ASSESSING IMPACT OF TERRACE GARDENS IN MITIGATING HEAT

Case Study of Anbagam Homeless Shelter, Purasaiwakkam, Chennai

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Prepared by Earthonomics and Chennai Resilience Centre

EARTHONOMIC ENGINEERS

CHENNAI RESILIENCE CENTRE

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Background and Purpose

The Chennai Resilience Centre (CRC) is dedicated to building an Enlightened, Just, and Integrated Chennai. CRC is a unit of Care Earth Trust and is fostered by Adrienne Arsht-Rockefeller Foundation Resilience Center (AARFRC) and Resilient Cities Network (RCN). CRC's mandate is to research, develop and implement resilience-building projects for the city of Chennai. Chennai's Resilience Strategy, developed with strategy partners Dalberg Advisors and Okapi Advisory, was released by the Greater Chennai Corporation in June 2019. The strategy identifies seven flagship projects for the city, including the 'Chennai Urban Horticulture Initiative' (CUHI).

The Resilience Strategy is available at www.resilientchennai.com/strategy

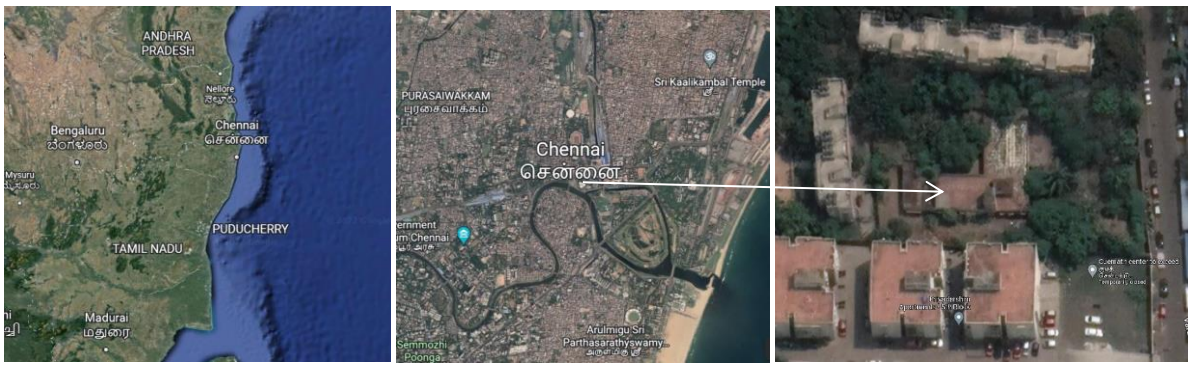
Chennai Urban Horticulture Initiative (CUHI) and Mitigating Heat

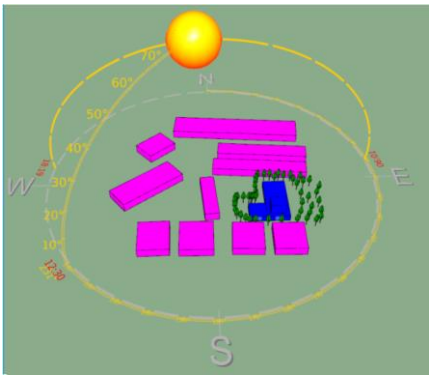
CUFI seeks to build climate resilience by setting up urban food gardens across the city as a means to achieve food security and better livelihood opportunities for vulnerable groups whilst contributing to greening and cooling efforts. In the past 5 years, Chennai has experienced bouts of extreme heat events thrice in the years 2017, 2019 and 2022 calling attention towards this manifestation of climate change. CRC recognizes the potential of transforming 1000s of acres of empty and concrete terrace space in Chennai to green edible and low albedo infrastructure that can contribute towards heat reduction, improved thermal comfort, and lower energy consumption. Thus, CRC is monitoring the implication of one of the terrace gardens set up in a homeless shelter in Otteri, to better understand how this green intervention can be best leveraged for heat reduction at the building level.

Study Site and Methodology

In January 2022, CRC helped a homeless shelter for women with psychosocial challenges set up a ~1000sqft rooftop garden using around 185 mobile vegetables garden kits. This shelter, called Anbagham, is located in Otteri, a neighbourhood in Purasaiwakkam, in the Western part of Chennai (see Figure 1 for satellite and simulated images). CRC chose this site for conducting a case study to examine the heat mitigation impact of a rooftop garden.

Figure 1: Site location in satellite (top) and simulated (bottom) images





Preparation

At the time of installation of the measuring instruments (April 2022) the terrace garden located along the eastern wall of the building with 184 grow bags covering an approximate area of 1000 sq. ft., was already well established, ensuring a adequate green density. The little stretch along the eastern wall that remained exposed was further covered with empty white cement bags made of plastic as it has been done for other areas with planter bags to avoid this area from behaving as a thermal mass.

Installation

Two sets of temperature and humidity sensors were installed which included, cased (IP67 rated) sensors for outdoor and exposed sensors for internal regions (see box 1 for details).

Box 1: Details of sensors used to measure humidity and temperature

AM2306 Mounted Temperature and Humidity Sensor 2nos. (External)

Typical accuracy (% RH)	± 2
Operating range (% RH)	0 to 99.9
Typical accuracy (°C)	0.5
Operating range (°C)	-40 ~ 80
Interface	1 – Wire
Supply Voltage (V)	3.3 ~ 5.5

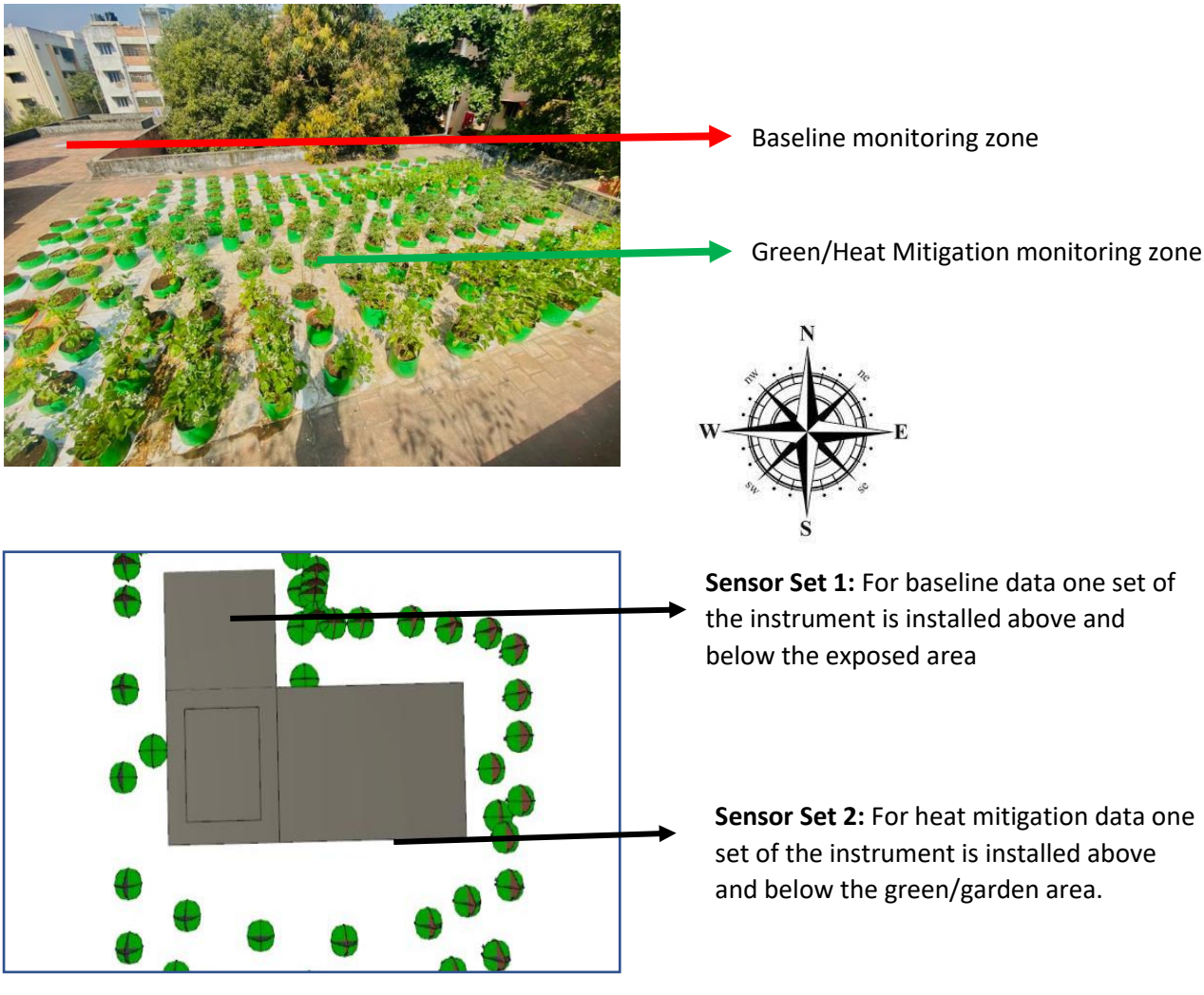
AM2105A Mounted Temperature and Humidity Sensor 2nos. (Internal)

Typical accuracy (% RH)	± 2
Operating range (% RH)	0 to 99.9
Typical accuracy (°C)	0.5
Operating range (°C)	-40 ~ 80
Interface	1 – Wire
Supply Voltage (V)	3.3 ~ 5.5

NOTE: Sensors used here are industry grade IP related.

One set of sensors were used to record baseline data from the area of the terrace where there is no garden (the baseline monitoring zone) and the second set was installed to record temperature in the area with the garden (the green/heat mitigation monitoring zone) (see figure 2).

Figure 2: Baseline and garden sites



The precise location of the 4 installed sensors were as follows (figure 3):

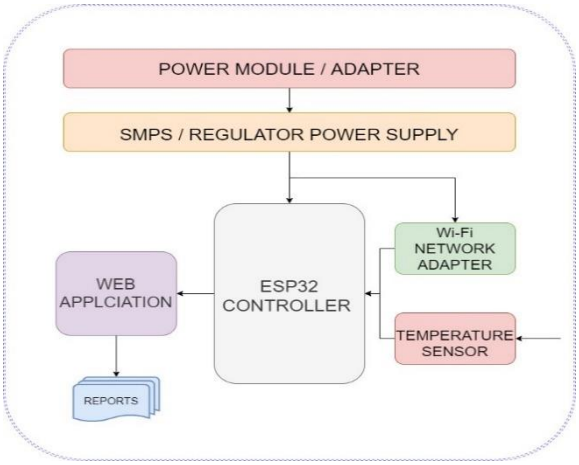
- The Sensor measuring external baseline data was set up in the Southwest corner of the terrace in the exposed portion of the terrace.
- The Sensor measuring internal baseline data was set up on the restroom ceiling, in the Southwest corner, below the external sensor.
- The external sensor measuring data from the green roof was installed amidst the planter bags, close to the parapet wall.
- A corresponding internal sensor to measure impact of the green terrace was installed on the ceiling of the store room directly below the planter bags.

Apart from our own sensors, we also relied on secondary weather data for the larger Otteri neighbourhood, sourced from weather online, AccuWeather and Visual Crossing.

Figure 3: A sensor in the garden area (left), a sensor in the exposed area (centre) and a sensor in one of the internal spaces (left)

Programme and calibration

Figure 4: The data recording system used



A simple system was used to process and calibrate the data captured through the sensors. A microcontroller programmed based on guidance from the sensor manufacturer was used to read the data signals. The controller interpreted these signals and processed the data using a web application called MATLAB. It then shared the data points via WIFI to a cloud application which was previous configured for this task. As such the sensors themselves do not need calibration unless a discrepancy or mismatch was observed in the collected data. However, we did calibrate the sensors to the extent of installing a new dongle to ensure that reporting intervals of data were for the same time stamps. To ensure accuracy of data collected, the team used a handheld temperature measurement device to intermittently check the temperature and compare it with the recorded data and calibrate if needed (see figure 4 representing a flow chart that explains the architecture of the recording system).

Assessment methodology

Data from the sensors were collected for the period of April 1st till June 6th, 2022. The following steps were carried out the assess data recorded during this period:

- Extreme measurements of low and high temperature were removed to ensure the results were not skewed.
- This data was then compared with the area specific weather data (Otteri weather data) to estimate the variance between weather data, external and internal temperature.
- This tabulation was then used to calculate the following:
    - The heat retained by surfaces by comparing weather data with external surface temperature of the exposed terrace space and exposed space with garden over time.

- The temperatures inside the building and on the corresponding surface space above.
- Temperatures in the room below the exposed surface area and the terrace garden that would indicate the impact of the garden.

Findings

In the next section, findings from this study are presented. Data was captured, analysed and interpreted for the period **April 1st to June 6th 2022, is presented.** During this time the garden was well maintained and all sensors were functional. While average difference in room temperatures (garden room vs. exposed room) across the whole period has been reported, the following assessment also specifically considered data from particular days which were recorded as hottest day or as a rainy day during this period.

Dates considered:

- 2nd June 2022: Peak Heat Day – Maximum recorded temperature = 40°C at 2:30 PM
- 2nd June 2022: Peak Real Feel Day – Maximum real feel recorded = 55°C at 3:00 PM
- 10th May: Rainy Day: Maximum temperature recorded = 31.40°C at 10:00 PM
- 10th May: Rainy Day: Maximum real feel recorded = 49.9°C at 10:30 PM

In addition to presenting the recorded data a number of scenarios were generated based on the data sets collated. Two specific scenarios are reported here.

1. Scenario 1: Peak heat day – no roof treatment – exposed and weathered concrete surface
2. Scenario 2: Peak heat day – whole roof layered with white cement bag followed by planter bags with foliage

Summary of recordings and results

Table 1 presents a summary of findings from data recorded at Anbagam shelter in Otteri, Purusaiwakkam.

Table 1: Summary of findings

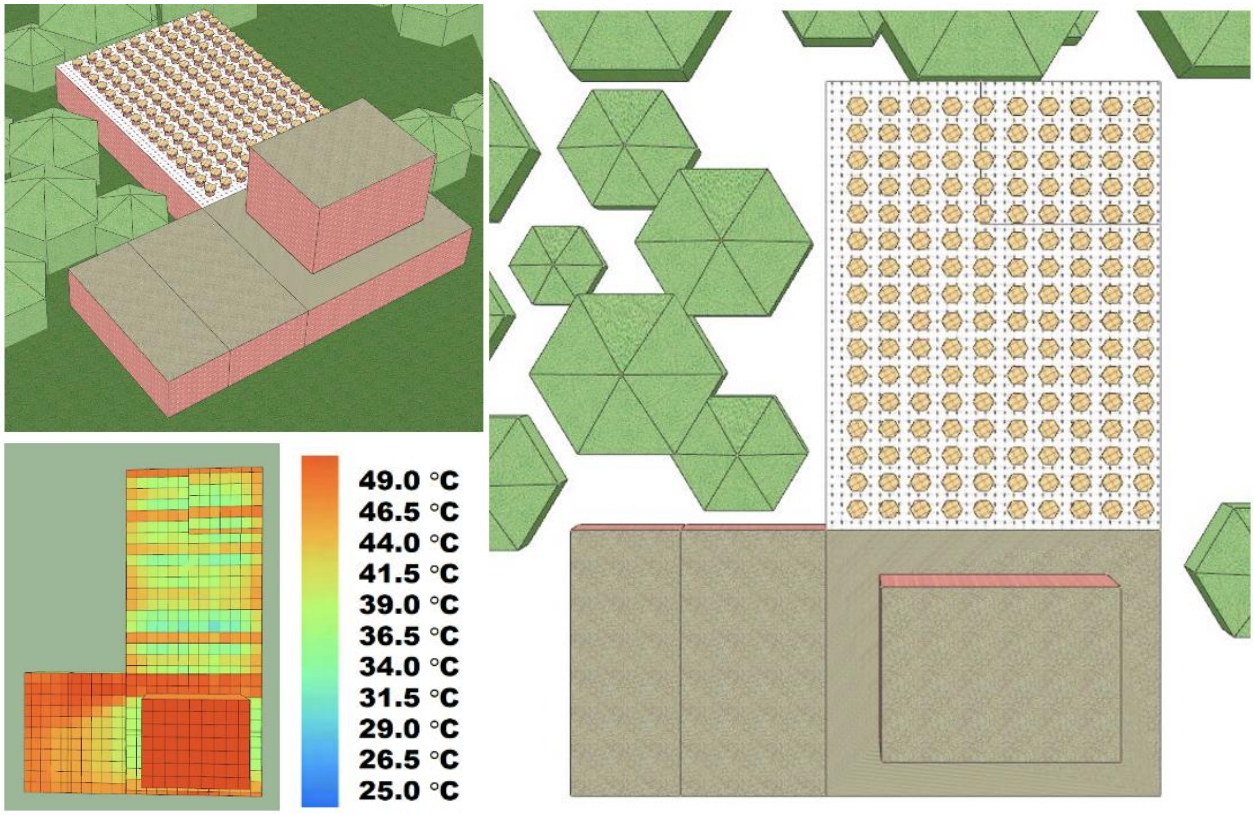
Parameter	Reading °C	Date	Time
External peak temperature	40.00	2nd of June	2:30PM
Real feel peak temperature	55.00	2nd of June	2:30PM
Peak temperature in Garden area	38.95	1st of June	4:30PM
Peak temperature in Exposed area	43.84	2nd of June	2:30PM
Peak temperature in Garden room internal	38.25	1st of June	4:30PM
Peak temperature in Exposed room internal	41.98	2nd of June	2:30PM
Temperature difference at external peak (40 °C)	3.48	2nd of June	2:30PM
Maximum Temperature difference (garden room vs. exposed room) on hottest day	**7.56**	**2nd of June**	**2:30PM**
Least temperature recorded at 2:30 PM (April 1 till June 6th) – Rainy Day	27.50	10th of May	2:30PM
Maximum Temperature difference (garden room vs. exposed room) on rainy day (coolest)	-4.10	10th of May	2:30PM

Parameter	Reading °C	Date	Time
Average difference – Exposed room vs Garden room April 1 till June 6th	**1.15**	**April 1-June 6th**	**24 hours**
Average difference – Exposed room vs Garden room Sunshine Hours April 1 till June 6th	**2.80**	**April 1-June 6th**	**6AM – 6PM**
Average difference – Exposed room vs Garden room Night Hours April 1 till June 6th	-0.81	April 1-June 6th	6PM – 6AM

I. Case 1: Current scenario – roof covered partially with white cement bags and planter bags with foliage in the Northeast section on the hottest day

These images (figure 5) provide a three-dimensional (3D) representation of the current set up at Anbagam shelter home.

Figure 5: 3D representation of the test site



From the thermal imagery, it can be noted that the average surface temperature in the external garden area was 40° C and the average surface temperature of the exposed roof space was 45°C.

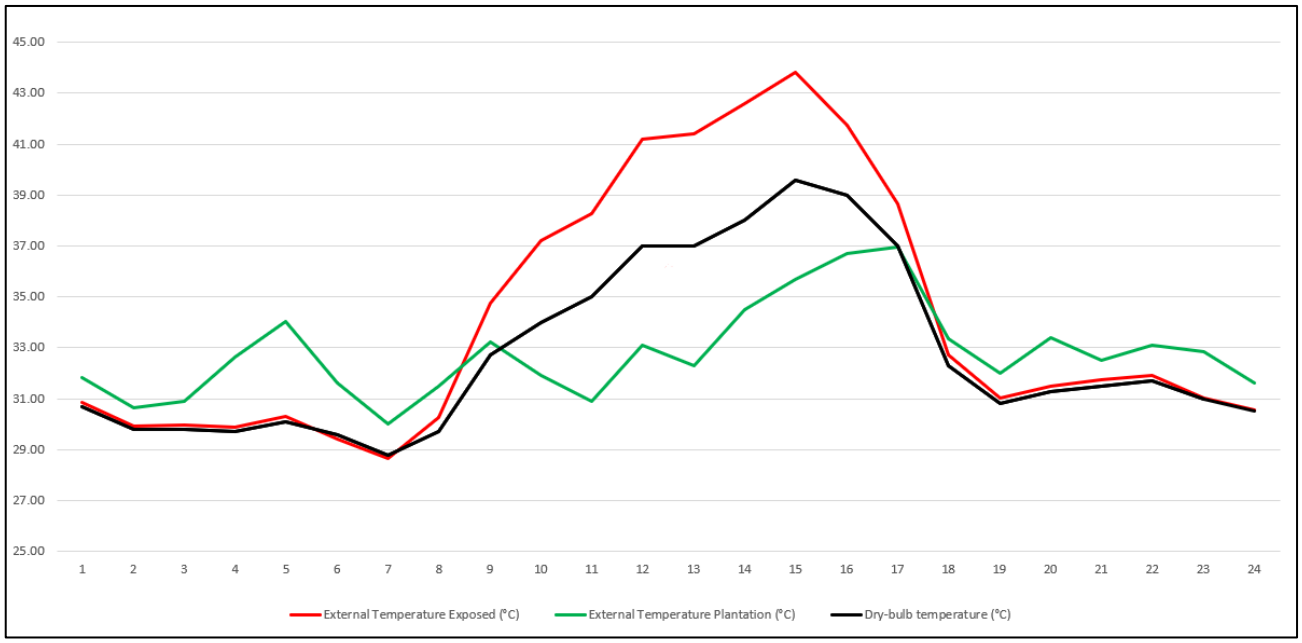
Table 2 provides data for June 2nd 2022 which was recorded as the hottest day within the study period. Based on this data, an analysis of external and internal temperature is presented below.

Table 2: Temperature data from the test site for June 6th 2022

Date	Time	Observed temperature in the neighbourhood (°C)	External Temperature Garden Area (°C)	Internal Temperature below Garden (°C)	External Temperature: Exposed Space (°C)	Internal Temperature below Exposed Space (°C)	Exposed Room vs Garden Room
02-06-2022 00:30	00:30:00	30.70	31.83	33.63	30.84	33.00	-0.63
02-06-2022 01:30	01:30:00	29.80	30.65	32.00	29.94	31.51	-0.49
02-06-2022 02:30	02:30:00	29.80	30.90	32.10	29.96	30.78	-1.32
02-06-2022 03:30	03:30:00	29.70	32.62	32.16	29.86	30.01	-2.15
02-06-2022 04:30	04:30:00	30.10	34.03	32.75	30.30	30.02	-2.73
02-06-2022 05:30	05:30:00	29.60	31.60	33.35	29.40	29.31	-4.04
02-06-2022 06:30	06:30:00	28.80	30.00	32.12	28.66	31.39	-0.73
02-06-2022 07:30	07:30:00	29.70	31.50	32.43	30.26	32.57	0.14
02-06-2022 08:30	08:30:00	32.70	33.22	33.20	34.75	36.24	3.04
02-06-2022 09:30	09:30:00	34.00	31.90	33.10	37.19	37.67	4.57
02-06-2022 10:30	10:30:00	35.00	30.88	33.72	38.28	38.74	5.02
02-06-2022 11:30	11:30:00	37.00	33.10	33.48	41.20	41.03	7.55
02-06-2022 12:30	12:30:00	37.00	32.30	35.02	41.39	40.80	5.78
02-06-2022 13:30	13:30:00	38.00	34.50	35.76	42.57	41.18	5.42
02-06-2022 14:30	14:30:00	39.60	35.70	38.50	43.84	41.98	3.48
02-06-2022 15:30	15:30:00	39.00	36.70	38.78	41.73	40.01	1.23
02-06-2022 16:30	16:30:00	37.00	36.95	37.25	38.66	37.78	0.53
02-06-2022 17:30	17:30:00	32.30	33.36	33.37	32.72	33.66	0.29
02-06-2022 18:30	18:30:00	30.80	32.00	32.70	31.04	32.80	0.10
02-06-2022 19:30	19:30:00	31.30	33.40	33.16	31.47	33.92	0.76
02-06-2022 20:30	20:30:00	31.50	32.50	33.80	31.73	34.21	0.41
02-06-2022 21:30	21:30:00	31.70	33.10	33.94	31.92	34.52	0.58
02-06-2022 22:30	22:30:00	31.00	32.84	32.76	31.02	33.70	0.94
02-06-2022 23:30	23:30:00	30.50	31.62	33.45	30.54	33.25	-0.20

i. Assessment of weather data and external surface temperature: Figure 6 presents the difference in temperature between the recorded weather data and temperatures on the exposed and garden covered roof space.

Figure 6: Observed external temperature in Otteri area compared to external temperature recorded for the exposed surface and surface with garden with time (every hour in the day) represented on the x-axis and temperature in °C represented on the y-axis



Note: Please zoom in to the images for better clarity

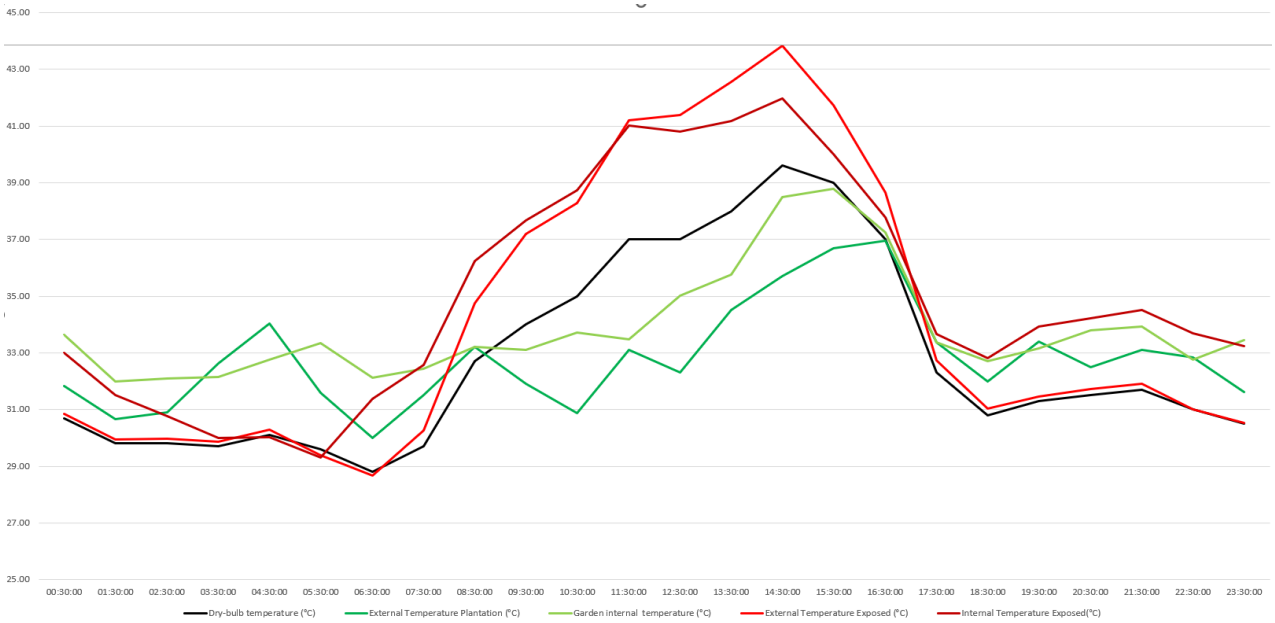
From the figure it can be understood that:

- During sunshine hours (6am to 6pm), temperature in the garden or plantation area is lesser than the externally recorded temperature for the larger location of Otteri (referred to as dry-bulb temperature in this subsequent graphs) and for the exposed roof space. This is attributed to the shading effect of the plants via the foliage, and the white cement bag under the planter bags.

- Post sunset (6pm) till 8am, the temperature in the garden area is greater than the recorded temperature for Otteri and the exposed roof temperature. This could be attributed to the release of trapped heat from inside the building moving upward through the ceiling to plantation area. The exposed terrace surface is cooler because there no planter bags obstructing contact with the atmosphere, enabling it to cool faster. There is a build-up of heat in the store room below the garden because there is no ventilation for that room and the doors are closed compare to the room below the exposed roof surface which has permanently opened windows that enable ventilation and therefore lesser movement of heat up to the terrace.

ii. Assessment of surface temperature and internal temperature: The following chart depicts the difference in temperature between the Otteri Neighbourhood, external roof sites and the corresponding rooms below (figure 7).

Figure 7: Comparison of temperature within the building, on the terrace and in the neighbourhood



Note: Please zoom in to the images for better clarity

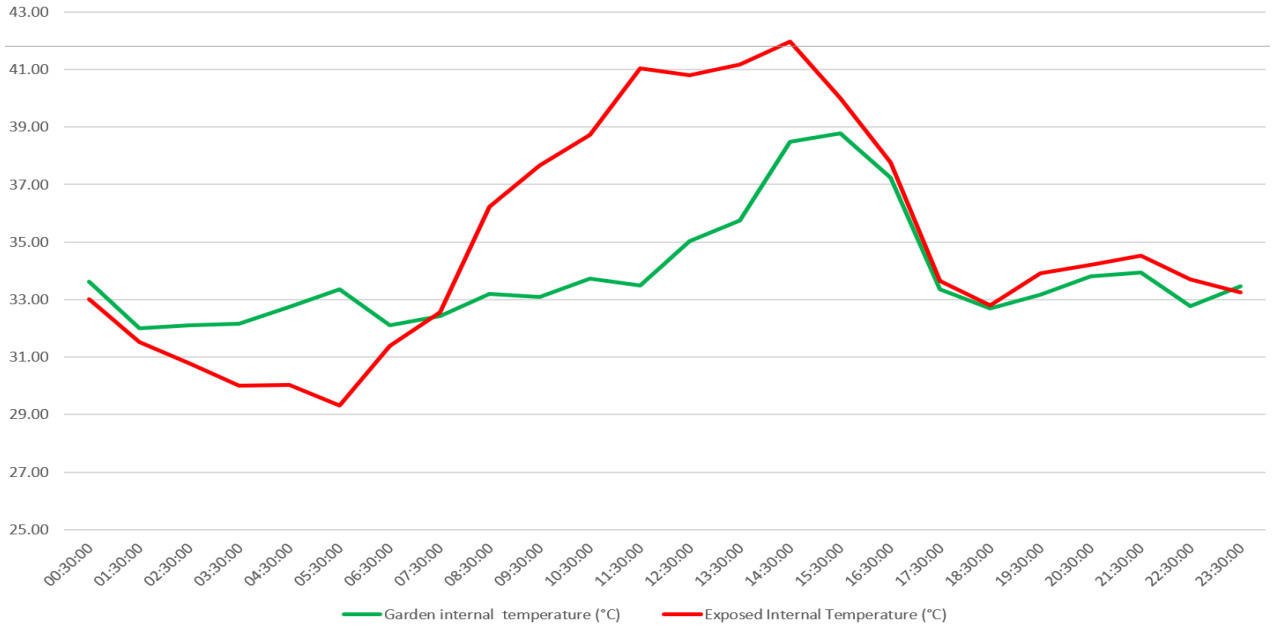
Figure 7 reveals that the internal temperature, within the building follows different patterns for both the rooms being studied.

- In the **exposed room** (or room below the exposed terrace space), temperature is predominantly lower than the corresponding exposed roof surface temperature as the internal space is ventilated, and heat dissipates to surrounding cooler rooms

- In the **garden room** (or the room below the garden), temperature is generally higher than external garden surface temperature. This is because heat flows into this room through internal partitions as this is the coolest room in the building, being situated directly below the roof top garden. This is indicative of the complex relationship between temperature, roof cover, ventilation, humidity, and the contextual structural flows that all collectively determine final outcomes on how heat is experienced.

iii. Assessment of roof temperature in the portions exposed and covered by the garden: Figure 8 depicts the difference in temperature between the rooms below the garden and exposed terrace space.

Figure 8: Temperatures in the rooms below the garden and exposed portion of the terrace with time measured on the x-axis and temperature (°C) measured on the y-axis.



Note: Please zoom in to the images for better clarity

From figure 8, it is noticed that:

- The temperature in the room below the garden is higher than the temperature in the room below the exposed terrace space between midnight and 7:30am. As mentioned earlier, this could be because the former is a storeroom with no windows and the doors are usually closed, blocking ventilation and enabling build up of heat.

- However, when the store room is opened at 7:30am, the reverse is observed – where the temperature in the storeroom is significantly below the temperature in the room below the exposed surface especially during the hottest hours of the day. A contributing factor could be that the store room doors are kept open enabling heat evacuation during this period.

II. Case 2: Current scenario – roof covered partially with white cement bags and planter bags with foliage in the Northeast section on a rainy day

Table 3 provides data for May 10th 2022 which was recorded as the wettest day within the study period. Based on this data, an analysis of external and internal temperature is presented below.

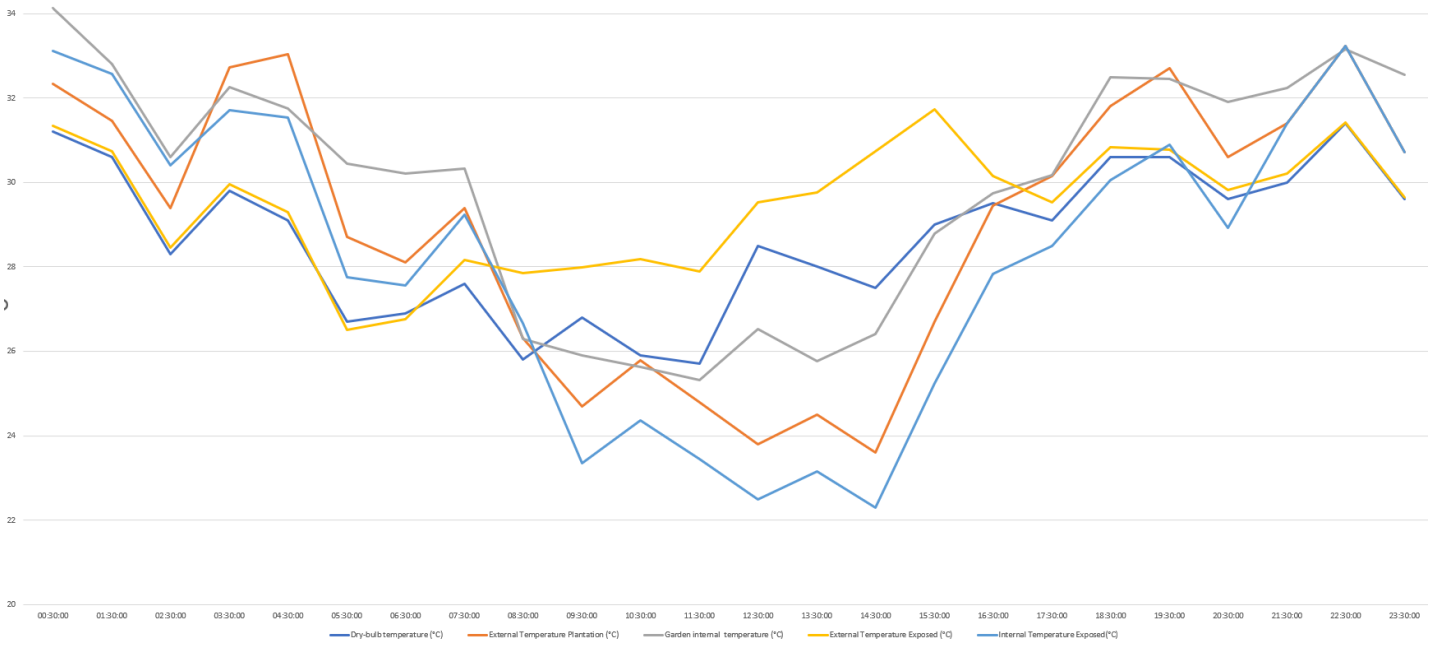
Table 3: Temperature data from the test site on the wettest day during the observed period

Date	Time	Observed temperature in the neighbourhood (°C)	External Temperature Garden Area (°C)	Internal Temperature below Garden (°C)	External Temperature: Exposed Space (°C)	Internal Temperature below Exposed Space (°C)	Exposed Room vs Garden Room
10-05-2022 00:30	00:30:00	00:30:00	31.20	32.33	34.13	31.34	33.12
10-05-2022 01:30	01:30:00	01:30:00	30.60	31.45	32.80	30.74	32.57
10-05-2022 02:30	02:30:00	02:30:00	28.30	29.40	30.60	28.46	30.40

Date	Time	Observed temperature in the neighbourhood (°C)	External Temperature Garden Area (°C)	Internal Temperature below Garden (°C)	External Temperature: Exposed Space (°C)	Internal Temperature below Exposed Space (°C)	Exposed Room vs Garden Room
10-05-2022 03:30	03:30:00	03:30:00	29.80	32.72	32.26	29.96	31.72
10-05-2022 04:30	04:30:00	04:30:00	29.10	33.03	31.75	29.30	31.54
10-05-2022 05:30	05:30:00	05:30:00	26.70	28.70	30.45	26.50	27.75
10-05-2022 06:30	06:30:00	06:30:00	26.90	28.10	30.22	26.76	27.56
10-05-2022 07:30	07:30:00	07:30:00	27.60	29.40	30.33	28.16	29.24
10-05-2022 08:30	08:30:00	08:30:00	25.80	26.32	26.30	27.85	26.66
10-05-2022 09:30	09:30:00	09:30:00	26.80	24.70	25.90	27.99	23.34
10-05-2022 10:30	10:30:00	10:30:00	25.90	25.78	25.62	28.18	24.36
10-05-2022 11:30	11:30:00	11:30:00	25.70	24.80	25.32	27.90	23.44
10-05-2022 12:30	12:30:00	12:30:00	28.50	23.80	26.52	29.52	22.49
10-05-2022 13:30	13:30:00	13:30:00	28.00	24.50	25.76	29.76	23.15
10-05-2022 14:30	14:30:00	14:30:00	27.50	23.60	26.40	30.74	22.30
10-05-2022 15:30	15:30:00	15:30:00	29.00	26.70	28.78	31.73	25.23
10-05-2022 16:30	16:30:00	16:30:00	29.50	29.45	29.75	30.16	27.83
10-05-2022 17:30	17:30:00	17:30:00	29.10	30.16	30.17	29.52	28.50
10-05-2022 18:30	18:30:00	18:30:00	30.60	31.80	32.50	30.84	30.05
10-05-2022 19:30	19:30:00	19:30:00	30.60	32.70	32.46	30.77	30.90
10-05-2022 20:30	20:30:00	20:30:00	29.60	30.60	31.90	29.83	28.92
10-05-2022 21:30	21:30:00	21:30:00	30.00	31.40	32.24	30.22	31.40
10-05-2022 22:30	22:30:00	22:30:00	31.40	33.24	33.16	31.42	33.24
10-05-2022 23:30	23:30:00	23:30:00	29.60	30.72	32.55	29.64	30.72

i. Assessment of temperature in the room below the garden and the exposed roof surface: Figure 9 illustrates the temperatures on roof spaces, in the rooms below and in the larger Otteri neighbourhood on the wettest day in the study period.

Figure 9: Temperatures in Otteri neighbourhood, on the roof and in the rooms below on a rainy day during the study period with time measured on the x-axis and temperature on the y-axis.



Note: Please zoom in to the images for better clarity

From figure 9, it can be noted that:

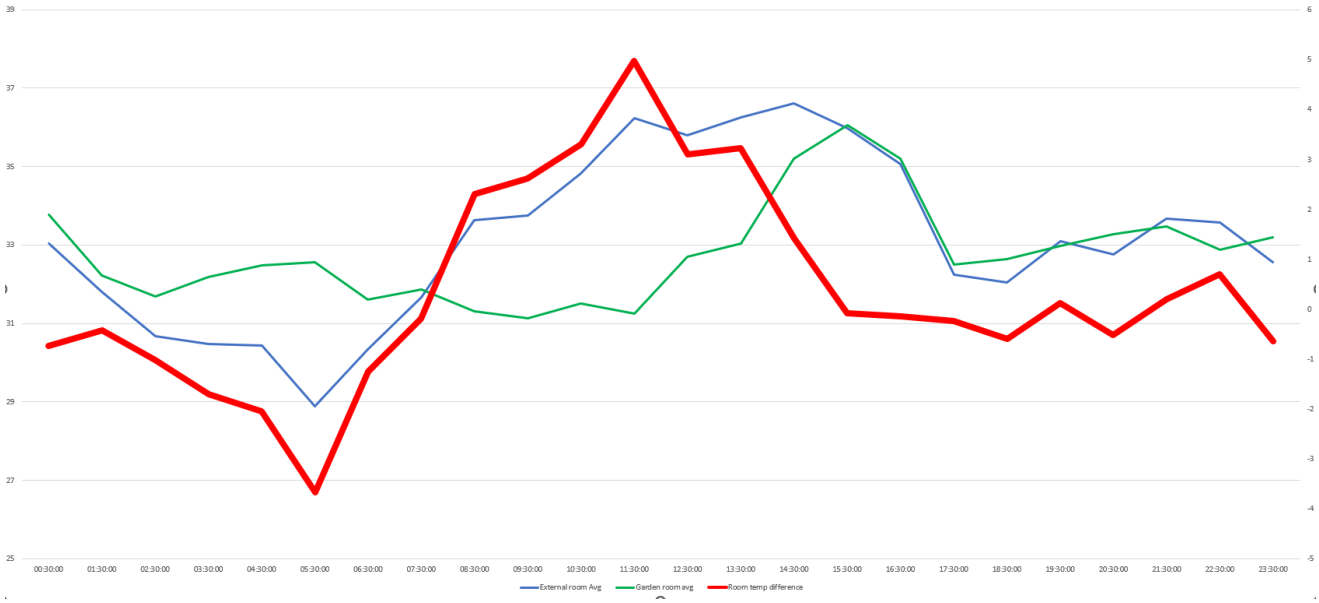
- Intermittent rains were recorded on the 10th of May from 5:30 AM to 3:30 PM corresponding with a general dip in temperature at a neighbourhood level (dry-bulb temperature). The rains resulted in release of trapped heat from inside the building to the surface and spikes in exposed area temperature can be observed at these release intervals – when the rain stops.

- The garden area remains cooler and temperature variations are regulated throughout this period.

III. Average temperature difference between the rooms during the entire study period

The following figure 10, shows the average difference in temperature between the room below the garden and the exposed roof space during the entire study period i.e from 1st April 2022 to 6th June 2022. **The figure highlights that the average peak difference between the two rooms is 5°C at around 12 noon.** In other words, the temperature in the room below the garden area is a maximum of 5°C lower than the room below the exposed roof space at the hottest time of the day.

Figure 10: Average temperature difference between the room under the garden and the exposed roof space with time on the x-axis and temperature in °C on the y-axis



Note: Please zoom in to the images for better clarity

IV. Simulated scenarios that compare a fully exposed roof space and a roof completely covered with planter bags[1]

The following data (table 4) has been simulated based on data readings from the project site. It has been used to create a likely estimate of the impact of a roof fully covered with grow bags compared to a roof with no grow bags. The estimate of internal temperature within the building is provided for the hottest day of the study period – June 2nd 2022, for the two scenarios.

Table 4: Likely external temperature on an exposed roof and a roof covered with a garden on a hot day

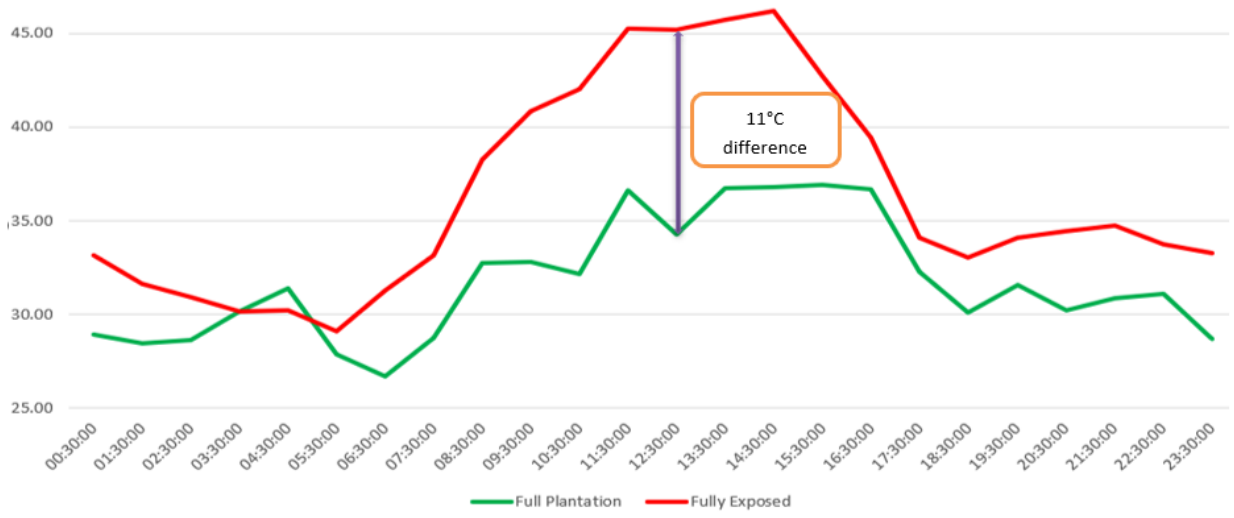
Date	Time	Temperature in the Otteri neighbourhood (°C)	Full Plantation (internal temperature) (°C)	Fully Exposed (internal temperature) (°C)	Difference (°C)
02-06-2022 00:30	00:30:00	30.70	28.90	33.14	4.24
02-06-2022 01:30	01:30:00	29.80	28.45	31.65	3.20
02-06-2022 02:30	02:30:00	29.80	28.60	30.94	2.34
02-06-2022 03:30	03:30:00	29.70	30.16	30.17	0.01
02-06-2022 04:30	04:30:00	30.10	31.38	30.22	-1.16
02-06-2022 05:30	05:30:00	29.60	27.85	29.11	1.26
02-06-2022 06:30	06:30:00	28.80	26.68	31.25	4.57
02-06-2022 07:30	07:30:00	29.70	28.77	33.13	4.36
02-06-2022 08:30	08:30:00	32.70	32.72	38.29	5.57
02-06-2022 09:30	09:30:00	34.00	32.80	40.86	8.06
02-06-2022 10:30	10:30:00	35.00	32.16	42.02	9.86
02-06-2022 11:30	11:30:00	37.00	36.62	45.23	8.61
02-06-2022 12:30	12:30:00	37.00	34.28	45.19	10.91

[1] Excluding the area covered by the water tank

Date	Time	Temperature in the Otteri neighbourhood (°C)	Full Plantation (internal temperature) (°C)	Fully Exposed (internal temperature) (°C)	Difference (°C)
02-06-2022 13:30	13:30:00	38.00	36.74	45.75	9.01
02-06-2022 14:30	14:30:00	39.60	36.80	46.22	9.42
02-06-2022 15:30	15:30:00	39.00	36.92	42.74	5.82
02-06-2022 16:30	16:30:00	37.00	36.70	39.44	2.74
02-06-2022 17:30	17:30:00	32.30	32.29	34.08	1.79
02-06-2022 18:30	18:30:00	30.80	30.10	33.04	2.94
02-06-2022 19:30	19:30:00	31.30	31.54	34.09	2.55
02-06-2022 20:30	20:30:00	31.50	30.20	34.44	4.24
02-06-2022 21:30	21:30:00	31.70	30.86	34.74	3.88
02-06-2022 22:30	22:30:00	31.00	31.08	33.72	2.64
02-06-2022 23:30	23:30:00	30.50	28.67	33.29	4.62

Figure 11 provides a visual illustration of the likely internal temperature difference between the two roof spaces.

Figure 11: External temperature comparison between roof fully covered by a garden and a roof fully exposed and without a garden



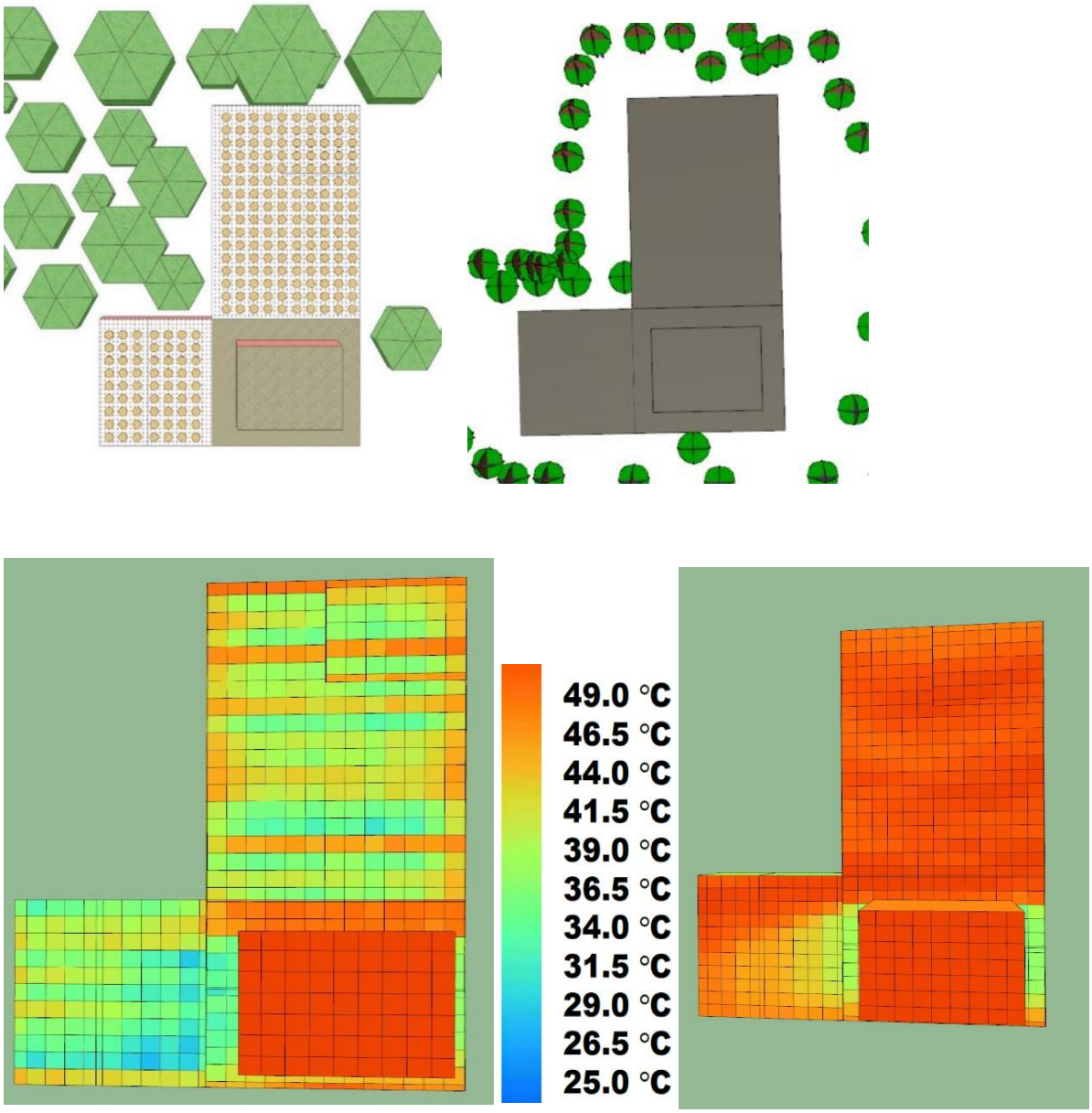
Results from the simulation indicate that:

- The internal temperature within the building, when the entire roof is covered with a garden is always lower than the internal temperature when the roof is fully exposed, during summers.
- **The difference in internal temperature is around 11°C if the facility is completely insulated with a garden on roof top. This is almost 4°C more relief than the current set up wherein only a part of the roof has been covered with plantation.**
- It is also worth noting that the peak difference in this simulated case occurs around 11:30am because there is exchange of heat between the two rooms. However, if the simulation were to be replicated with two independent buildings – one with a roof garden and one without - where there is no internal heat transfer, then the peak temperature difference would be observed at 3pm and the difference could go up to 14°C. The temperature difference between the project specific simulated model and a hypothetical scenario of two independent buildings

is attributed to the learning data set from the sensors where the peak differential occurs at around 11:30am – 12 noon. Whereas, in a real time scenario this build up translates to a peak temperature difference around 230pm to 3pm.

The following set of images (figure 12) provides a visual presentation of the simulated scenario. They indicate that the average surface temperature on the roof top is around 38°C where the whole terrace is covered with grow bags and around 49°C when the entire roof is exposed.

Figure 12: Simulated scenario with the terrace fully covered with a garden (top left), a fully exposed terrace (top right) and corresponding thermal images of the same spaces i.e. fully covered roof (top left) and fully exposed roof (top right)



Discussion and Recommendations

Based on the data captured from 1st April to 06th of June 2022, some general observations are evident.

During Sunshine hours:

I. Temperature in the exposed areas is on an average 2-3°C more than reported temperature for the locality.
II. Temperature in the garden region is 1.5°C lesser than the reported temperature for the locality.
III. The room under plantation is 2-3°C cooler than and the exposed room is on an average.

Post sunset till sunrise:

IV. Temperature in the exposed areas is at par with the reported temperature for the locality.
V. Temperature in the garden region is 1.5°C more or at par with reported temperature for the locality.
VI. The temperature of room under the garden is at par with the exposed room on an average.

Comparison of both the rooms:

I. Depending on time of the day, there is a significant difference (2 to 7°C) in temperatures between the rooms – the room under garden is cooler than the exposed roof area room at almost all times.

II. There is an increase in internal temperature of the room below the garden around 12 noon, where the temperature gets closer to the room under the exposed roof space. This is attributed to the following factors:
    a) Owing to a cooler condition inside the room below the roof top garden, heat begins to flow to the cooler room from the hotter envelope.
    b) The roof slab that connects these 2 zones is common (no thermal barrier) and hence, there is a time delay, but eventually the heat starts flowing in and the temperatures in the 2 zones is comparable.

III. On a rainy day: The facility remains cool if there are continuous rains, however, once rain stops, the envelope releases heat into the atmosphere and to the rooms (bi-directional) thereby the temperature increases after the rain stops. The roof garden has no impact on this.

IV. Overall, its physically possible to perceive the difference and the data measured confirm the impact of lower indoor temperature attributed to roof top gardening.

Recommendations

Based on this case study we recognize that,

I. covering the complete roof with planter bags and promoting foliage would ensure 4°C to 11°C lower temperatures compared to a completely exposed roof setup, and,
II. upon simulation, it is observed that this difference may go up to 14°C (best case scenario) if the planter bags are replaced with an evenly spread out soil bed (2-3 feet depth) with a dense foliage of plants. Therefore, it is recommended that covering the entire terrace space with a

garden on soil bed rather than with growbags will produce better result. However, this may or may not be practically always feasible. And therefore using grow bags as in the current situation to cover the entire terrace space can yield better results.

Going forward, CRC intends to conduct more rigorous study of the impact of terrace gardens with grow bags on surrounding (external, internal) temperature for extended period of time – considering terrace gardens in different localities and building structures will add more intricacies to this assessment to derive the range of impact that this type of green infrastructure may have on heat mitigation and building climate resilience.