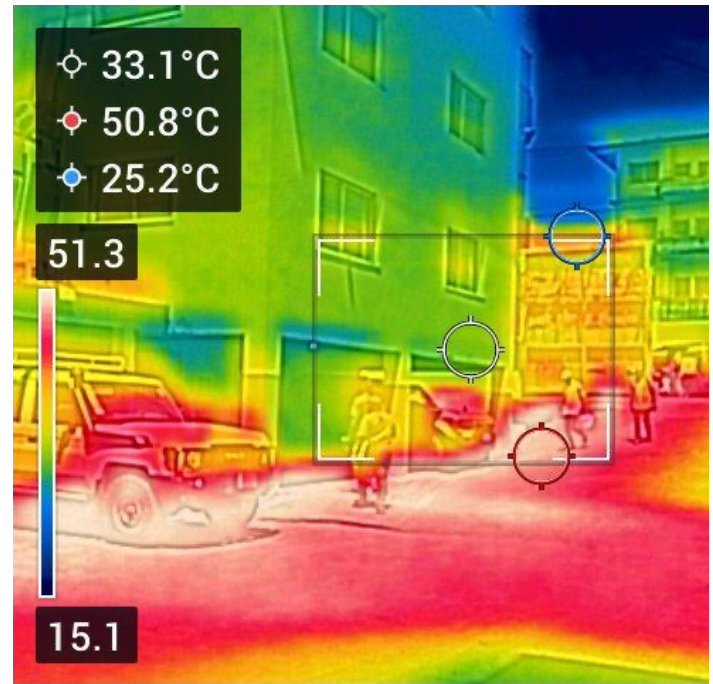




MRV for Climate Action

Bilateral Support for Climate Action -
Implementation and Climate Governance

Assessing Urban Heat Island in Liberia



By: National University Climate Action Laboratory

October 2025



This project was undertaken with the financial support of:
Ce projet a été réalisé avec l'appui financier de :



Environment and
Climate Change Canada

Environnement et
Changement climatique Canada

MAIN AUTHORS

Emmanuel T. Olatunji, Ph.D., Principal Investigator, UHI Pilot

T. Calvin Kollie Pilot, Lead / EPA-NCCSC

Richard Giah Jr, NUCAL Coordinator / University of Liberia

N Lewis Aldo, Coordinator, Environmental Studies and Climate Change, University of Liberia

James S. Eisah, Instructor, Environmental Science Department, University of Liberia

RIGHTS AND PERMISSIONS

The material in this report is subject to copyright. It may be reproduced in whole or part for non-commercial purposes if full attribution to the authors is given. Any queries regarding rights and licenses, should be addressed to the National University Climate Action Laboratory, University of Liberia, capitol Hill Campus.

CITATION

Olatunji, E.T, Kollie, T.C., Giah, R., Aldo, N.L., Eisah, J.S., (2025). Assessing Urban Heat Island in Liberia, National University Climate Action Laboratory, University of Liberia.

Table of Contents

1.0. Introduction.....	4
2.0. Literature Review.....	7
2.1. Policy Review and Gap Analysis.....	9
3.0. Methodology	13
3.1. Desk Study: Literature and Policy Review	13
3.2. Remote Sensing Analysis (Land Surface Temperature and ND Indices via GEE)	13
3.3. In-situ Air Temperature Monitoring (iButtons Deployment)	14
3.4. Key Informant Interviews (KII).....	16
4.0. Results and Discussion	16
4.1. Results and Discussion	16
4.1.1. Rainy Season Temperature Profiles (July 28 – August 28).....	16
4.1.2. Comparison to Dry-Season Land Surface Temperatures.....	19
4.1.3. Building Energy Use and Seasonal Differences (Case study of the EPA & NUCAL)	22
3.2. Policy Implications	25
4.0. Recommendations.....	27
5.0. Implementation Plan: 30-Day Intervention at EPA (Shading & Green Roof)	29
6.0. Conclusion	31

Acronym

AC	Air Conditioning
ARREST	Agriculture, Roads, Rule of Law, Education, Sanitation, and Tourism
BTU	British Thermal Unit
BUR	Biennial Update Report
CDR	Carbon Dioxide Removal
EPA	Environmental Protection Agency
GEE	Google Earth Engine
GS	Graduate School (site)
HVAC	Heating, Ventilation, and Air Conditioning
ICA	International Consultation and Analysis
iButton	Thermochron iButton (temperature logger)
LEC	Liberia Electricity Corporation
LST	Land Surface Temperature
MCC	Monrovia City Corporation
MME	Ministry of Mines and Energy
MPW	Ministry of Public Works
MRV	Measurement, Reporting and Verification
NAP	National Adaptation Plan
NDBI	Normalized Difference Built-up Index
NDVI	Normalized Difference Vegetation Index
NDC	Nationally Determined Contribution
NUP	National Urban Policy
PCC	Paynesville City Corporation
SOP	Standard Operating Procedure
UHI	Urban Heat Island

1.0. Introduction

Urbanization and climate change pose significant challenges to cities worldwide, increasing problems related to heat stress (Tamball et al 2024). Urban heat islands occur when city landscapes

of asphalt, concrete, and buildings absorb and re-emit more heat than vegetated or rural areas, causing urban temperatures to rise above those of surrounding regions. Monrovia, the capital of Liberia, has a tropical climate and is one of the wettest capital cities, with high humidity and consistently warm temperatures year-round. Over the past decades, Greater Monrovia has undergone rapid urban expansion, driven by population growth and rural-to-urban migration, resulting in extensive land-use/land-cover changes (Brian 2024). This development has led to the replacement of natural landscapes (such as forests, wetlands, and open green spaces) with impervious surfaces and dense built-up areas. As a result, the UHI effect is emerging in Monrovia: urban neighborhoods experience noticeably higher temperatures than greener or less built-up areas, especially during the day.

Recent analyses underscore this local trend. A geospatial study of Greater Monrovia found that built-up land cover increased dramatically from about 14.6% in 1991 to 36.1% by 2020, while vegetated areas shrank significantly (Brian 2024). Correspondingly, land surface temperatures in heavily built parts of the city have risen. The same study noted that mean LST in dense urban neighborhoods reached around 42°C, compared to roughly 33–37°C in vegetated areas and about 30°C over water bodies (Brian 2024). In other words, surfaces in built-up Monrovia can be nearly 9°C hotter than those in nearby green or water-covered zones during peak heating periods. Such data, though limited, confirms that an urban heat island effect is taking hold in Monrovia, likely exacerbated by the decline of urban green cover and the increase in concrete and asphalt surfaces. This is consistent with global observations that impervious urban surfaces absorb and retain solar energy, creating localized heating (Brian 2024).

The impacts of rising urban heat in Monrovia are a growing concern. Higher ambient temperatures contribute to heat stress for residents, potentially leading to adverse health effects (heat exhaustion, heat stroke, exacerbated medical conditions) and reduced outdoor comfort (Tamball et al 2024). They can also increase energy demand for cooling, straining electricity supply and raising costs for a city where access to power and air conditioning is limited for many. In general, heat islands have been linked to increased air pollution (as stagnant hot air can worsen smog) and even impacts on water quality due to heated runoff. Vulnerable groups, such as the elderly, young children, and low-income households in densely populated informal settlements are at particular risk from extreme heat and lack of cooling options. Monrovia's coastal location means high humidity, which

can make the heat index (or “felt” heat) very severe even if air temperatures are moderately high (Climate risk profile report, 2024). Climate change is expected to intensify these challenges: projections for Liberia indicate that by mid-century both minimum and maximum temperatures will increase, with more frequent hot days and warm nights (Climate risk profile report, 2024). In a hot, humid city like Monrovia, such changes could amplify the UHI effect and its consequences over time (Brian 2024).

Despite these risks, urban heat resilience is a relatively new subject in Liberia. There is a knowledge gap regarding the extent and drivers of UHI in Monrovia to date, no comprehensive on-the-ground assessment integrating meteorological measurements, remote sensing, and community experiences has been conducted. At the same time, addressing heat risk aligns with Liberia’s broader climate resilience and public health priorities. The National Adaptation Plan (NAP 2020–2030) and other climate strategy documents acknowledge extreme heat as a concern, but they lack city-specific heat action measures. For Monrovia to plan effectively – whether by increasing green spaces, improving building designs, or developing heat warning systems, a solid evidence base on urban heat patterns is needed. This study is therefore highly relevant: it will fill data and information gaps by quantifying the UHI effect in Greater Monrovia and gathering insight into how residents and institutions perceive and cope with urban heat. The findings will inform policies and practical interventions to make the city more livable and resilient in the face of rising temperatures. Moreover, as part of the MRV for Climate Action Community of Practice, this pilot effort in Liberia can serve as a model for other cities and contribute to regional knowledge-sharing on urban climate resilience.

- Organize and execute field visits to collect: Air temperature and LST data.
- Process and analyze field data to identify local UHI effects, patterns, and drivers.
- Develop maps and visualizations to communicate the results effectively.
- Prepare a report summarizing UHI effects, field data, and stakeholder feedback.
- Assess the impact of the UHI on energy consumption in selected locations in Monrovia.

2.0. Literature Review

The urban heat island effect is a well-documented climatic phenomenon wherein urban areas experience higher temperatures than their rural surroundings. The temperature differential arises from several factors associated with urbanization:

- **Impervious Surfaces and Lack of Vegetation:** Cities are built with materials like concrete, asphalt, and roofing that absorb and store solar radiation during the day, then re-radiate heat, especially at night. In contrast, natural surfaces (soil, vegetation, water) tend to absorb less heat or cool off faster via evaporation. The loss of trees and green spaces exacerbates this effect, as vegetation provides shade and cooling through evapotranspiration. Odindi et al. (2015) note that impervious urban surfaces can hold and re-emit significantly more heat than pervious vegetated surfaces, directly contributing to UHI formation (Brian 2024). Conversely, areas with trees, parks, or water bodies act as cooler “oases” within the city.
- **Urban Geometry and Trapped Heat:** The layout and structure of cities impact their thermal environment. Jahanbakhsh (2016), opines that the city's geometry and section, the height and size of the buildings, the direction of the buildings, the streets, and the exterior surface, are all factors of the city's climate change. Poorly oriented streets and buildings and design structures, narrow streets, closely spaced high-rise buildings – can create urban canyons that hinder airflow and trap heat. These configurations reduce convective cooling (natural wind flow) and limit the sky exposure needed for heat to radiate away, thereby causing urban cores to retain more warmth, especially overnight.
- **Anthropogenic Heat Emissions:** Human activities in cities also add heat to the environment. Vehicles, industrial processes, and air conditioning units release waste heat. Dense traffic and generator use in cities like Monrovia can locally elevate temperatures. While this component is smaller than solar heating, it can contribute to nighttime temperature differences between urban and rural areas.
- **Weather and Location Factors:** Calm, clear weather tends to maximize UHI intensity, as strong solar heating in the day and low wind at night allow cities to heat up and retain warmth. On windy or cloudy days the UHI effect is less pronounced. Geographic location also matters: for instance, coastal cities may get daytime sea breezes that provide cooling, but if they are in generally hot-humid climates the baseline temperatures are high and

nights may remain sultry (Brian 2024). In summary, UHI intensity can vary with local climate conditions – some studies find UHI magnitudes up to 5–10°C in large metropolitan areas under certain conditions (Brian 2024), though smaller or less dense cities may have lower intensity.

Compared to Europe, Asia, or North America, there has been relatively little research on UHI in sub-Saharan African cities, largely due to limited weather station networks and data availability (Obe and Morakinyo, 2022). Nevertheless, the region's rapid urbanization rates and high exposure to climate change warrant attention to urban heat issues. For instance, studies in Nigeria (e.g., Kano, a fast-growing city) observed significant intra-urban temperature differences, with informal high-density neighborhoods showing daytime surface UHI intensities of several degrees Celsius above peripheral areas (Ramsay et al, 2023). Research on Lagos has similarly identified UHI effects, and efforts are being made to model how continued urban expansion will alter local temperatures (Obe & Morakinyo, 2022). A recent systematic review of West African UHI studies highlighted that while evidence of UHIs exists in cities like Accra, Abuja, and others, data gaps remain and UHI is often an overlooked issue in urban planning across the region (Obe and Morakinyo, 2022).

In the case of Monrovia, Liberia, direct studies have only begun to emerge very recently. The city's tropical coastal setting (low latitude, near sea level) means it naturally has a warm climate; average maximum temperatures are around 30–32°C year-round, with high humidity. Monrovia's urban form includes a dense historic downtown, expanding suburban districts, and several informal settlements. As noted earlier, a 1991–2020 remote sensing analysis (Brian 2024) documented the sharp increase in built-up area and concurrent reduction in vegetative cover. That study found a clear inverse relationship between vegetation and surface temperature: areas of the city with higher Normalized Difference Vegetation Index (NDVI) had lower LSTs, while areas with higher Normalized Difference Built-up Index (NDBI) (indicating more impervious surfaces) had elevated LSTs (Brian 2024). Specifically, it reported that NDVI was negatively correlated with LST (i.e. greener neighborhoods were cooler), whereas built-up index was positively correlated with LST, underscoring that urban green infrastructure (UGI) provides a cooling effect while impervious built surfaces contribute to heating (Brian 2024). These findings align with global knowledge and reinforce the idea that expanding green spaces could mitigate Monrovia's UHI. Another study by

Tamball et al. (2024) examined urban greening in Monrovia and concluded that the city's tree planting and green initiatives are crucial for heat mitigation, but they remain limited in scope. The authors noted Monrovia's urban greening efforts are few and recommended scaling up such efforts as a sustainable strategy to alleviate heat stress in the city (Brian 2024).

2.1. Policy Review and Gap Analysis

Liberia's policy landscape on climate change and urban development is still evolving, and explicit focus on urban heat or UHI is largely absent currently. Key relevant policies include:

- The National Climate Change Response Strategy (2018) and the National Adaptation Plan (NAP 2020–2030) – these outline Liberia's climate risks and adaptation priorities. They primarily emphasize threats such as coastal erosion, flooding, agriculture impacts, and public health, but do not specifically mention urban heat islands. Heat waves and heat stress are acknowledged in broad terms as emerging climate concerns (Climate risk profile report, 2024). However, there are no concrete adaptation measures targeting heat in urban areas. The focus of climate action has been on sectors like agriculture, forestry, coastal zone management, and early warning systems for extreme weather. This represents a gap: urban heat risk has not yet been mainstreamed into national climate adaptation planning.
- The Monrovia Metropolitan Climate Resilience Project (2021–2027), funded by the Green Climate Fund, is currently being implemented to protect coastal communities in Monrovia from sea-level rise and storms. While this project improves general resilience (e.g., through mangrove restoration and flood defenses), it concentrates on coastal flooding and erosion issues. Urban heat or UHI mitigation is not within its scope. This again indicates that climate resilience efforts to date have prioritized water-related hazards over heat.
- Urban Development and Environmental Policies: Liberia until recently lacked a formal urban policy. In 2021–2022, the government launched the formulation of a National Urban Policy (NUP) with support from UN-Habitat. The NUP, still in draft as of 2025, aims to promote sustainable and resilient urban growth. Its stated goals include improving the livability of cities through poverty reduction, better environmental conditions, and climate resilience. This suggests that issues like urban greening and infrastructure improvements could be part of the policy. However, since the NUP is in development, it remains to be

seen whether it will directly address urban heat. So far, UHI has not been explicitly highlighted in public discussions of the NUP. Ministry of Internal Affairs (MIA), which oversees urban affairs, and city governments (MCC, PCC) have recognized problems of poor waste management, drainage, etc., but heat has not been a top-line issue. The NUP does present an opportunity to incorporate climate considerations such as UHI mitigation (e.g., by encouraging urban planning that includes green belts, ventilation corridors, reflective building materials, etc.). If evidence from this study is available in time, it can feed into the NUP process to ensure that urban heat is considered as part of improving “environmental conditions and climate resilience” in Liberian cities.

- **Planning and zoning:** Liberia faces a huge challenge in planning and managing urban areas. While current efforts at developing policies and laws such as the NUP and a new zoning law, are laudable, the country’s urban planning system is plagued with not only obsolete frameworks, but fragmentation of urban management functions across government institutions. The current Zoning law of 1958 provide standards regarding placement of buildings and other amenities from the general perspective of achieving functional efficiency, harmony, environmental sustainability and aesthetics. However, it did not provide clear guidance on climate change and issues of thermal dynamics such as urban heat, since at the time of promulgation, climate change was not at the core of environmental discussions. Even though, the current legal reliance for development control is the 1958 Zoning Ordinance, implementation has also been a major challenge,
- **Municipal Initiatives:** The Monrovia City Corporation (MCC) and Paynesville City Corporation (PCC) have undertaken some limited initiatives that indirectly relate to heat mitigation. For example, city authorities have occasionally organized tree-planting campaigns along streets and in communities (often in partnership with civil society) to beautify the city and restore greenery. These efforts are usually framed around beautification or sanitation rather than explicitly as climate adaptation but increasing urban tree cover can help reduce local temperatures. Additionally, development partners have introduced the concept of “blue-green infrastructure” in Monrovia’s urban planning; for instance, a project on rain gardens and urban wetlands aimed at flood control also has co-benefits for cooling and greening the city (Tamball et al 2024). Despite these, there is no comprehensive urban forestry or heat action plan for Monrovia. The city lacks regulations

or incentives for cool roofs (highly reflective roofing) or cool pavements, which are measures adopted in some other countries to combat UHI.

Institutional Roles and Awareness: Several government bodies have mandates that could encompass aspects of UHI:

- The Environmental Protection Agency (EPA) is Liberia's lead agency on climate change and environmental management. EPA's focus has been on broad environmental policy, pollution control, and coordinating climate change strategies. While EPA raises awareness on climate impacts (including extreme heat) broadly, it has not yet rolled out any program specifically on urban heat islands. This study's findings will be shared with EPA, potentially highlighting UHI as an area for environmental monitoring.
- The Ministry of Health and National Disaster Management Agency (NDMA) deal with public health and disaster risks, respectively. Heat waves or extreme heat events could fall under their purview as health hazards, but until now heat has not been recognized as a formal "disaster" in Liberia (unlike floods or epidemics). Part of the gap is due to the lack of historical data on heat-related illness or mortality in the country – data which this study can help start to establish via community surveys (e.g., reports of heat illness symptoms).
- The Ministry of Public Works (MPW) and city corporations influence building standards and urban infrastructure. Currently, building codes in Liberia are outdated and enforcement is limited; they do not include climate-responsive design norms like insulation or passive cooling requirements. There is room in future revisions to integrate standards for ventilation, green space allocation in developments, etc. The Ministry of Mines and Energy (MME), which oversees energy policy, might be concerned with how increased heat drives energy demand and how to ensure electricity for cooling – but again, this linkage is not yet a policy focus.

Gap Analysis: From the above, policy gaps exist in addressing UHI/urban heat:

- Neither national climate policies nor urban development plans explicitly recognize the urban heat island effect or extreme heat in cities as an issue requiring targeted action. This is a critical gap in awareness at the policy level.

- There is no systematic monitoring of urban temperatures in Monrovia beyond the airport meteorological station (Roberts International Airport, which is outside the city) (Tamball et al 2024). Urban micro-climate data (e.g., temperature readings within city neighborhoods) are absent, making it hard for policymakers to appreciate the extent of heat buildup. This study will provide initial data points to begin filling that gap.
- The challenge of UHI spans multiple sectors (urban planning, environment, health, energy). Currently, there is no coordinated mechanism or task force in Liberia focusing on urban climate resilience that could bring these sectors together. The ongoing National Urban Policy formulation could serve as a platform to integrate such cross-sectoral issues.
- Policies on land use in Greater Monrovia have not prevented the loss of green cover. Wetlands and open spaces in the city are often encroached by informal settlements (Brian 2022), as seen in the Mesurado wetland case. This not only raises flood risk but also eliminates natural cooling zones, worsening UHI. A gap in enforcement of land-use zoning and in proactive urban greening policies is evident. The study's outcomes can highlight areas where protecting or creating green spaces would yield climate (cooling) benefits for the city.
- Liberia's disaster risk reduction strategies have traditionally not included heat waves or urban heat events in their scenarios. Given global trends, it may be prudent to start considering extreme heat as part of the country's disaster/emergency preparedness. This is currently a gap – and one that could be addressed once there is local evidence of heat impact, which this project aims to provide.

While Liberia has begun to embrace the concepts of climate resilience and sustainable urban development, the specific issue of urban heat islands remains underserved in policy and practice. This inception report identifies that gap and sets the stage to address it by generating localized evidence. Bridging this gap could lead to integrating heat mitigation measures (like urban greening or reflective infrastructure) into city plans and climate adaptation strategies, thus improving the overall livability of Monrovia in the face of climate change.

3.0. Methodology

This study employs a mixed-methods approach, combining quantitative measurements (remote sensing and in-situ temperature data) with qualitative research (interviews and surveys). All data will be primarily collected or generated for this assessment, using tools like Google Earth Engine for spatial analysis and field instruments (iButtons) and questionnaires for ground data. The methodology is structured into several components:

3.1. Description of Study Site:

The assessment was conducted in great Monrovia, Montserrado County, Liberia. Geographically, Greater Monrovia lies at the lower part of the county boarder at the south by the Atlantic Ocean and occupies approximately 196 km². The study area experiences tropical monsoon climate with wet and dry seasons and have an average annual temperature of 25⁰C (World Bank, 2021). The rainy season is from May to October while the dry season is from November through April.

3.2. Desk Study: Literature and Policy Review

As an initial step, a thorough desk review was conducted. This involves collating and synthesizing relevant academic research, case studies, and reports on urban heat islands globally and in West Africa, with special attention to any findings for Greater Monrovia/Liberia. Simultaneously, the policy context is reviewed by examining national documents (climate strategies, urban plans) and any city-level programs touching on climate resilience or urban environment. The output of this step, presented above, informs the research design by highlighting knowledge gaps and contextualizing the importance of the study.

3.3. Remote Sensing Analysis (Land Surface Temperature and ND Indices via GEE)

Remote sensing is the cornerstone of quantifying the spatial extent of the UHI in Greater Monrovia. We utilize Google Earth Engine (GEE), a cloud-based geospatial analysis platform to obtain and process satellite imagery for Land Surface Temperature and related indices. The method includes:

- **Satellite Data Selection:** Sources are the Landsat 8 and Landsat 9 satellites (2022-2024), which provide thermal infrared bands suitable for LST calculation at 100m (resampled to 30m) resolution. Landsat is chosen for its moderate resolution and free data availability in GEE. We targeted images from recent dry season months (when sky is clearer and UHI effect may be pronounced due to strong solar heating and less rain).
- **Land Surface Temperature (LST) Retrieval:** Using GEE, we applied algorithms to convert satellite thermal band data to LST. For Landsat 8, this involves using the Thermal Infrared Sensor (TIRS) Band 10 radiance values, correcting for atmospheric effects, land surface emissivity, and applying the Planck's law inversion to get temperature in °C. GEE has built-in functions or community scripts that can aid in this conversion. The result yield is a raster map of estimated LST across the Greater Monrovia area for the chosen date(s). We validated these values qualitatively and quantitatively, if possible, by comparing with any available ground station reading.
- **Energy consumption:** We conducted an inventory of energy consumption at appliances used to establish the relationship between UHI and energy consumption.
- **Map Production:** High-resolution maps of Greater Monrovia's land surface temperature distribution were be prepared. A focus was on the central Monrovia pilot locations. We zoomed in on that area to produce a detailed map showing internal variation.

3.4. In-situ Air Temperature Monitoring (iButtons Deployment)

To capture the canopy layer UHI (air temperature near ground level where people live), we will deploy Thermochron iButton temperature loggers in the field from July to August 28, 2025, which primarily fell within the raining season in Liberia. These are small, durable, battery-powered sensors that record temperature at set intervals. Key aspects of this method:

- **Sensor Description:** The iButtons (Maxim DS1921 or DS1922 models) record temperature with an accuracy of about $\pm 0.5^{\circ}\text{C}$ and have a memory to store thousands of readings. They are ideal for distributed urban temperature monitoring due to their low cost and compact size (Elmes et al 2020). Each iButton was be programmed to log air temperature at a regular interval (for every one hour) throughout the day and night.

- Installation SOP: We followed a standard installation Standard Operating Procedure (SOP) to ensure data quality and consistency. According to best practices for microclimate measurement (Corpuz et al 2024; Elmes et al 2020), the SOP includes:
 - Mounting each iButton in a well-ventilated radiation shield to protect it from direct sunlight and rain. This would be a simple white plastic shield (solar shields for iButtons) (Scott et al, 2024).
 - Placing the sensors at a standard height above ground (typically 1.5 to 2 meters, to approximate human height/standard screen level). They were attached to trees and building eaves, within five different locations, including the University of Liberia Graduate School, the UL park, near the national university climate action laboratory, the Monrovia city corporation and the environmental protection agency of Liberia premises, (Table 1) ensuring they are secure and not easily tampered with.
- Data Logging Period: The iButtons will be left in place to log temperatures continuously at an interval of 1 hours over a defined period at least 4 weeks (from July 28 to August 28, 2025), to capture different weather conditions. We aimed to cover a period that is climatologically hot, however the time period fell within the raining season.
- Data Retrieval: After the monitoring period, the iButtons were be collected and data downloaded using the appropriate interface (a USB reader). The raw data (timestamps and temperature readings) was stored for analysis.
- Calibration and Quality Control: The iButtons typically come pre-calibrated, but we performed a quick validation by comparing a few iButtons side by side in a controlled setting before deployment to ensure they are reading consistently (within the expected $\pm 0.5^{\circ}\text{C}$ tolerance). We also ensured their clocks were synchronized.
- Analysis of Air Temperature Data: Once retrieved, the data from all sensors were processed.

This in-situ monitoring was meant to provide ground truth data to complement the satellite LST, however, because of the season difference during the data collection, the dataset complimented each other in a different perspective, which allowed a comparison of the raining season and dry season.

3.5. Key Informant Interviews (KII)

To incorporate institutional and expert perspectives, the team conducted Key Informant Interviews with a range of stakeholders who have roles in urban management, climate policy, or related fields. The targeted key informants include representatives from:

- Environmental Protection Agency (EPA) – climate change division or environmental planning department.
- Ministry of Public Works (MPW) – planning or infrastructure department (to discuss urban planning, building guidelines).
- Monrovia City Corporation (MCC) – possibly the City Mayor’s office or the sanitation/environmental department.
- Ministry of Mines and Energy (MME) – which in Liberia also covers aspects of energy policy and maybe meteorological services.

4.0. Results and Discussion

4.1. Results and Discussion

4.1.1. Rainy Season Temperature Profiles (July 28 – August 28)

Continuous monitoring with iButton sensors revealed distinct microclimate patterns across five sites (UL Park, EPA building, Graduate School (GS) site, MCC Office, and NUCAL) during the heart of the rainy season. Nighttime temperatures were uniformly mild (lows ~22.5–23°C at all sites), but daytime peaks varied widely. UL Park (a vegetated open area) and NUCAL Lab (shaded environment in Jallah Town) stayed relatively cool, never exceeding ~29–30°C. In contrast, the more built-up sites, EPA (Mamba Point), GS, and MCC Office, experienced extreme midday spikes of 33–36°C, suggesting stronger solar heating and less shading. The EPA and MCC sites in particular saw the highest peaks (~36°C), roughly 7°C hotter than the park and lab maxima. These differences are evident in the distribution of observed temperatures: sites like UL Park and

NUCAL had a narrower range and lower median temperature, whereas MCC and EPA showed broader variability with higher upper extremes (see Figure 1).

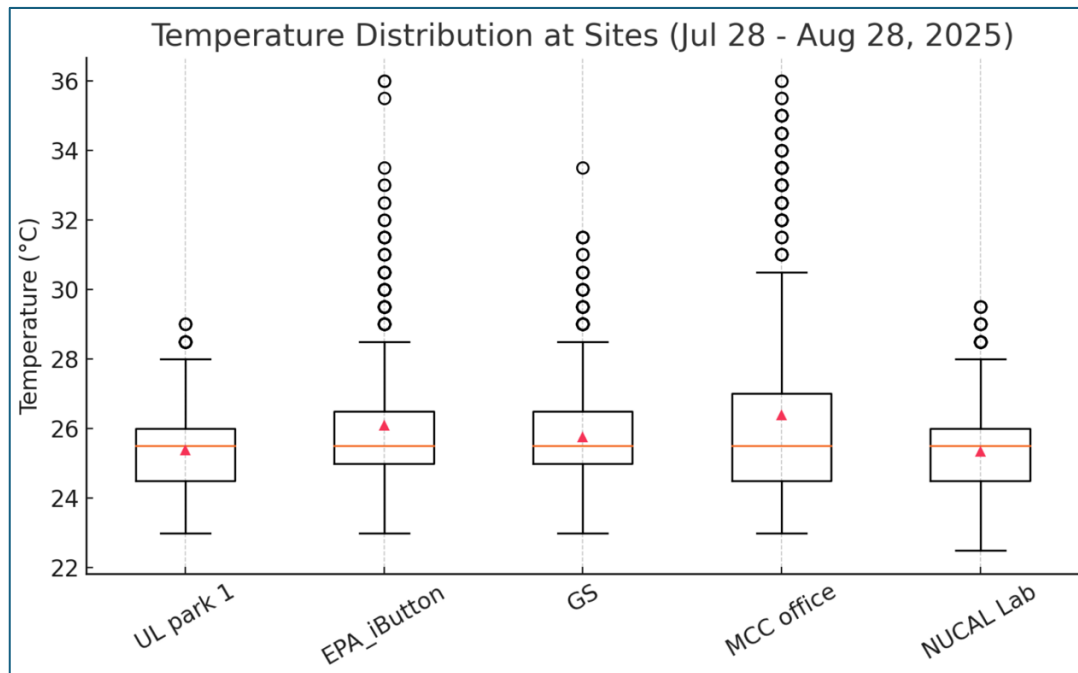


Figure 1: Distribution of air temperature at five sites over July 28–Aug 28, 2025 (rainy season). Boxes show median (orange line) and interquartile range; whiskers and points indicate the span of values. EPA and MCC sites exhibit higher peak temperatures and averages compared to the park and NUCAL lab sites.

The temporal trends reveal a clear daily cycle modulated by site conditions. All locations cooled to ~24–25°C overnight, then began rising by mid-morning. By late morning (10–11 a.m.), temperatures in the urbanized sites pulled ahead. MCC Office heated the fastest, averaging ~30°C at midday, followed by EPA and GS sites (~28–29°C). Meanwhile, UL Park and NUCAL Lab climbed only to ~26–27°C before cooling off. This pattern indicates an urban heat island (UHI) effect even during the wet season: the hottest urban site (MCC) was about 3°C warmer at midday than the coolest (NUCAL or UL Park), despite all sites being within Greater Monrovia. By evening, temperatures converged as rain-cooled air and lack of sun leveled conditions. Figure 2 illustrates the average diurnal profile for each site, highlighting how green or shaded locations (blue and orange lines) stay cooler during the day, while built environments (red/pink lines) accumulate more heat.

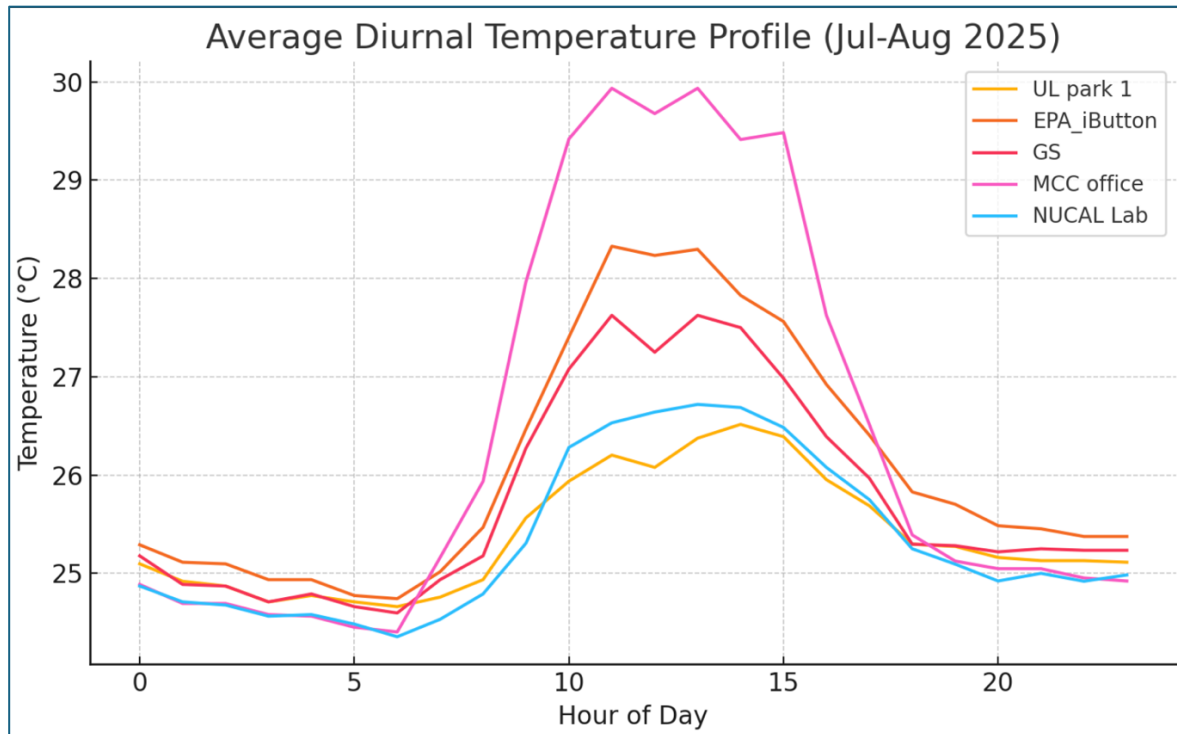


Figure 2: Average daily temperature profile during the rainy-season period for each site. Urban built-up sites (EPA, GS, MCC) show higher daytime temperatures, peaking in early afternoon, whereas the park and shaded lab site remain ~2–3°C cooler at peak. Nighttime temperatures are uniformly cooler (~24–25°C) across all sites.

These findings underscore that even in Monrovia’s rainiest months, micro-scale land cover and shading significantly influence air temperature. Frequent cloud cover and rainfall do moderate overall temperatures with daily highs rarely above ~28°C (82°F) in August (Tamball et al, 2024). The data align with this, as the vegetated and shaded sites stayed near or below 28–29°C on average. Yet, where urban surfaces are exposed, they can still heat well into the 30s °C during breaks in the clouds. Intense solar radiation on building materials and asphalt leads to localized spikes, briefly mimicking dry-season heat conditions. Notably, the UHI intensity (urban–park temperature difference) around 2–3°C here is lower than in the dry season, when reduced cloud/rain allow sustained heating. This suggests that Monrovia’s UHI, while present year-round, is less pronounced in the wet season, a result of frequent rain cooling and overcast skies limiting solar gain.

4.1.2. Comparison to Dry-Season Land Surface Temperatures

The rainy season air temperatures can be contrasted with dry-season land surface temperature (LST) patterns observed via satellite imagery (Figure 3). Greater Monrovia experiences spatially uneven land surface temperatures. In the dry-season analysis the LST map shows values ranging from approximately 23.4°C to 32.1°C. Cooler areas (green hues) correspond to vegetated wetlands, mangroves and coastal zones, while hotter clusters (orange and red) coincide with dense built-up settlements, major roads and open bare ground. These hotspots form a continuous belt along the urban core, indicating the emergence of an urban heat island (UHI) where impervious surfaces trap and re-radiate heat. Areas outside the urban core remain significantly cooler, underscoring the role of vegetation and water bodies in moderating local microclimates. The map provides a baseline for comparing seasonal and site-specific temperature patterns.

As depicted in Figure 3 central Monrovia shows that temperature variability is more pronounced. Areas such as West Point, Mamba Point, Snapper Hill, Randall/Center Streets, Bernard Quarters, BTC Area, Jallah Town and Saye Town display high LST values, shown by red patches. These districts are characterized by dense building footprints, concrete roofs and paved yards with minimal vegetation, leading to strong UHI effects. Adjacent coastal and wetland areas, including Slipway and Rock Spring Valley, appear cooler due to vegetation and proximity to water. This spatial pattern highlights the direct relationship between land cover and temperature, and it pinpoints the locations where cooling interventions could yield substantial benefits.

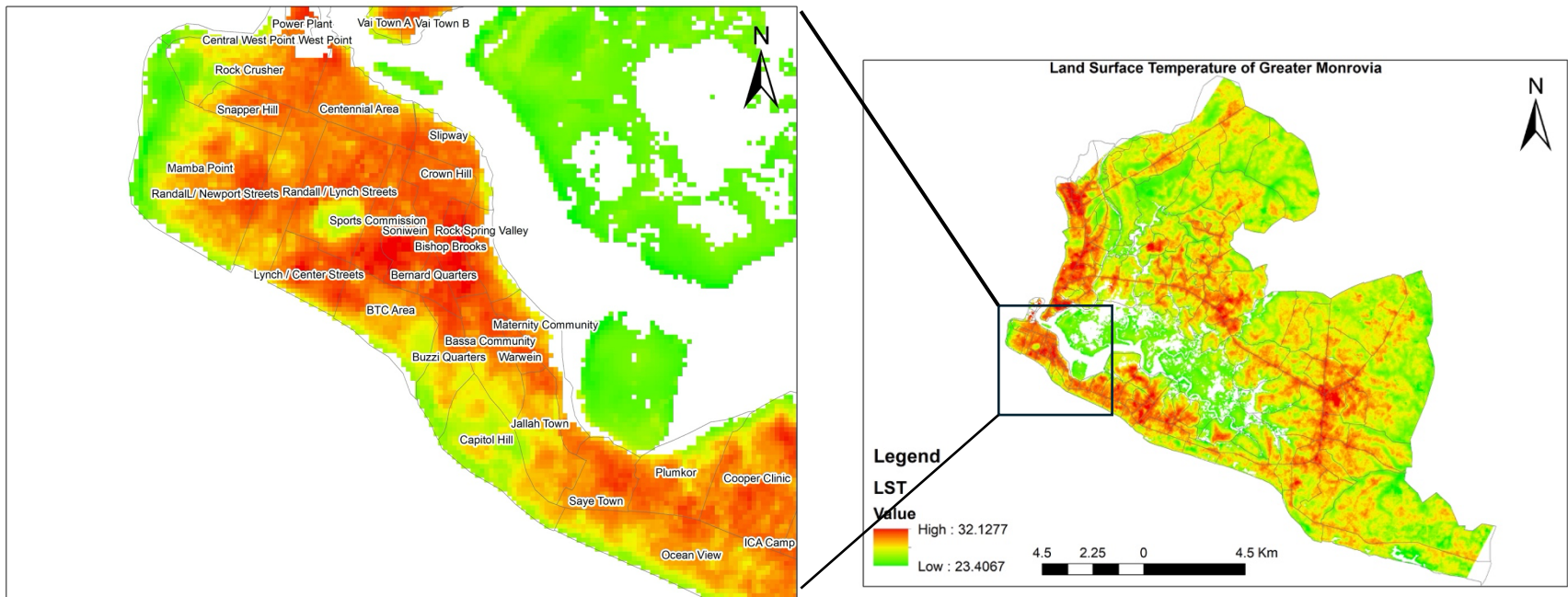


Figure 3: Urban Heat Island Map of greater Monrovia and Monrovia

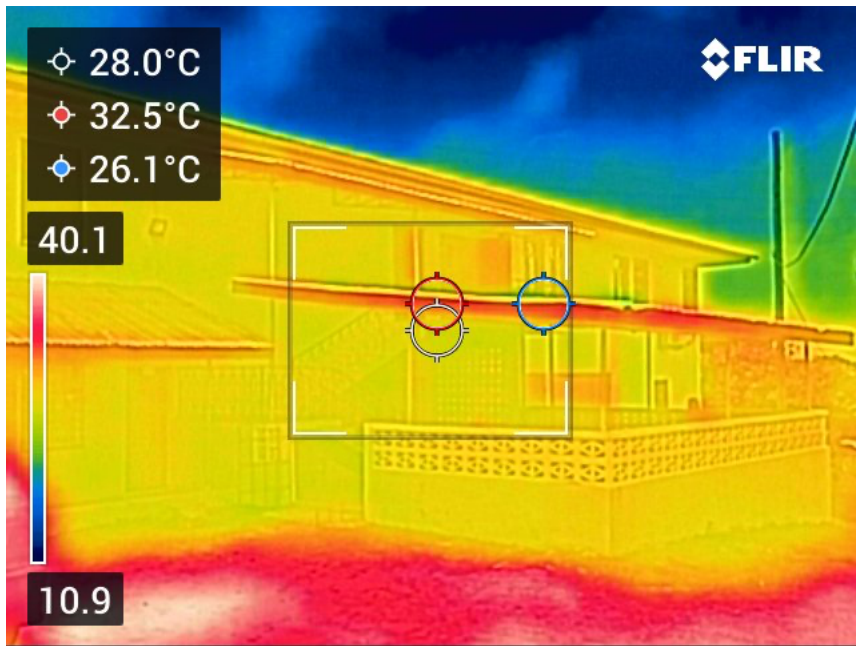


Figure 4a: National university Climate Action Lab solar flir



Figure 4b: Environmental Protection Agency Solar flir

In Monrovia's dry months, clear skies and intense sun drive land surface temperatures dramatically higher than wet-season air temps. Published LST analyses also show that built-up urban surfaces in Greater Monrovia can average 40°C+ in the dry season, vastly hotter than vegetated area. In 2020 the mean midday LST in dense city areas reached ~42°C, whereas areas of mangroves, grass, or water remained much cooler; in the high 20s to low 30s°C range (Brian 2024). In other words, impervious urban materials heat up about 10–15°C more than natural landscapes under dry-season sun. This stark contrast is attenuated during the rains, in the study period, even the hottest urban surface (MCC site) only hit 36°C briefly, and vegetated spots stayed near 29°C, a smaller 7°C gap. It implies that Monrovia's wet season provides natural heat relief, keeping surface and air temperatures more uniform.

However, the dry-season imagery foreshadows the potential intensity of the UHI in drier months. Areas that were a few degrees warmer than the park in August could become extreme hot spots in January–April when rainfall is minimal. The EPA building's site at Mamba Point, for instance, benefits from coastal breezes and frequent rain in August, but in a dry March its concrete surfaces bakes in the sun, raising local air temperatures and indoor cooling loads. Likewise, the NUCAL Lab's shaded courtyard remains comfortable in rains, but surrounding dense neighborhoods in Jallah Town sees much higher surface heating in dry conditions. The satellite image (figure 3) confirms that built and paved areas “light up” with heat in the dry season relative to greener area (Brian 2024). Thus, the rainy-season measurements and dry-season maps together illustrate Monrovia's UHI dynamic: the city's urban surfaces have the capacity to greatly amplify heat, but this is seasonally dampened by rain and clouds. Strategically increasing vegetative cover like trees, parks and green roofs in the city can exploit the rainy season's cooling effect and also mitigate the severe heat extremes of the dry season by lowering surface temperatures year-round (Tamball et al, 2024).

3.1.3. Building Energy Use and Seasonal Differences (Case study of the EPA & NUCAL)

Energy consumption patterns at the EPA headquarters (figure 4b) and the NUCAL Laboratory (figure 4a) closely reflect the temperature dynamics observed across Monrovia. The data show that both facilities rely heavily on artificial cooling and lighting, but at different scales and efficiencies due to their structural characteristics and operational demands.

Environmental Protection Agency (EPA)

The EPA headquarters in Mamba Point is a large, fully air-conditioned concrete structure less than 500 meters from the ocean and elevated more than 74 feet above sea level. Despite its coastal position, the site's extensive concrete paving and poor natural ventilation create significant heat buildup. The building uses 88 air conditioners and two fans, operating about 20 hours per week on cool days and up to 40 hours per week during warm periods. Lighting is entirely electric, and the building lacks passive ventilation or shading.

During the dry season, these conditions combine with higher outdoor temperatures (averaging ~31°C) to drive energy demand sharply upward. Cooling systems must maintain indoor comfort near 24°C, requiring a temperature reduction of roughly 7°C throughout much of the workday. The EPA's grid-connected system consumes about 43.04 kWh daily during peak hours (09:00–16:00), totaling 344.35 kWh over 12 days, supplemented by a diesel generator using roughly 40 gallons of fuel per day when grid power is unreliable. This generator use adds substantial operational cost and emissions.

In the rainy season, when average highs drop to ~26–27°C, the same cooling system operates with much lower stress. The smaller temperature differential (only 2–3°C) allows shorter compressor cycles, reducing total cooling load. Field analysis suggests the building's electricity use for cooling in the dry season is 20–30 percent higher than in the wet season. Even so, the EPA remains energy-intensive year-round due to the scale of equipment, lack of shade, and reflective hard surfaces around the building that amplify heat. The pattern demonstrates how urban heat and poor building design magnify energy consumption, reinforcing the link between heat-island intensity and operating costs.

National Climate Action Laboratory (NUCAL)

NUCAL, located near the Mesurado wetland on the University of Liberia campus, has a smaller footprint and partial exposure to natural ventilation. The exterior is light-colored, but the surrounding surfaces, bare ground, zinc roofing, and a concrete basketball court at the front still absorb and re-radiate heat. The laboratory depends on four air conditioners (two 48,000 BTU, one

24,000 BTU, and one 12,000 BTU) and limited fan use, typically operating 5 hours per week on cool days and up to 40 hours per week in warm conditions.

NUCAL draws power solely from the Liberia Electricity Corporation (LEC) grid, consuming approximately 59.33 kWh per day during an eight-hour peak, or 178 kWh over three days. Although its absolute energy use is far lower than the EPA's, the per-capita dependency on mechanical cooling is proportionally similar, since the building lacks cross-ventilation and relies on closed windows for noise and humidity control.

During the rainy season, ambient conditions (typically 25–27°C) and the site's shading keep indoor temperatures closer to comfort levels, allowing staff to rely mainly on the natural ventilation and limited AC use. However, in the dry season, the same building faces sharp increases in heat load, with indoor spaces easily surpassing 30°C on clear afternoons. If air conditioners run at full capacity to offset this, energy consumption and costs could double. If they remain off to conserve power, work efficiency and comfort decline. NUCAL thus experiences an adaptation gap, balancing energy affordability with heat resilience.

Comparative Analysis and Seasonal Insight

Together, the data reveal a clear seasonal contrast:

- The EPA building's cooling systems run continuously, consuming high energy even in wet months, and surging further in dry periods when both grid electricity and generator fuel are heavily used.
- The NUCAL Lab, though smaller and less energy-intensive, lacks the thermal performance to remain comfortable without AC during the dry season, exposing staff to heat stress or forcing costly energy use.

This comparison shows that urban microclimate and building design strongly influence energy behavior. The EPA's paved compound and minimal vegetation increase conductive heat gain, while NUCAL's partly shaded setting moderates' temperatures but not enough to eliminate cooling needs. Both cases confirm that cooler micro-environments directly reduce cooling demand.

If the EPA building's exterior were shaded or partially vegetated, the reduction in roof and façade temperatures could lower AC runtime by an estimated 10–20 percent, translating to meaningful savings in both grid electricity and generator fuel. For NUCAL, adding roof insulation or reflective coatings could stabilize indoor temperatures and halve fan or AC hours during dry months.

Monrovia's rainy season provides temporary relief with lower energy consumption, but it also highlights the potential efficiency gains from design improvements. The observed UHI effect increases dry-season energy use by at least 20–30 percent, straining both the national grid and institutional budgets. Proactive interventions like green roofs, shading devices, reflective coatings, and enhanced ventilation would therefore not only improve comfort but also reduce recurrent energy expenses and emissions, aligning directly with Liberia's NDC 3.0 goals for energy efficiency and climate resilience.

3.2. Policy Implications

The above results carry important implications for Liberia's national climate and energy policies, especially as articulated in Liberia's NDC 3.0 (Nationally Determined Contribution) and related plans. One key alignment is with the NDC's focus on adaptation and resilience. Liberia's NDC 3.0 explicitly aims to embed climate resilience across all sectors including energy and infrastructure¹. The urban heat challenges shown by this study underscore the need for such resilience measures. For instance, our data confirm that heat stress is already affecting Monrovia's urban environment, which echoes concerns in the NDC that flooding and heat stress exacerbate public health risks for vulnerable populations². By documenting urban heat island effects and cooling demand, we provide evidence to inform adaptation targets related to health, energy, and urban planning.

In particular, national energy efficiency goals stand to benefit from addressing urban heat. Liberia's NDC 3.0 sets a target of 20% improvement in energy efficiency in public institutions by

¹ https://unfccc.int/sites/default/files/2025-09/Liberias_2035_NDC_3.0_Final.pdf#:~:text=bold%20targets,important%20carbon%20sinks%20and%20by

² https://unfccc.int/sites/default/files/2025-09/Liberias_2035_NDC_3.0_Final.pdf#:~:text=respiratory%20infections,health%20facilities%20and%20schools%20with

2035³. Government buildings like the EPA headquarters are exactly the kind of facilities this target envisions upgrading. Our findings suggest that tackling cooling inefficiencies – through better thermal design and UHI mitigation – can be a big part of achieving that 20% reduction. For example, if passive cooling measures (green roofs, shading, etc.) lower the EPA building’s AC consumption by even 10–15%, that contributes significantly toward the NDC efficiency goal while also enhancing climate adaptation. The NDC also calls for a government-wide building energy management program and efficiency upgrades (e.g. phasing out diesel generators, integrating renewables)⁴. Retrofitting buildings for thermal performance aligns perfectly with these measures, reducing reliance on backup generators during peak cooling periods and enabling future solar PV integration (since a cooler building needs a smaller, more affordable PV-battery system to run its loads).

Another relevant aspect is urban heat resilience and land use in national climate strategy. Liberia’s climate commitments highlight cross-sector adaptation in areas like health and energy, but also imply urban planning actions. Our case studies show that simple nature-based solutions in cities – trees, parks, green roofs can mitigate heat. This supports broader adaptation initiatives such as those in the National Adaptation Plan, which emphasize climate-smart infrastructure and reducing climate risks in cities. By reducing local temperatures and energy use, UHI interventions contribute to Liberia’s mitigation targets too. They dovetail with the NDC’s mitigation pledges, which include improving cooling appliance efficiency and possibly developing building codes for energy efficiency. For instance, encouraging or requiring cool roofs and green roofs on public buildings could become part of Liberia’s strategy to meet its greenhouse gas reduction and adaptation commitments concurrently.

Finally, these findings feed into Liberia’s broader development agendas Ensuring public buildings are comfortable and energy-efficient in a warming climate contributes to goals of reliable energy access, reduced pollution, and safeguarding public health. By quantifying UHI impacts on energy,

³ https://unfccc.int/sites/default/files/2025-09/Liberias_2035_NDC_3.0_Final.pdf#:~:text=respiratory%20infections,health%20facilities%20and%20schools%20with

⁴ https://unfccc.int/sites/default/files/2025-09/Liberias_2035_NDC_3.0_Final.pdf#:~:text=respiratory%20infections,health%20facilities%20and%20schools%20with

this study provides local data that policymakers can use to prioritize urban greening projects under the NDC. In summary, mitigating urban heat aligns with national policy priorities on multiple fronts – it is an adaptation action that protects communities (consistent with NDC adaptation goals), it reduces energy waste and emissions (supporting NDC mitigation targets), and it contributes to sustainable urban development as envisioned in Liberia’s climate and energy plans.

4.0. Recommendations

Based on the data and analysis, we recommend several practical interventions to reduce urban heat stress and cooling energy use at the building scale, using the EPA building and similar structures as exemplars:

- Converting rooftop surfaces into green roofs at the EPA building (and other public buildings) will provide natural insulation and cooling. A vegetated roof keeps the building cooler by shading the roof membrane and through evapotranspiration. This directly lowers indoor temperatures and AC demand. Studies have found that green roofs can *dramatically* reduce roof surface temperatures – in one analysis, green roofs in a tropical city cut near-surface temperatures significantly, performing ~14% more effectively in cooling than even reflective solar-panel roofs. In Monrovia’s context, a green roof will absorb less heat than a bare concrete roof (which can exceed 60°C under dry-season sun). Moreover, as noted by sustainable building experts, living roofs provide insulation and reduce heat absorption, thereby improving indoor comfort and reducing energy consumption in tropical climates. For the EPA building, a modular green roof system with hardy native plants (e.g. sedums or grasses that thrive in Liberia’s climate) is recommended. This will also help manage rainwater (important in heavy downpours) and improve urban air quality.
- Installing external shading devices on the EPA building’s windows and walls can sharply cut down solar heat gain. During our rainy-season study, sites with more shade (trees or overhangs) stayed ~2–3°C cooler at midday than unshaded sites, underscoring the value of shading. We suggest adding horizontal overhangs, louvered screens, or brise-soleil on the building’s sun-facing facades (particularly west and east, where low-angle sun penetrates in mornings and afternoons). These devices block direct sunlight from hitting windows and walls, thus keeping interior spaces cooler. Design considerations include using durable

materials (metal or treated bamboo slats) and angling the louvers to allow light but not direct sun. Such passive shading can reduce indoor room temperatures and cut air-conditioning load significantly (often by 20–30% for west-facing offices). It aligns with passive cooling techniques suited for Liberia’s climate – e.g. designs with shaded windows and ample ventilation can minimize reliance on AC. In addition to fixed shades, high-reflectance window tints or films could be applied to further reduce solar heat ingress without sacrificing natural light.

- While not explicitly asked, we note that improving ventilation (large-opening windows, vents, and ceiling fans) is a low-cost intervention complementary to shading. During much of the rainy season when ambient temperatures are moderate (mid-20s°C), the EPA building could leverage cross-breezes and fans instead of air conditioning for cooling. High ceilings and vented windows, as mentioned in sustainable design principles, help exhaust hot air and keep interiors cool with less energy. We recommend assessing the EPA building’s ventilation and installing additional louvered vents or roof turbines if needed to release hot air buildup. This can reduce the AC usage on milder days, directly contributing to energy savings and resilience during power outages.
- For portions of the EPA building’s roof not converted to green roofing (e.g. areas around HVAC equipment or walkways), applying a reflective “cool roof” coating is advised. Bright white or high-albedo roof paint will reflect a large share of solar radiation, keeping surface temperatures much lower (often 10–20°C cooler than typical dark roofs under sun). This complements the green roof sections and ensures the entire roof is working to reject heat. Cool roof treatments are cost-effective and can be done quickly, yielding immediate temperature reductions inside the top-floor offices. In synergy with the green roof, this creates a roof system that dramatically cuts heat gain.

These interventions are technically feasible and financially prudent. Green roofs and shading directly address the causes of the site temperature spikes we observed, thus promising a reduction in UHI intensity at the micro-scale. By lowering indoor cooling loads, these measures save electricity and reduce generator fuel use, supporting both adaptation and mitigation goals. Furthermore, they set visible examples of climate-smart building practices: an EPA headquarters

with a lush green roof and attractive shading devices can serve as a demonstration to inspire other institutions (and signal Liberia's commitment to sustainable infrastructure under its NDC).

5.0. Implementation Plan: 30-Day Intervention at EPA (Shading & Green Roof)

To demonstrate these recommendations, we outline a **phased 30-day work plan** for installing shading devices and a pilot green roof at the EPA Building, Mamba Point. This rapid implementation plan assumes mobilization of a skilled local workforce and readily available materials:

- Week 1 (Days 1–7): Planning and Preparation – Conduct a structural assessment of the EPA building's roof to confirm it can support a lightweight green roof system. Identify suitable roof section (e.g. over the top-floor conference room) for an extensive green roof (soil depth ~10–15 cm). Simultaneously, survey the building's facades (especially west and east sides) to design custom-fit shading devices. By Day 3, hold a design charrette with engineers and architects to finalize the green roof layout (drainage layer, soil media, plant selection) and shading structure dimensions. By end of Week 1, procurement of materials begins: order waterproof membrane, geo-textile, soil substrate, and drought-tolerant plants (such as native grasses or sedums) for the roof; and fabricate steel/aluminum frames and louvers for window shades per measurements. Milestone: Final design approved; materials and plants ordered.
- Week 2 (Days 8–14): Site Preparation and Fabrication – Clear and clean the target roof area at EPA. Apply waterproofing membrane over the roof surface (Day 8–9) and install edge guards to contain the green roof. While the membrane cures, the team off-site builds the shading devices: cutting and welding frames, painting them with corrosion-resistant paint. If using prefabricated louver systems, ensure delivery by mid-week. By Day 12, start installing mounting brackets on the building's west and east walls (these are anchor points for the shading devices above windows; work done preferably on weekends or off-hours to minimize office disruption). On the roof, lay down drainage mats and a lightweight soil mix by Day 14. Milestone: Roof is prepped (membrane and soil in place), and shade device components are ready for installation.

- Week 3 (Days 15–21): Installation of Green Roof and Shading Devices – Begin planting on the roof (Day 15–16): transplant hardy vegetation plugs or roll out pre-grown sedum mats across the prepared roof section. Ensure an irrigation method is in place (temporary drip hose or manual watering schedule, especially if this period is in the dry season; during rainy season, natural rainfall may suffice initially). By Day 17, turn focus to shading device installation: using a crane or scaffolding, attach the fabricated louvers/overhangs to the pre-installed brackets on the building facade. Work section by section, prioritizing the upper-floor windows which get the most sun. Each shade structure is bolted securely and tested. By Day 20, the majority of shading devices should be mounted, visibly reducing direct sunlight entry. Green roof planting is completed by Day 18 and given a first watering. Milestone: Green roof vegetation installed and establishing; all planned shading devices mounted on building.
- Week 4 (Days 22–30): Finishing, Training and Monitoring – Conduct a thorough inspection of all installations (Day 22–23). Check that the green roof’s drainage is working (simulate heavy rain to see water flow), and that no leaks are observed underneath (critical for roof integrity). Inspect each shading device for stability and adjust any louver angles to ensure optimal shading without blocking desired daylight. Day 24–26: develop a maintenance plan with EPA facilities staff – e.g. assign watering duties for the roof (if needed during dry spells), periodic weeding, and cleaning of shade structures. Train the maintenance team on green roof care (perhaps with input from a landscaping expert) and on how to safely remove debris from shade louvers. Establish a simple monitoring regime: for example, set up a thermometer on the green roof and one on a neighboring bare roof area to record temperature differences, and likewise measure indoor temperatures in shaded vs. unshaded rooms for comparison. Day 27–30: Wrap up any punch-list items, such as painting touch-ups, replacing any plants that didn’t take, or tightening fixture bolts. Finally, organize a brief walkthrough with EPA management and possibly energy stakeholders on Day 30 to showcase the new green roof and shading system. Milestone: Project handover – EPA staff take ownership of a functioning green roof (already visibly lowering roof skin temperature) and shading devices providing cooler interior conditions. The building is now set as a model of a quick turnaround climate-resilient retrofit.

This 30-day plan is ambitious but achievable with strong coordination. It yields immediate improvements: by the end of the month, parts of the EPA building will have a lush green cover and critical facades will be shielded from the sun. Even within the first days of completion, benefits should be felt – lower afternoon temperatures in top-floor rooms, reduced glare, and perhaps a drop in AC electricity consumption. The rapid timeline also demonstrates that with political will and resource allocation (in line with NDC goals), tangible climate adaptation upgrades can be delivered on existing structures in a short period.

6.0. Conclusion

Greater Monrovia's rainy-season temperature assessment, combined with insights from land surface imagery and energy use, highlights both challenges and opportunities at the nexus of urban climate and building performance. **Key insights** include: even in the wet season, urban design factors (like vegetation and shading) create noticeable temperature differences between sites, pointing to an active urban heat island effect. In drier conditions these differences amplify, driving up cooling energy needs and straining comfort in buildings not adapted to the heat. The EPA and NUCAL case studies illustrated the spectrum – from a modern building incurring high energy costs to maintain comfort, to an older facility naturally cooler but potentially vulnerable to future heat.

The benefits of intervention are compelling. Implementing green roofs and shading at the EPA building will directly reduce UHI intensity at the micro-scale, dropping rooftop and indoor temperatures. This in turn lowers air-conditioning requirements, cutting energy consumption and costs – savings that accumulate year after year. For the EPA, this means a cooler, more efficient workplace (aligning with the NDC's public sector efficiency targets and setting an example for others). For the city, widespread adoption of such measures would mean a more heat-resilient urban environment with reduced peak electricity demand and improved livability. Vegetated roofs and trees can even improve stormwater management and urban biodiversity, offering co-benefits beyond heat mitigation.

Crucially, these interventions support Liberia's national climate pledges on both mitigation and adaptation fronts. By reducing electricity use (much of which comes from fossil-backed generation in Liberia's grid mix), efficiency measures like better building cooling directly contribute to

emissions reductions. Simultaneously, they boost adaptation by protecting citizens from heat stress and reducing the vulnerability of energy systems during extreme weather (for instance, a building that stays cooler naturally is more resilient to power outages or fuel shortages). In a broader sense, addressing urban heat aligns with Liberia's development priorities – it improves public health, productivity, and environmental quality in cities.

In conclusion, the rainy-season study provided a vital evidence base: it showed that Monrovia's urban heat island is present and impactful, but also that smart design can alleviate it. By pursuing recommended interventions such as green roofs, shading devices, cool materials, and improved ventilation, policymakers and practitioners can make immediate strides toward cooler, more efficient cities. As Liberia moves forward with NDC 3.0 implementation, the lessons from EPA and NUCAL can inform a template for retrofitting public buildings nationwide. The result will be not only compliance with climate targets, but tangible improvements in everyday life – lower energy bills, safer buildings during heat waves, and greener, more comfortable urban spaces for all. Such outcomes represent a win-win for climate action and urban development, ensuring that Monrovia's growth is both sustainable and resilient in the face of a warming future.

7.0. References

- Chapman, S. et al. (2017). "The impact of urbanization and climate change on urban temperatures: a systematic review." *Landscape Ecology* 32(10):1921–1935. (Need for combined study of urban growth and climate; urban heat research gaps).
- Jahanbakhsh, H. (2016). *Energy Management in Architecture and Urban Planning*. Payam Noor Iran University.
- Tamba II, J. S., Eze, V. H. U., & Bawor, F. H. (2024). Urban greening as a sustainable solution to heat stress in tropical cities: a case study of Monrovia in Liberia. *KIU Journal of Science, Engineering and Technology*, 3(1), 100-111.
- Odindi, J. et al. (2015). (Referenced in Yekeh thesis) – Finding: impervious surfaces in cities absorb more solar radiation contributing to UHI.
- Westendorff, A. (2020). (Referenced in Yekeh thesis) – *Finding*: UHI is a complex phenomenon occurring globally, projected to worsen with climate change

World Bank Climate Change Knowledge Portal (2021). "Liberia Climate Risk Profile."
(Extreme heat risk projections: higher temperatures by mid-century).

Yekeh, H. F. (2023). *Geospatial Assessment of the Role of Urban Green Infrastructure in Mitigating Urban Heat Island: a Case Study of Greater Monrovia District, Liberia* (Doctoral dissertation, University of Nairobi).