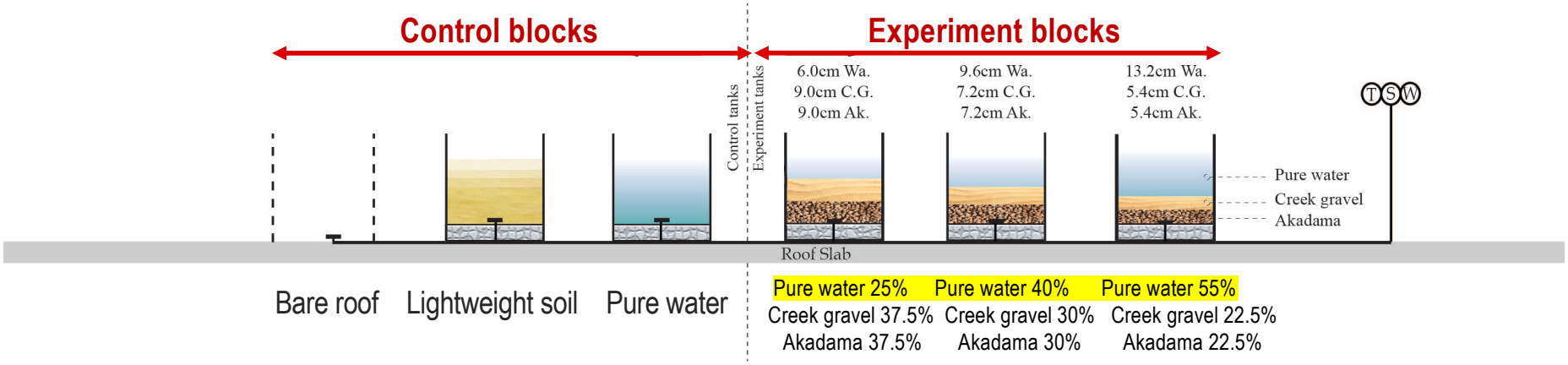
Stage 2

- **Factor:** different ratio of soil mixture → exploring the optimal ratio for creek gravel-and-akadama mixture



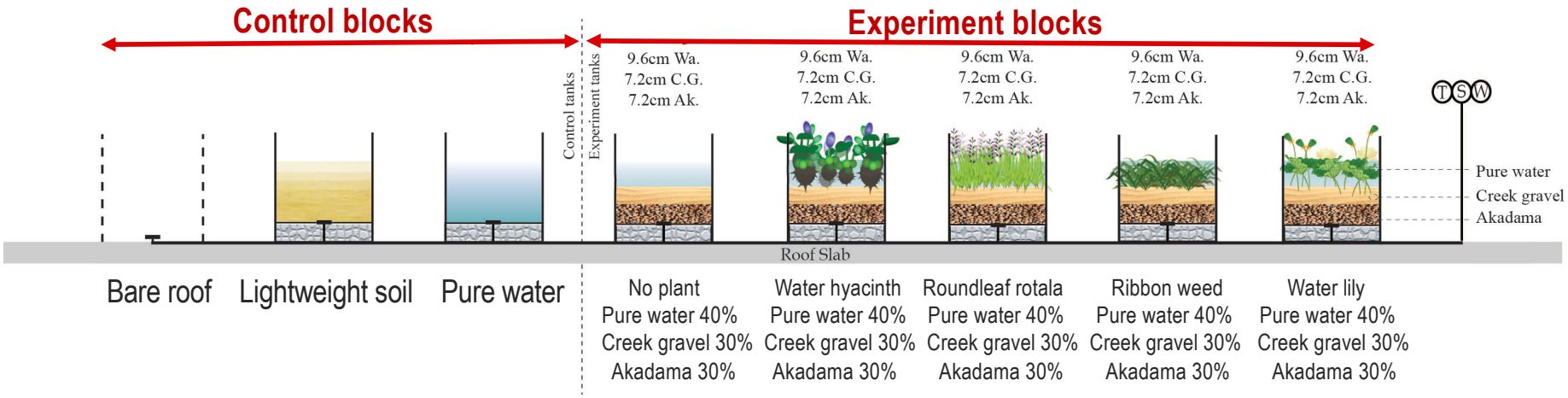
Stage 3

- **Factor:** different ratio of pure water (given creek gravel and akadama is fixed at 50%-50% ratio) → exploring the optimal ratio for pure water



Stage 4

- **Factor:** different <u>type</u> of wetland plant → exploring the optimal plant <u>species</u>

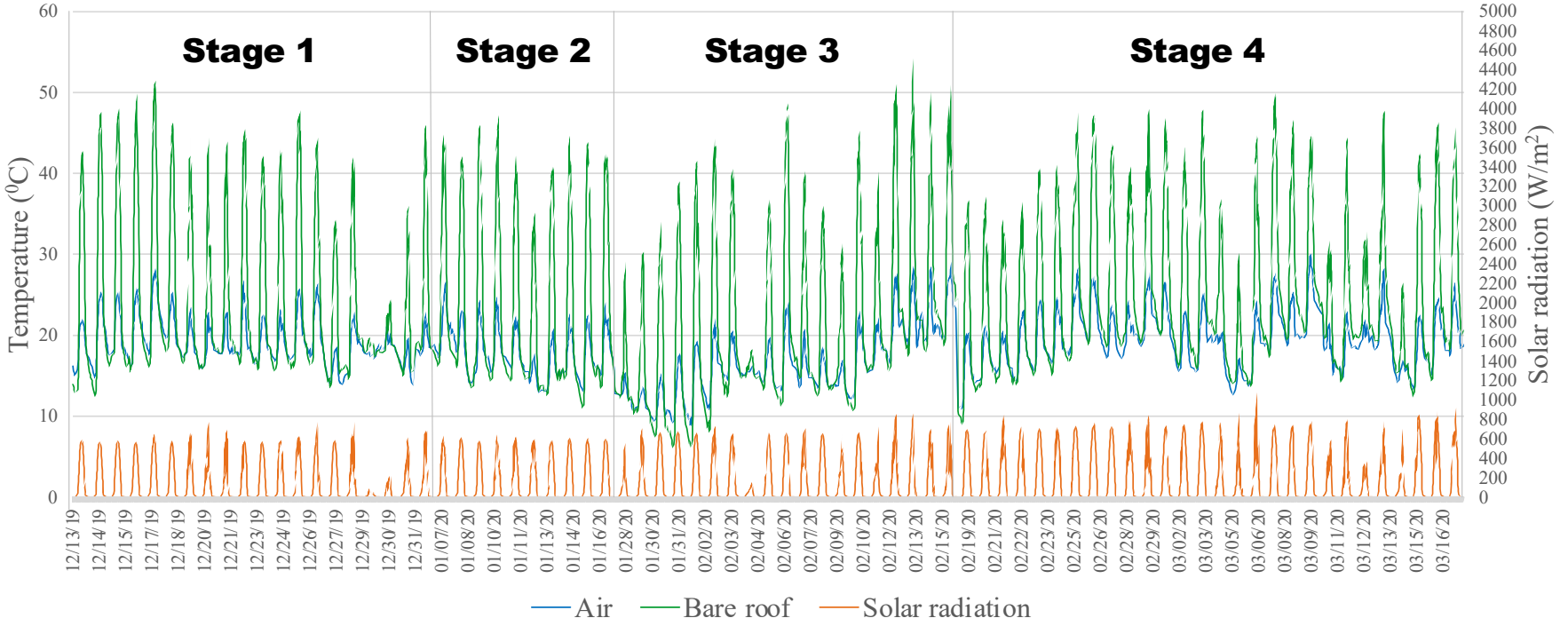


(T) Temperature; (S) Solar Radiation; (W) Wind Speed; [D.L.] Data Logger; Styrofoam

The drawing is mainly to convey the concept, not to the actual size.

Research Results

Weather Data Measured for 4 Stages, Taichung, Taiwan

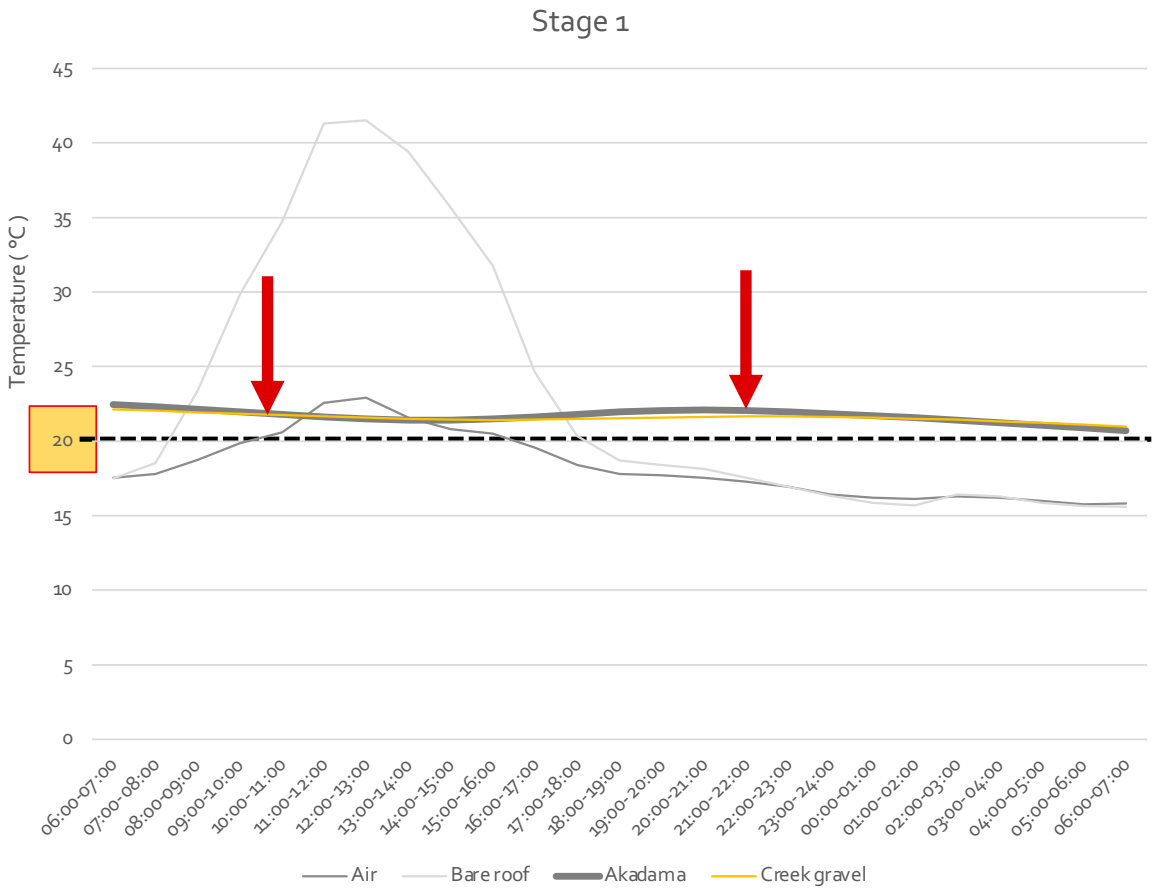


Average
Winter, 4 months (Dec.12, 2019-Mar.17, 2020)
18.2 °C (8.7-30.3 °C)
22.8 °C (5.9-51.5 °C)
Very humid 87.5 %
2-day periods (x4)
Well controlled samples, fall within1 °C range (23.4-24.4 °C)

. **Challenge and Opportunity:** Temperature variation is greater for the bare rooftop than the surrounding environment by about 3 times. Using the extensive wetland green roof to cool down bldg. during daytime, to warm up bldg. during nighttime, and to achieve temperature stability around 20°C is always very favorable for dwellers.

Stage 1

. **Purpose:** Exploring the optimal kind of wetland soil among “Creek gravel” and “Akadama”



Treatment	min	max	difference	reduction of heat amplitude	daytime average temp. (06:00-18:00)	nighttime average temp. (18:00-06:00)
air	15.8	22.9	7.2	–	20.1	16.7
bare rooftop	15.7	41.5	25.9	–	29.9	16.8
creek gravel	20.9	22.5	1.6	**0.94**	**21.8**	**21.7**
akadama	21.1	22.1	1.0	**0.96**	**21.7**	**21.5**

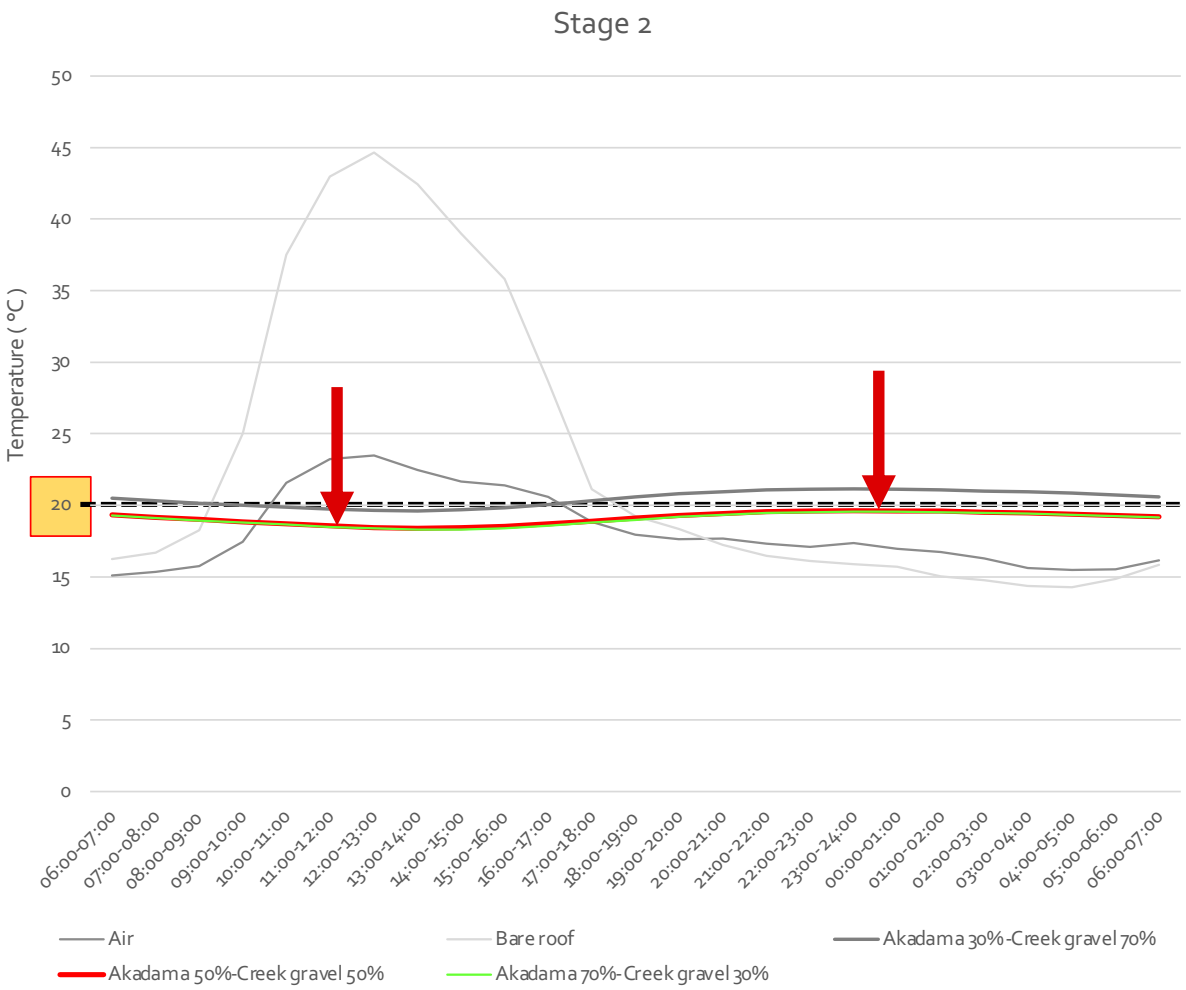
. **Daytime:** no sig. difference | keep building warmer than air temp. (2K+), cooler than bare rooftop (8K–) → more comfy

. **Nighttime:** no sig. difference | keep building warmer than air temp. (5K+) and bare rooftop (5K+) → more comfy

. **Reduction of heat amplitude:** super excellent, about 0.95

Decision: use both “Creek gravel” and “Akadama”

Stage 2 . **Purpose:** Exploring the optimal ratio for creek gravel-and-akadama mixture



Treatment	min	max	difference	reduction of heat amplitude	daytime average temp. (06:00-18:00)	nighttime average temp. (18:00-06:00)
air	15.1	23.5	8.4	–	19.7	16.8
bare rooftop	14.3	44.7	30.4	–	30.7	16.0
Ak.30%-C.G.70%	18.1	19.7	1.6	**0.95**	**18.5**	**19.5**
Ak.50%-C.G.50%	18.4	19.6	1.2	**0.96**	**18.8**	**19.5**
Ak.70%-C.G.30%	18.3	19.6	1.3	**0.96**	**18.7**	**19.4**

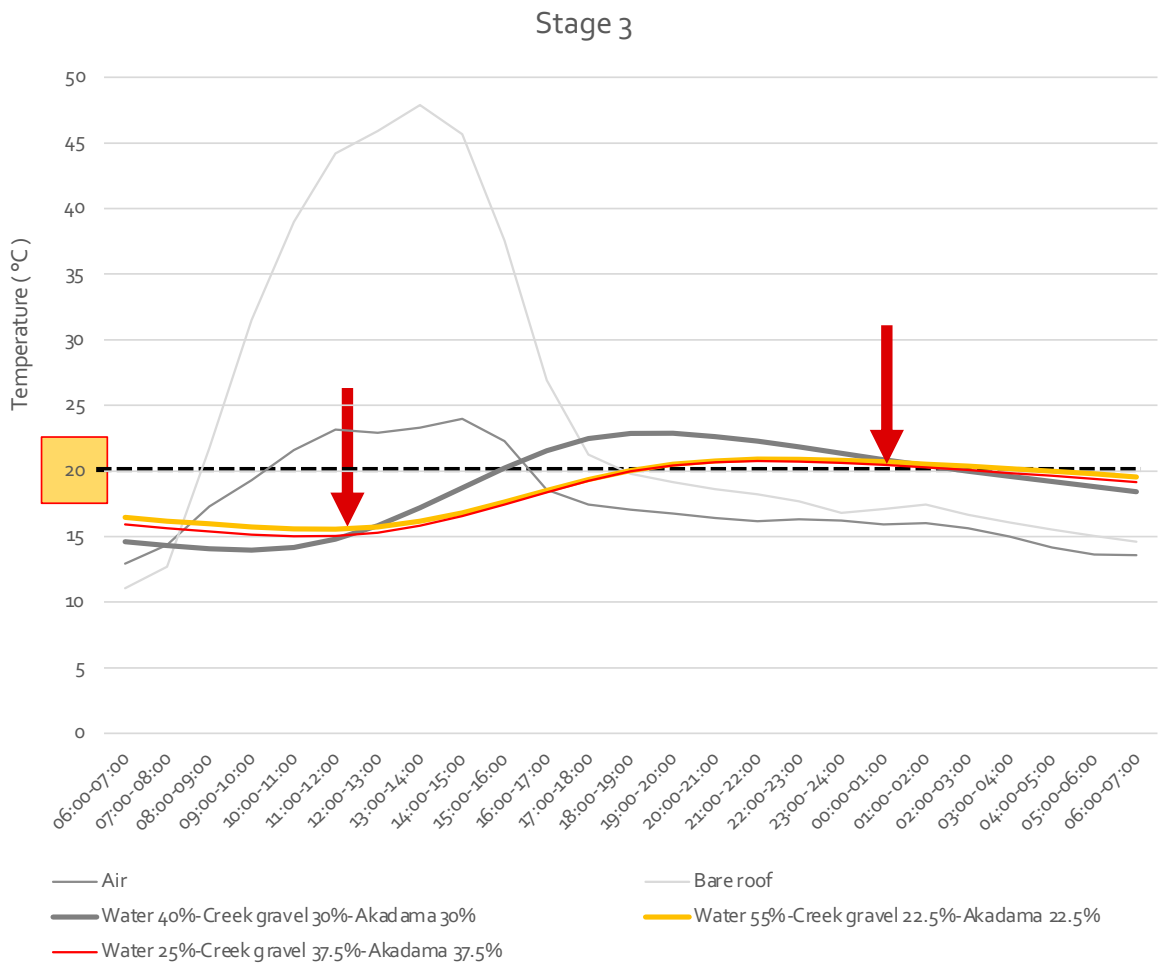
. **Daytime:** no sig. difference | keep building colder than air temp. (1K–), cooler than bare rooftop (12K–) → more comfy

. **Nighttime:** no sig. difference | keep building warmer than air temp. (3K+) and bare rooftop (4K+) → more comfy

. **Reduction of heat amplitude:** super excellent, about 0.95

Decision: select **50-50%** Creek gravel-Akadama mixture b/c of sightly better performance in term of daytime & nighttime comfy and temp. stability

Stage 3 . **Purpose:** Exploring the optimal ratio for pure water



Treatment	min	max	difference	reduction of heat amplitude	daytime average temp. (06:00-18:00)	nighttime average temp. (18:00-06:00)
air	12.9	24.0	11.0	–	19.8	15.8
bare rooftop	11.1	47.9	36.8	–	32.1	17.3
Wa.40%-C.G.30%-Ak.30%	14.0	22.9	8.9	**0.76**	**16.8**	**21.1**
Wa.55%-C.G.22.5%-Ak.22.5%	15.6	20.9	5.3	**0.86**	**16.6**	**20.4**
Wa.25%-C.G.37.5%-Ak.37.5%	15.0	20.8	5.7	**0.84**	**16.2**	**20.2**

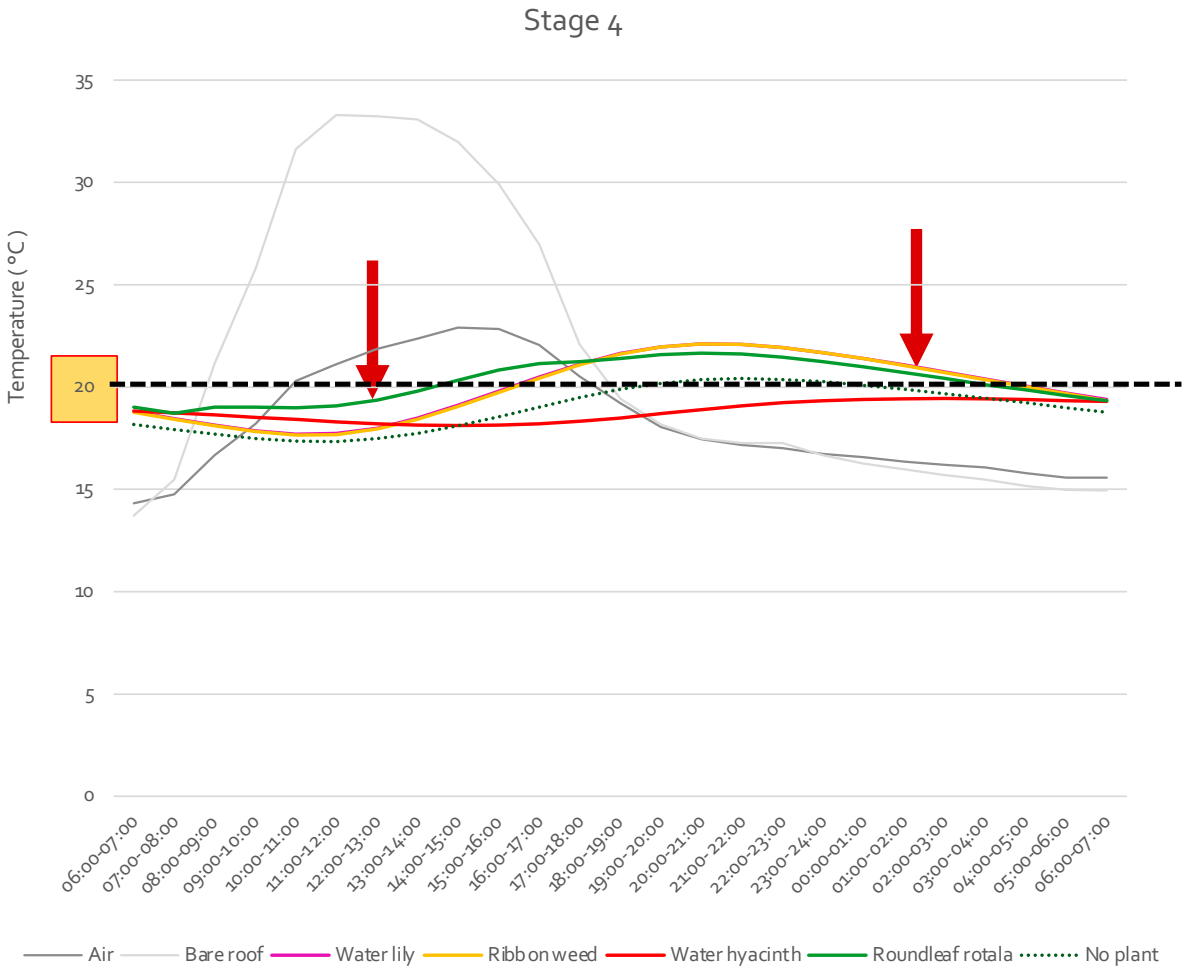
. **Daytime:** no sig. difference | keep building colder than air temp. (3K–), cooler than bare rooftop (16K–) → more comfy

. **Nighttime:** no sig. difference | keep building warmer than air temp. (5K+) and bare rooftop (3K+) → more comfy

. **Reduction of heat amplitude:** pretty good, 0.76-0.86

Decision: select **40%** Water ratio b/c bldg. been kept relatively the warmest

Stage 4 . **Purpose:** Exploring the optimal <u>type</u> of wetland plant species



Treatment	min	max	difference	reduction of heat amplitude	daytime average temp. (06:00-18:00)	nighttime average temp. (18:00-06:00)
Air	14.3	22.9	8.6	–	19.8	16.9
Bare rooftop	13.7	33.3	19.6	–	26.5	16.7
Water lily	17.7	22.1	4.4	**0.77**	**18.8**	**21.2**
Ribbon weed	17.7	22.1	4.5	**0.77**	**18.8**	**21.2**
Water hyacinth	18.1	19.4	1.3	**0.93**	**18.4**	**19.2**
Roundleaf rotala	18.7	21.7	2.9	**0.85**	**19.7**	**20.9**
No plant	17.3	20.4	3.1	**0.84**	**18.0**	**19.9**

. **Daytime:** no sig. difference | keep building colder than air temp. (1~2K–), cooler than bare rooftop (7~8K–) → more comfy

. **Nighttime:** no sig. difference | keep building warmer than air temp. (2~4K+) and bare rooftop (2~4K+) → more comfy

. **Reduction of heat amplitude:** pretty good, 0.77-0.93

Decision: select **<u>Emergent, Submerged, Floating-attached plants</u>** b/c bldg. been kept relatively the warmest

Conclusions & Suggestions

Conclusion & Suggestions

Third stage

2020/02/06-2020/02/07

Variable	Min. temp.	Max. temp.	Temp. range	Heat amplitude reduction	Daytime average temp.	Nighttime average temp.
Wa.25%-C.G.37.5%-Ak.37.5%	15.02	20.75	5.73	0.84	16.23	20.23
Wa.40%-C.G.30.0%-Ak.30.0%	13.96	22.87	8.91	0.76	16.82 **Too cold**	21.06 **Comfy**
Wa.55%-C.G.22.5%-Ak.22.5%	15.56	20.88	5.32	0.86	16.64	20.44
Air	12.93	23.97	11.04	--	19.76	15.77
Bare rooftop	11.06	47.88	36.83	--	32.11	17.34
Thermal performance					降溫 15.29°C	升溫 3.72°C
					cooler 48%	**warmer 21%**
					😄	😄

Goal 20℃

Fourth stage

2020/02/22-2020/02/23

Variable	Min. temp.	Max. temp.	Temp. range	Heat amplitude reduction	Daytime average temp.	Nighttime average temp.
Water lily	17.69	22.11	4.42	0.77	18.80	21.23
Ribbon weed	17.65	22.11	4.46	0.77	18.76	21.21
Water hyacinth	18.12	19.44	1.32	0.93	18.38	19.18
Roundleaf rotala	18.72	21.66	2.94	0.85	19.71 **Comfy**	20.88 **Comfy**
No plant	17.33	20.42	3.09	0.84	18.03	19.90
Air	14.32	22.90	8.59	--	19.82	16.85
Bare rooftop	13.71	33.29	19.58	--	26.53	16.65
Thermal performance					降溫 6.82°C	升溫 4.23°C
					cooler 26%	**warmer 25%**
					😄	😄

Goal 20℃

. **vs. no plant:** The extensive wetland roof w/out plants tends to make bare rooftop become TOO COLD during day-time, and NOT warm enough during night-time, hence the wetland roof with plants is recommended. Plants can help make the wetland green roof LESS COLD and MORE WARM, hence make bldg. dwellers feel more comfy, and then cut down A.C. and heating consumption.

. **Type of plant:** However, type of plant matters. Emergent (roundleaf rotala), Submerged (ribbon weed), Floating-attached (water lily) types of plants seem to outperform Free-floating (water hyacinth) plant.

. **Advantages of the wetland roof:** Compared with the extensive terrestrial green roof, the advantages of the wetland roof include: less cost (material, labor, time); low-maintenance (weed-free, easy fertilization); healing and soothing effects; stormwater management.

Thank You