GREEN ROOF PROOF OF CONCEPT FOR HONOLULU, HAWAI’I

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Master of Geoscience for Professionals

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Abstract

Growing urbanization has resulted in the exchange of vegetated land for impermeable, non reflective buildings and infrastructure. One of the consequences of this is an increase in the phenomena known as urban heat island effect. This localized warming of the air has been directly correlated to an increase in human mortality, increased energy consumption, and negative effects on the local economy. The implementation of green roofs as a strategy to mitigate these ill effects has been proven effective in many cities. Through the process of evapotranspiration plants cool the surrounding areas, thus reducing the fluctuation of daytime temperatures. In this study, we quantify the temperature decreasing effect of a sedum species covered, extensive type, green roof in urban Honolulu. To accomplish this we built a 64 ft2 green roof on top of a commercial building and monitored temperature changes during the summer. Data was collected from the surface of the green and existing white roof, as well as at the heights of 2 ft and 4 ft above the surface. From the results obtained, it was shown green roofs cool the roof surface an average of 4.1°F during the daytime. Extreme fluctuations in heat were also tempered with 18°F difference in peak temperatures between the existing white roof and the green roof. These effects were less pronounced at 2ft above the surface, and effects were negligible at the height of 4 ft above the roof surface. We can conclude from the data gathered that introducing vegetation in the form of green roofs, in concert with other heat island mitigation measures such as tree planting, would result in the abatement of urban heat island effect in Honolulu, Hawai'i.

Note

This paper was independently prepared by Elizabeth Dionne as a part of her internship and degree requirements. It is meant to be used as a resource and a guide. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the Honolulu Office of Climate Change, Sustainability, and Resilience. For use of this paper or the data collected, please contact Elizabeth Dionne at edionne@hawaii.edu

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Executive Summary

Purpose of Study
This study was conducted to quantify the potential for decreasing surface and local ambient air temperatures in the urban environment of Honolulu, Hawai'i. The data and results are to be useful in affecting the decisions of policy makers in their efforts to utilize green infrastructure.

Background
Concrete and paved surfaces in cities retain heat during day resulting in higher local and surrounding air temperatures. This phenomenon is known as the urban heat island effect (UHI) and has been linked to increased energy demand, human mortality, and lowered productivity. Painting roofs white, and planting trees has seen some positive effects in mitigating UHI but urban roofs are an overlooked resource that could make significant contributions too.

Green Roof Types
The construction of a green roof involves a waterproof barrier, a drainage layer, soil or engineered substrate, and vegetation. There are two types of green roofs, *extensive* and *intensive.*

Intensive roofs have a thicker layer of soil three times the depth of an extensive roof to support many different shrub, plants, and trees. The build is much heavier but has a potential for use as a recreational area. Only suitable for buildings with low roof slopes (1-3%) and load bearing capabilities, this build requires regular maintenance and upkeep.

Extensive roofs allow for a limited selection of vegetation. Its purpose is for environmental benefit, rather than recreation. The extensive roof is lighter and can be designed to fit around current infrastructure. This build can be put on a roof with a steep slope (1-30%). Maintenance requirements after initial setup are minimal, though an irrigation system may still be required depending on rainfall and seasonality

Costs and Benefits
The economic costs of installing a green roof are the cost of construction and continued maintenance. The benefits include:

- Less frequent replacement of roofs.
- Reduced storm water stress on drainage and sewage systems.
- New job opportunities for unskilled laborers.

Environmental benefits include:

- Lowered temperatures of building surface and overlying air.
- Improved air quality.
- Improved water quality of storm water runoff.
- Decrease in quantity of storm water runoff.

Difficulties and Considerations of Implementation
During the design, construction, and continued upkeep of a green roof, there are a few considerations.

- The ability of the building to support the additional dry and wet weight.
- Prevention of leaks and damage to the existing rooftop.
- Permits for a permanent irrigation system.

- Continued cost of maintenance and replacement of vegetation if lost to environmental conditions.

Method
This study took place between 23 June 2018 and 26 July 2018 in urban Honolulu at zip code 96815 on top of an un-shaded 11-story building. During this time continual, synchronous temperature measurements were taken on the existing white roof, and on an installed, sedum plant covered, 8 ft x 8 ft green roof. Temperature measurements were recorded at the roof surfaces, 2 ft above the surfaces, and 4 ft above the surfaces.

Findings
The surface of the green roof was cooler than the white roof by an average of 4.1°F in the day time. At a height of 2 ft above the surface, the green roof was cooler by an average of 3.4°F in the day time. At 4 ft above the surface there was no difference in temperature between the two roofs. Comparing the two roofs over a 24 hr time period showed a difference of approximately 2°F at surface, and 2 ft above surface heights. There was no discernible temperature difference a night, and it was found the green roof takes between 1 and 3 hours longer to reach peak daytime temperatures.

Conclusion
The implementation of green roofs would be an effective measure to alleviate the urban heat island effect. Sedum species are capable of surviving on the hot and windy roof surface, and create a cooling effect greater than what has been produced by painting a roof white.

Introduction

Purpose of Study

As summer temperatures continue to soar year after year the need to reduce the urban heat island effect has become pressing. Urban heat island (UHI) effect is an accumulation of heat from daily activities and structural features of the city. Cities are many degrees warmer than surrounding areas and they take much longer to cool at night (Fig.1). UHI effect causes many problems, such as increased energy consumption, reduced air quality, and negative effects on human health and mortality [1]. To mitigate this, cities have begun using light-colored paint on rooftops to reflect the sun rays back into the atmosphere, avoiding their absorption. Planting more trees has proven another effective action for reducing UHI effects. By providing shade, city surfaces do not absorb sun rays. Additionally, trees provide a cooling effect during the process of evapotranspiration. However, when in a dense city that will allow for no more green space on the ground, a green roof can be the solution to the question of how to cool our warming city. This pilot study was enacted in order to decide whether or not a green roof is an effective option for Honolulu, Hawai'i.

Background

A green roof provides a multi-beneficial, sustainable option for reducing the impact of UHI. Green roofing is the practice of planting vegetation on a roof. A green roof assists in cooling the surrounding air by insulation, evapotranspiration, and radiation reflection. A green roof serves as a building insulator during summer by reducing the transfer of heat from the roof to the topmost rooms, thereby lowering the need for air conditioning. Plants cool the surrounding environments by a process called evapotranspiration, whereby water is absorbed through the roots and emitted through the leaves. Evaporation occurs on the surface of leaves where released water turns into vapor. The transformation of water into vapor is endothermic, thus has a cooling effect on the surrounding air. Another way a green roof cools is by affecting albedo. Albedo is the measure of how much solar radiation a material surface reflects back into the atmosphere. This study did not assess changes in albedo but we may expect that the albedo of a green roof will generally be lower than a white roof, a value of 0.25 - 0.3 and 0.8 respectively. However, through evaporative cooling a green roof can exhibit the same cooling effect as a white roof [2] [3].

It is beyond the scope of this report, but it is important to note green roofs also improve air and storm water runoff quality. Plants absorb the airborne pollutants carbon dioxide (CO_2), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), and capture particulate matter [4]. Storm water quantity and quality are improved by the installation of a green roof by first storing water during a rain event, reducing the volume and stress on water management systems. Then the quality is improved by the neutralization of acid rain and absorption of micronutrients and heavy metals [5]. Water quality may still suffer if soil nutrients are in excess. Field trials can be performed to assess nutrient leaching from newly installed green roof systems to mitigate this [6].

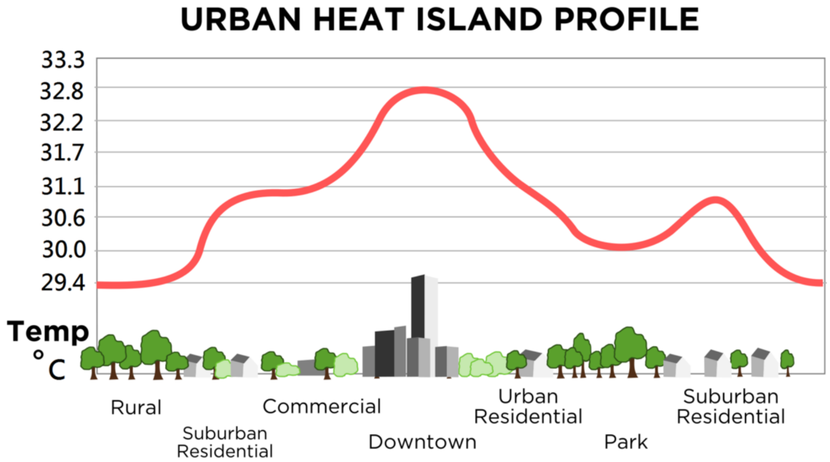

Figure 1. Sketch of an urban heat-island temperature profile (Solecki et al., 2004).

Types of Roofs

Intensive: The intensive green roof is capable of housing a variety of plants and shrubs. The design can be simple or elaborate to encourage human interaction and viewing. However, the intensive green roof diverges from the typical backyard garden in its defined layered build. Ideally, these green roofs are built upon a relatively low slope roof surfaces (1-3%). Typical soil or substrate depths start at 6 - 8 inches and may be up 24 inches. This variability in growth media and soil depths allow for a larger selection of plants, to include flowering shrubs and trees. The limiting factors here are the roof load bearing capability and construction budget. Intensive green roofs weigh substantially more due to the deeper level of substrate and vegetation. They allow for more plant choices, consequently requiring more maintenance. Intensive green roofs may cost anywhere from $20 per sq. ft. to $200 per sq. ft. [7].

Extensive: Extensive green roofs are lightweight and composed of thin layers. Drought tolerant vegetation such as sedums, grasses, mosses, and flowers requiring little or no irrigation (depending on the regional climate), are encouraged or required. Shallow rooting plants require less maintenance than those of an intensive roof. The extensive roof is generally not intended for use as a recreation area, or to accommodate the weight of larger shrubs or trees. These green roofs can be built on a roof slope of up to 33%. Soil depth varies between 3 - 6 inches and weighs approximately 8 to 17 lbs. /sq. ft. The extensive roof may cost anywhere between $10 per sq. ft. to $13 per sq. ft. [7]. One of the greatest advantages is that they can be designed to fit around existing structures. Continued maintenance and care is required until the plants are well established.

Figure 2. Intensive Green Roof (retrieved from www.ateliergroenblauw.nl/)

Figure 3 Extensive Green Roof. (retrieved from www.myrooff.com)

Construction

Both the intensive and extensive roofs are built with layers (Fig 4). Beginning at the roof surface, a waterproof membrane is laid down to prevent water damage. A drainage layer above the waterproof membrane does preclude accumulation of standing water. A root resistant fabric above the drainage layer prevents roots from damaging the waterproof membrane and the roof. A filtration layer limits the passage of fine debris and soil. Lastly, soil or an engineered substrate is laid on top. Depending on the atmospheric conditions, an additional layer to prevent soil erosion or manage water retention may be added.

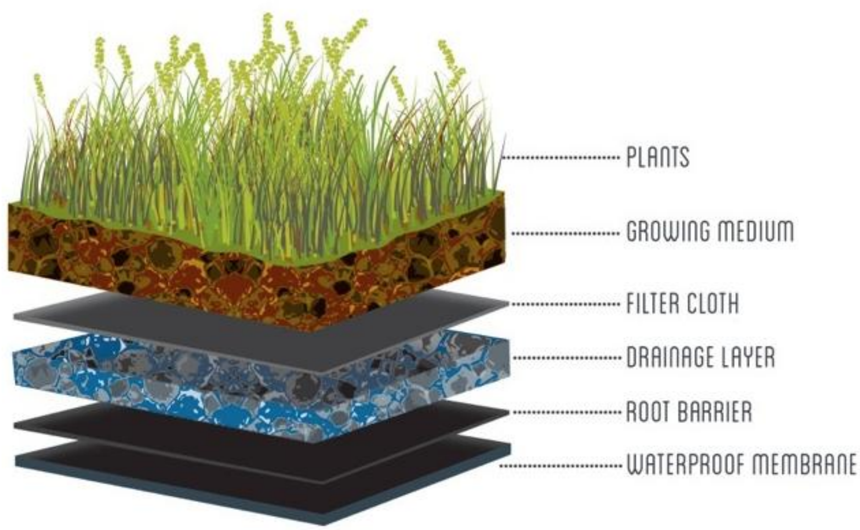

Figure 4. Components of a Green Roof (retrieved from www.restorationgardens.ca).

Vegetation

Selected vegetation to populate an extensive green roof must be both drought tolerant and sun tolerant. *Sedum* genus is an ideal candidate for a green roof because of its shallow rooting system and tolerance for harsh conditions [8]. However, *Sedums* from nurseries may not adapt to the temperature and water changes a rooftop environment brings, therefore it has been recommended that biomass from prairie lands be considered [9].

Proof of Concept Study, Honolulu

Method

The project green roof was built on top of a commercial building in downtown Waikiki. Located at 1969 Ala Moana Blvd., the Equus Hotel provided an ideal location (Fig. 5). The roof has a minimal slope that disallows for standing water, and is in full sunlight for a minimum of 10 hrs per day. Two planters measuring 8 ft x 4 ft were built side by side encompassing a total area of 64 ft^2. Planters were built following the general outline of a green roof (Fig 4).

Each box has a set of evenly spaced wooden support beams to keep the substrate 1 inch off of the roof removing the need for a waterproof membrane or root barrier. A plastic lattice panel was placed on top of the support beams to provide even support for soil across the boxes. A double-layered screen, to prevent soil loss from underneath, as placed on top of the lattice and 3" of soil was set on the screen (Fig 6). To retain soil moisture and to keep the soil from eroding due to high winds, a layer of cinder rocks was placed on top of the soil after the plants had been sown (Fig 7).

This extensive green roof was filled with shallow-rooting sedums. Sedums are preferred to grasses due to their comparatively low water requirement. Requiring full sunlight, these succulents are well suited for most climates. Plant species *sedum makinoi* (Ogon), *sedum lineare* (Sea urchin), and *sedum spurium* (Red Carpet) were spaced evenly apart at 6-inch intervals. All plants were provided by the Hawaiian Sunshine Nursery in Waimanalo. The sedums measured approximately 3 inches across during planting. At this size they may now begin adapting to new soils outside of their containers. The plants were hand watered in the morning daily until established (3 weeks) after that they were watered every other or third day as required.

Sensors to measure temperature and humidity (Elitech GS-6) were set up on the center of the green roof and on the unaltered white roof of the hotel. The accuracy of the sensors was ±.1°C. Sensors were placed on the surface, 2 ft above the surface, and 4 ft above the surface. Measurements were taken every 30 min, 24 hours a day for 36 consecutive days. Data was collected twice during the project and analyzed using software R and Excel.

Figure 5. Location of the green roof. 1696 Ala Moana Blvd. Waikiki, Hawaii (Google Maps, 2018). The red box shows the location of planters.

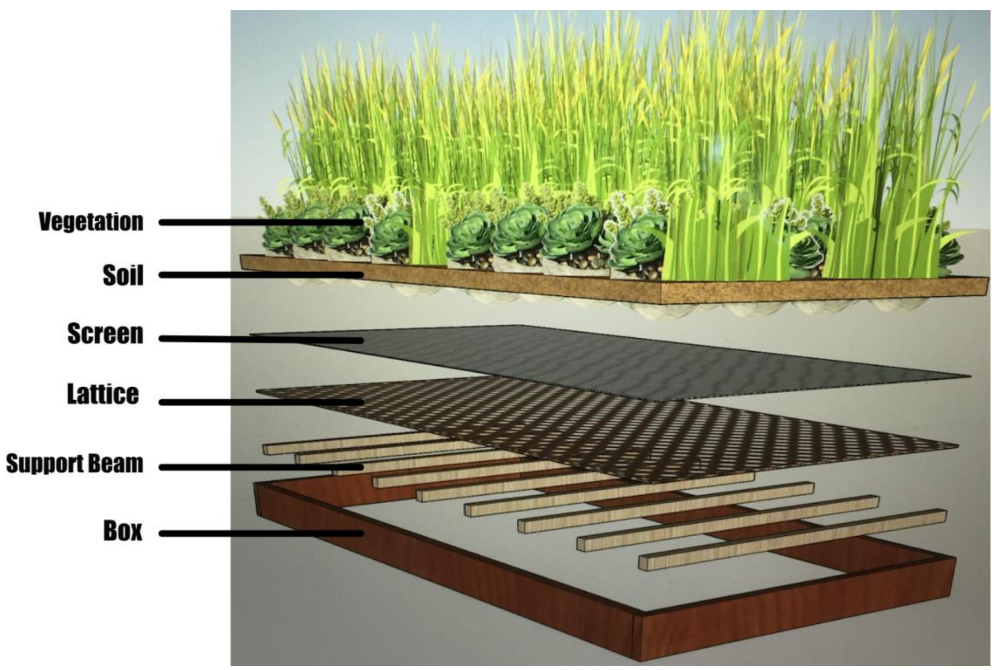

Figure 6. Honolulu Extensive Type Green Roof Design.

Figure 7. Plants in planter boxes.

Results

Comparing the green and white roofs, the green roof was cooler on the surface and at a height of 2 ft above the surface. At a height of 4 ft above of the surface the green and white roof displayed similar temperatures. The surface temperatures of the white roof averaged 82°F (27.7°C) over a 24 hour period. Between the daylight hours of 07:00 a.m. and 07:00 p.m. the average temperature was 86.7°F (30.4°C). This is higher than the surface of the green roof, which measured an average of 80.1°F (26.7°C) throughout a 24 hr period, and an average of 82.6°F (28.1°C) between the daylight hours of 07:00 a.m. and 07:00 p.m. (Table 1). During the night time there was no discernible difference between the white and green roof temperatures.

Watering the plants took place every morning for approximately two weeks. After plants were established in the soil, watering was done every other or third day as required. There was no noticeable change in the temperature at any height between the days when the plants were watered and when they were not. This does not indicate that watering had no effect on the temperatures, but rather any effect is not differentiable from the cooling of shade provided by the plants or transpiration.

The average daily fluctuations on the surface of the white roof were 24.9°F. On the green roof the daily fluctuation was only 14.1°F. Peak temperatures on the white roof appear between 12:30 and 13:00, while on the green roof peaks are reached between 14:00 and 15:00 (Fig 5). This 1 to 3 hour delayed response to the sun's heat shows that the green roof has thermal inertia.

Table 1. Average temperatures in °Fahrenheit from 26 June 2018 - 26 July 2018

	White Roof Surface	Green Roof Surface	Difference
Peak Temperature	113	94.5	18.5
Average Daytime	86.7	82.6	4.1
Average 24hrs	82	80	2
	White Roof 2ft Above	Green Roof 2ft Above	Difference
Peak Temperature	107.6	90.9	16.7
Average Daytime	85.6	82.2	3.4
Average 24hrs	82.4	79.9	2.5
	White Roof 4 ft Above	Green Roof 4 ft Above	Difference
Peak Temperature	95.5	91.9	3.6
Average Daytime	82.8	82.9	0.1
Average 24hrs	79.9	80.4	0.5

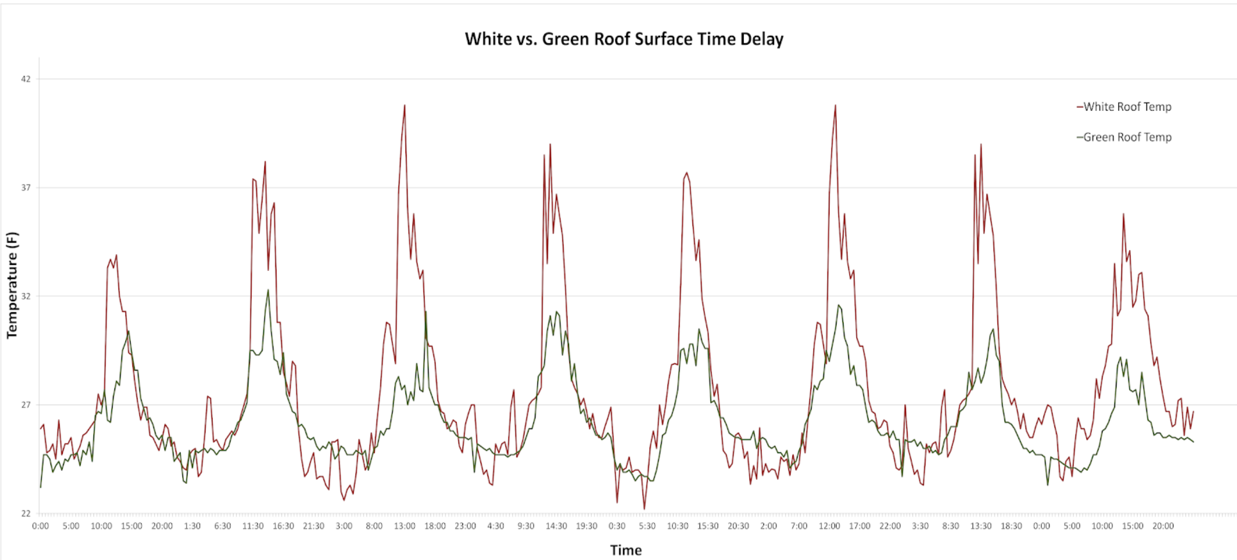

Figure 8. Peak Temperatures of White and Green Roof Surfaces.

Discussion

The largest differences in temperatures were measured at the surface of the white and green roof during daylight hours. The 4.1°F difference could be attributed to evaporative cooling from the vegetation, and a change in albedo. At night the differences were less than 1°F. Considering that sedums function as C3 plants when water is in adequate supply, allowing for ample transpiration during the day, but function as CAM (Crassulacean acid metabolism) plants when water is scarce and at night, a small, but still noticeable temperature difference was expected during the night, and was supported by the data collected. This difference at the surface was .5°F and it was 1°F at 2 ft above the surface.

Air temperature differences are pronounced at distances up to 2 ft above the roof surface. At 4 ft, air may already be well mixed with little to no temperature variability. Both white and green roof areas measured were away from building protrusions or equipment to minimize the effect of any radiative heating. The delayed acclimatization (Fig. 8) a of the green roof surface temperatures by 1 to 3 hours is indicative of the green roof soil being a good insulator, which is paramount in lowering a buildings energy demand.

Sedum species were used on this roof because they are resistant to drought. During the observation period all of the *sedum spurium* (red carpet) wilted and were replaced with ogon and sea urchin types. This may be because, coming from a nursery and early in their life, they were not well suited to a dry and windy rooftop environment. Additionally, watering at night instead of morning could have allowed for an additional uptake of water. Sedums were planted as soon as the nursery said they would take to foreign soil, all sedums were 3.5” in diameter. By the end of the month the ogon species grew to approximately 6” in diameter covering more surface area. The full possible effects of a change in albedo were not observed as sedums species often grow to 1’ in diameter. A larger plant would also have a higher rate of evapotranspiration creating evaporative cooling.

Conclusion

Strategies to lessen urban heat island effect, white roofs and tree planting, have seen success in cities and the addition of green roofs in Honolulu would have an additional verifiable positive effect. Roofs represent a high portion of exposed urban area that is unused, or only used for solar cell installation. The installation of a green roof would bring about a substantial lowering of daytime surface and ambient temperatures of at least 4.1°F at our study site. Less heat taken in by surfaces means less heat released in the evening hours. Following is a reduction in energy consumption, betterment of air quality, sleep quality, human mortality and increased labor productivity. Honolulu is in an excellent place to maximize the benefits that a green roof brings because of all-season sunlight. However, more research into green roofs using higher amounts of biomass, and a different or deeper substrate is needed. Higher evapotranspiration rates combined with increased soil moisture would permit maximizing the effectiveness of a green roof.

Acknowledgements
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Appendix A: Monthly Data

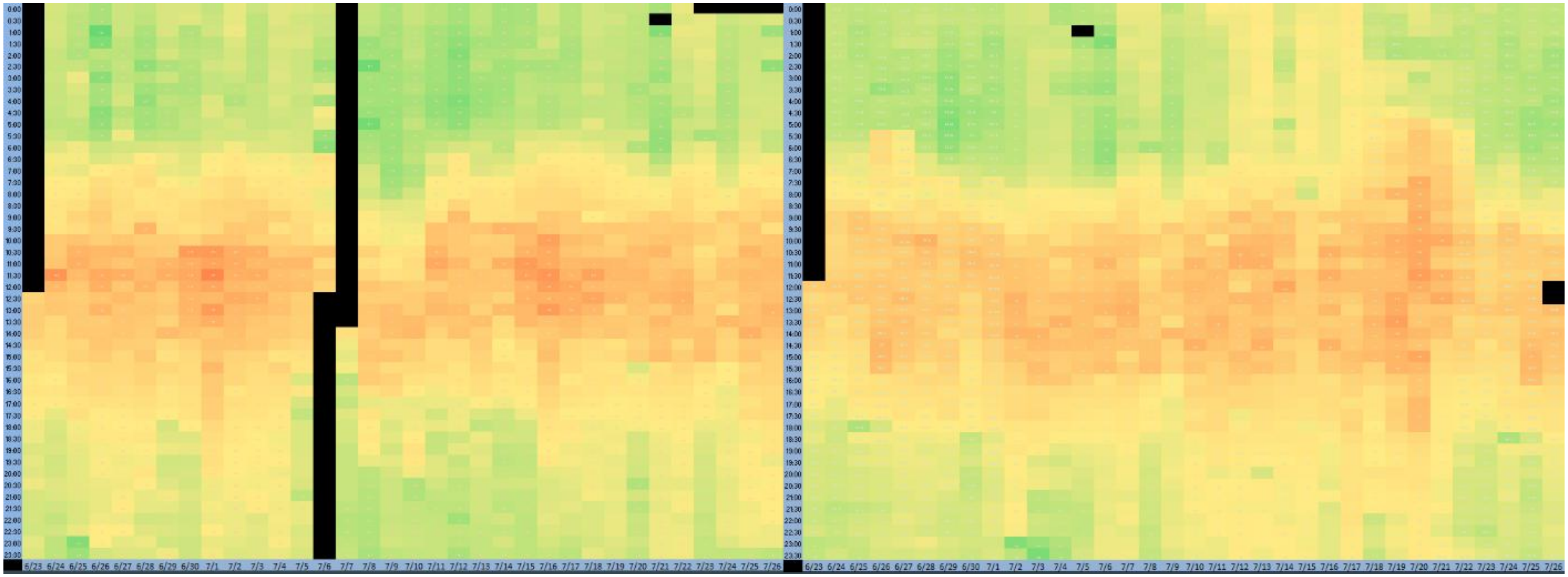

Figure 1. Temperatures of White Roof (left) & Green Roof (right) at 4 ft above surface. 6/23/2018 to 7/26/2018.

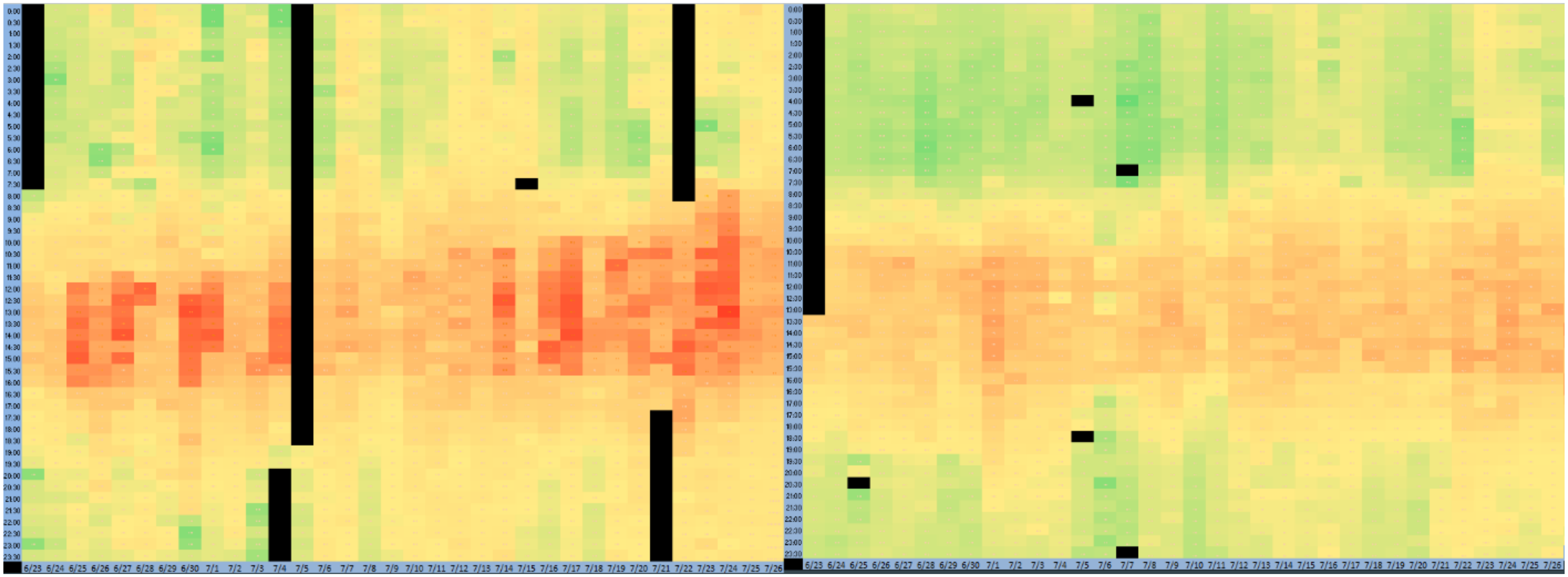

Figure 2. Temperatures of White Roof (left) & Green Roof (right) at 2 ft above surface. 6/23/2018 to 7/26/2018.

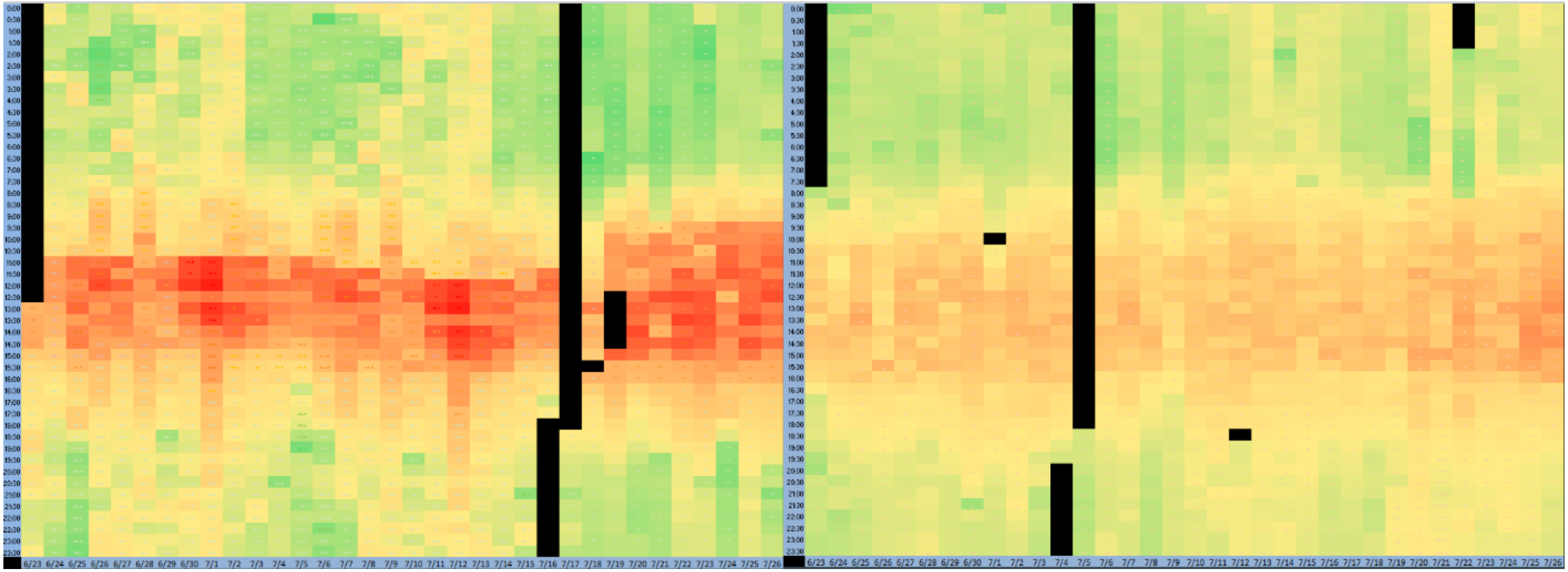

Figure 3. Temperatures of White Roof (left) & Green Roof (right) at surface. 6/23/2018 to 7/26/2018.