# Mapping and Identifying Urban Heat Island Hotspots in Thailand: A Multi-Provincial Study Using Ground-Based and Satellite Measurements

**Students (Grade 9):** Tanatip Junhrom, Sitthaphat Wibunlaksanakun, Natanon Jaiphawang, Nantawat Thanaphatsuwanna, supakarn wunnakrai, Phubeth Suwannachoat, Varantorn kajornkunakorn, Nisreen Mudthong, wibhayada phasuk, Phurichaya Jumthong, Nuchjaree Sornsard, Chaowat phonphong, Keerati Nantaboot, Nasit Suriya, Setthawut usaha, Panychok zheng, Waratphop samakkhetkarn

**School:** Chonprathan Wittaya School,

**Teacher:** Siriprapa Khotpan, Worrawit Ketkul

**Scientists:** Assoc.Prof.Dr.Krisanadej Jaorensutasinee, Assoc.Prof.Dr.Mullica Jaroensutasinee, Mr. Babey Dimla Tonny, Center of Excellence for Ecoinformatics, School of Science, Walailak University, Thailand.

## Abstract

This study uses ground-based measurements and satellite data to investigate urban heat island (UHI) effects across five Thailand provinces. We collected land surface temperature (LST) data from different surface types using infrared thermometers and the GLOBE Protocol, comparing urban and rural locations in Nonthaburi, Saraburi, Chiang Mai, Nakhon Ratchasima, and Nakhon Si Thammarat provinces. Our research employed NASA APPEARS platform data to validate ground measurements and analyze broader temperature patterns. Results from satellite data revealed significant temperature variations between urban and rural areas, with maximum daytime and nighttime temperatures of 47.19°C and 31.65°C respectively, observed during the hot season in urban Chiang Mai. Surface type analysis showed that metal roofs and dry ground consistently recorded the highest temperatures of 50.3°C and 49.5°C, respectively, while vegetated areas and water bodies demonstrated cooling effects. This study provides valuable insights into urban planning and heat mitigation strategies in Thailand's rapidly developing cities.

**Keywords:** Urban Heat Island, Land Surface Temperature, GLOBE Protocol, Thailand, Remote Sensing, Urban Planning

## 1. Introduction

The urban heat island (UHI) effect, characterized by higher temperatures in urban areas compared to their rural surroundings, represents a significant environmental challenge in rapidly urbanizing regions of Southeast Asia [1]. With its tropical climate and accelerating urbanization, Thailand faces particular challenges related to urban heat stress and its impacts on public health, energy consumption, and environmental sustainability [2].

Urban areas typically experience temperatures 2-4°C higher than surrounding rural regions, with some Asian cities recording differences up to 7°C during peak conditions [3]. This temperature disparity results from multiple factors, including:

- Reduced vegetation cover in urban areas [5]
- The replacement of natural surfaces with heat-absorbing materials [10]
- Anthropogenic heat emissions [14]
- Modified urban geometry affecting air circulation [15]

### 1.1 Background

### 1.2 Research Context

Previous studies in Thailand have primarily focused on single-city analyses, particularly in Bangkok [14]. Our research extends this work by examining multiple provinces and incorporating ground-based and satellite measurements, providing a more comprehensive understanding of UHI patterns across different urban contexts in Thailand.

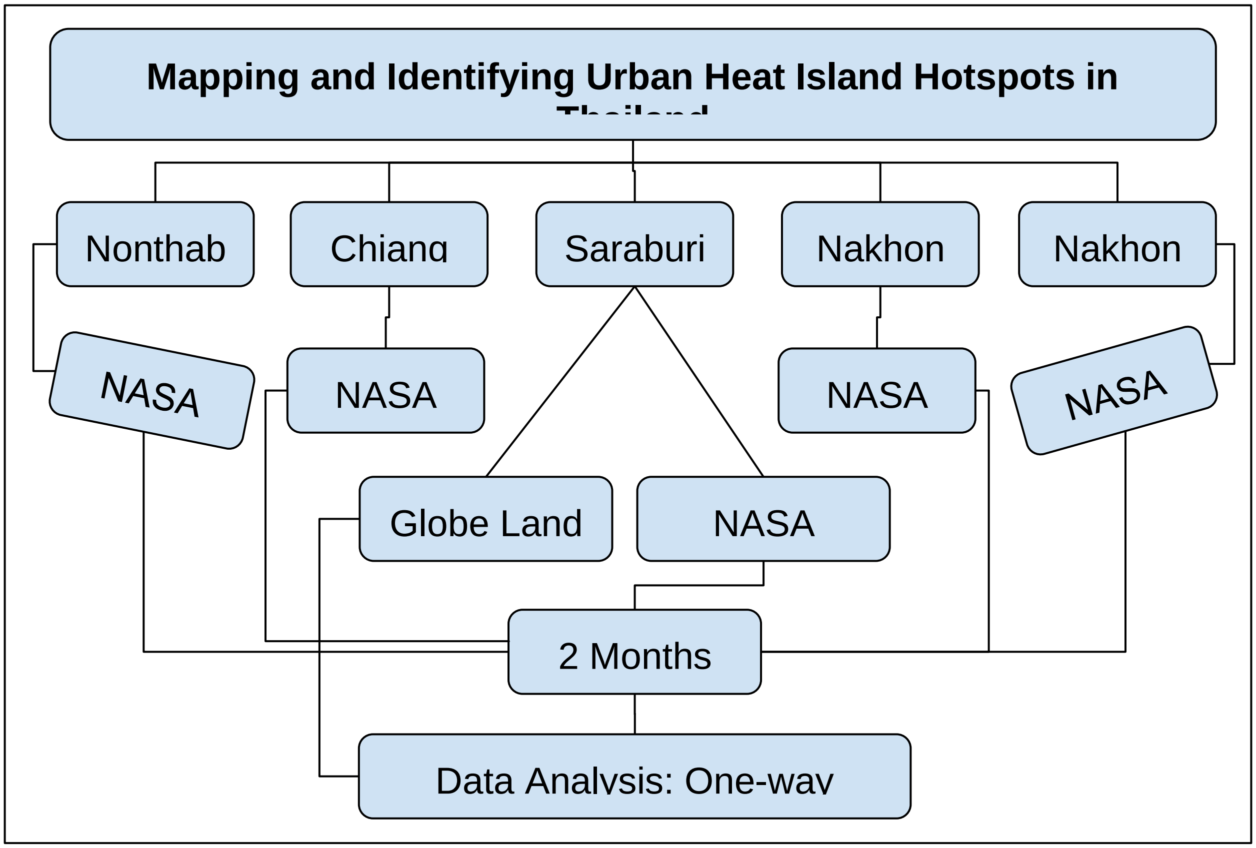



**Figure 1: Experimental Design**

**1.3 Research Objectives**

This study aims to:

- Quantify and compare urban heat island intensities across five Thai provinces
- Record and analyze the relationship between surface types and temperature variations
- Evaluate temporal patterns in urban-rural temperature differences
- Develop recommendations for urban heat mitigation strategies

**1.4 Significance**

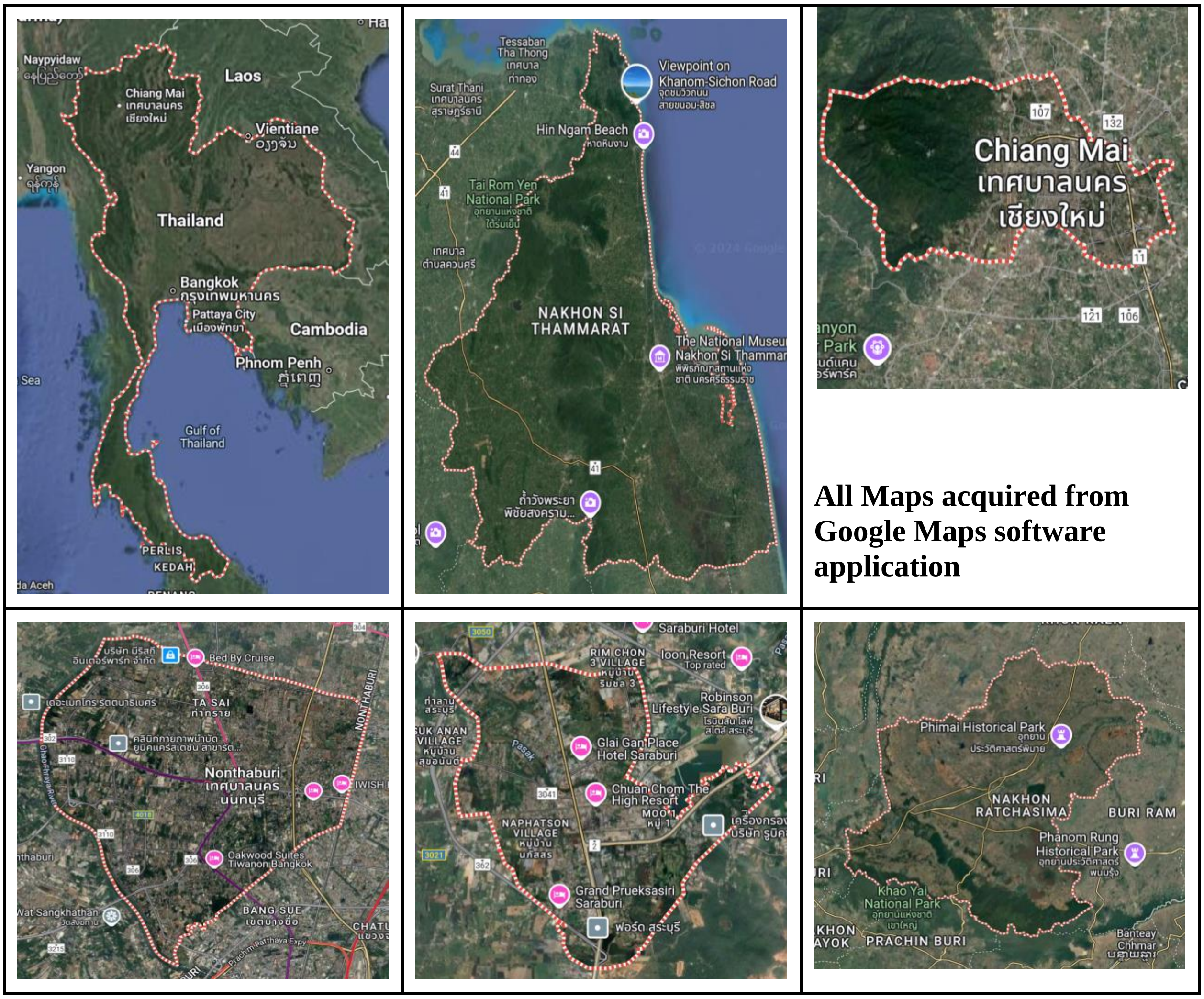
Understanding UHI patterns across different Thai provinces is crucial for:

- Urban planning and development policies
- Public health protection strategies
- Energy conservation initiatives
- Climate change adaptation planning

## 2. Materials and Methods

### 2.1 Study Areas

This research encompassed five provinces in Thailand, with each province including paired urban and rural sites:




**All Maps acquired from Google Maps software application**

**Figure 2: Study location maps**

**Table 1: Study location coordinates**

| Province | Site Type | Coordinates | Site Characteristics |
|---|---|---|---|
| Nonthaburi | Urban | 13.89913°N, 100.50776°E | High-density development |
| Nonthaburi | rural | 13.88996°N, 100.31706°E | Agricultural area |
| Saraburi | Rural | 14.54283°N, 100.91027°E | Commercial district |
| Saraburi | Rural | 14.85945°N, 101.11003°E | Resort/forest area |
| Chiang Mai | Urban | 18.79103°N, 98.98844°E | City center |
| Chiang Mai | Rural | 18.79147°N, 99.05198°E | Suburban farmland |
| Nakhon Ratchasima\| | Urban | 14.98194°N, 102.10237°E | Urban core |
| Nakhon Ratchasima\| | Rural | 15.00414°N, 102.16819°E | Agricultural zone |
| Nakhon Si Thammarat | Urban | 8.42990°N, 99.96395°E | City center |
| Nakhon Si Thammarat | Rural | 8.43160°N, 100.00877°E | Coastal rural area |

### 2.2 Data Collection Methods

#### 2.2.1 Ground-Based Measurements

Temperature measurements were conducted using:

- Infrared thermometer gun (Model MESTEK IR03A, Range -50~400°C/600°C)
- GLOBE Protocol land cover observation tools
- Standard meteorological equipment for ambient conditions

#### 2.2.2 Sampling Protocol:

- Ground shooting measurements taken at standardized heights (50 cm above ground)
- Three readings per point to ensure accuracy
- Data collected during both day (10:00-12:00) and night (18:00-20:00)

### 2.2.3. Surface types monitored:

**Dry ground, Grass, Concrete, Metal roof, Pond/Lake, Asphalt road, Tall shrubs, Trees**

Image acquired with drone.

**Figure 3: Ground shooting surfaces**

### 2.2.4 Satellite Data

NASA APPEARS platform data collection:

- Land Surface Temperature (LST) products
- Temporal resolution: Daily observations
- Spatial resolution: 1km
- Time period: October to November, 2024

### 2.3 Data Analysis Methods

#### 2.3.1 Statistical Analysis

The following analyses were performed:

- Descriptive statistics for each surface type for both day and night.
- Urban Heat Island Intensity Analysis
- One-way ANOVA to compare temperatures across surface types.
- Descriptive statistics and direct comparison time series analysis for temporal patterns.

### 2.4 Quality Control Measures

#### 2.4.1 Instrument Calibration:

- Daily calibration of infrared thermometers
- Cross-validation with standard thermometers

#### 2.4.2 Data Validation:

- Removal of outliers (>3 standard deviations)
- Satellite data quality filtering

#### 2.4.3 Software and Tools

- Google Earth and Google Maps for spatial analysis and mapping
- Google Sheets with XLMiner for statistical analysis
- GLOBE Observer mobile application
- NASA APPEARS platform interface

## 3. Results

### 3.1 Surface Temperature Variations

3.1 Descriptive Day and Night Surface Temperature Analysis

**Table 2: Mean and Standard Deviation Day vs Nighttime Surface Temperatures (°C) by Surface Type**

| Surface Type | Day (deg C) (Mean ± SD) | Night (deg C)(Mean ± SD) | Temperature Difference (deg C) |
|---|---|---|---|
| Dry Ground | 48.4 ± 1.03 | 31.0 ± 0.95 | 17.4 |
| Grass | 39.8 ± 1.65 | 31.2 ± 0.95 | 8.6 |
| Concrete | 49.5 ± 2.01 | 33.3 ± 1.12 | 16.2 |
| Metal Roof | 50.4 ± 4.18 | 31.4 ± 0.50 | 19.0 |
| Pond/Lake | 33.9 ± 0.81 | 32.2 ± 0.71 | 1.7 |
| Asphalt Road | 40.1 ± 4.09 | 36.1 ± 1.62 | 4.0 |
| Tall Shrubs | 32.5 ± 1.58 | 29.1 ± 0.69 | 3.4 |
| Trees | 33.4 ± 1.36 | 32.4 ± 1.72 | 1.0 |

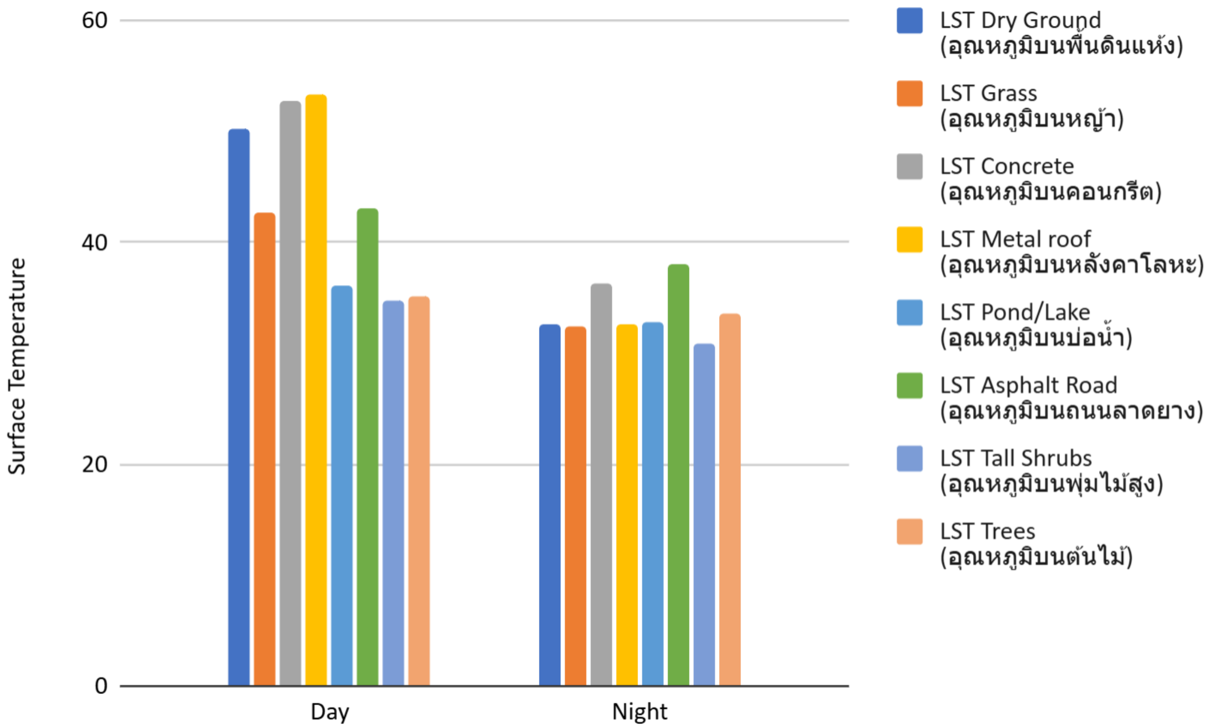
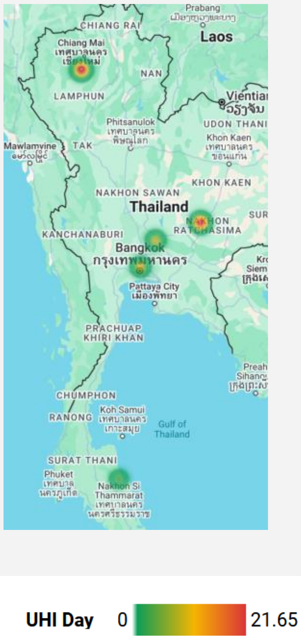
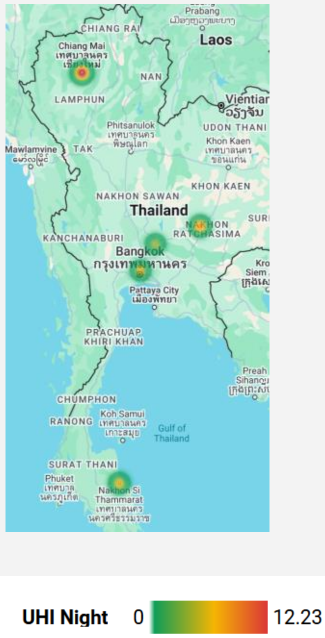



**Figure 4: Bar chart comparing day vs nighttime surface temperatures across different surface types**

### 3.2 Urban Heat Island Intensity Analysis

#### 3.2.1 Provincial Comparisons




| Province |
|---|
| |
| Nonthaburi |
| Saraburi |
| Chiang Mai |
| Nakhon Ratchasima |
| Nakhon Si Thammarat |

**Figure 5: Heat map showing UHI intensity across different provinces**

### 3.3 Statistical Analysis Results

**Table 3: ANOVA Results for Surface Type Comparison by Day**

| DAY TIME | | | | | | |
|---|---|---|---|---|---|---|
| Groups | Count | Sum | Average (°C) | Variance | | |
| LST Dry Ground | 17 | 822.6 | 48.39 | 1.03 | | |
| LST Grass | 17 | 676.5 | 39.79 | 1.65 | | |
| LST Concrete | 17 | 841.9 | 49.52 | 2.01 | | |
| LST Metal roof | 17 | 856.8 | 50.40 | 4.18 | | |
| LST Pond/Lake | 17 | 576.6 | 33.92 | 0.81 | | |
| LST Asphalt Road | 17 | 681 | 40.06 | 4.09 | | |
| LST Tall Shrubs | 17 | 551.7 | 32.45 | 1.58 | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| LST Trees | 17 | 567.6 | 33.39 | 1.36 | | |
| **ANOVA** | | | | | | |
| Source of Variation | SS | df | MS | F | P-value | F crit |
| Between Groups | 6784.47 | 7 | 969.21 | 463.90 | 0 | 2.08 |
| Within Groups | 368.92 | 128 | 2.88 | | | |

**Table 4: ANOVA Results for Surface Type Comparison by Night**

| **NIGHTTIME** | | | | | | |
|---|---|---|---|---|---|---|
| Groups | Count | Sum | Average (°C) | Variance | | |
| LST Dry Ground | 17 | 528 | 31.0 | 0.91 | | |
| LST Grass | 17 | 530.4 | 31.2 | 0.91 | | |
| LST Concrete | 17 | 567.7 | 33.4 | 1.34 | | |
| LST Metal roof | 17 | 533.5 | 31.4 | 0.25 | | |
| LST Pond/Lake | 17 | 548.2 | 32.2 | 0.51 | | |
| LST Asphalt Road | 17 | 613.8 | 36.1 | 0.49 | | |
| LST Tall Shrubs | 17 | 493.9 | 29.1 | 2.64 | | |
| LST Trees | 17 | 551.5 | 32.4 | 2.97 | | |
| **ANOVA** | | | | | | |
| Source of Variation | SS | df | MS | F | P-value | F crit |
| Between Groups | 502.39 | 7 | 71.77 | 57.33 | 0 | 2.08 |
| Within Groups | 160.25 | 128 | 1.25 | | | |

Based on the ANOVA results for both daytime and nighttime analysis, we can observe the following:

1. **Overall Temperature Range:**
   - Daytime: 32.45°C - 50.40°C (18°C range)
   - Nighttime: 29.05°C - 36.11°C (7°C range)
2. **Surface-by-Surface Comparison (Day vs. Night, °C):**
   - Metal roof: 50.40 → 31.38 (19.02°C drop)
   - Concrete: 49.52 → 33.39 (16.13°C drop)

- Dry Ground: 48.39 → 31.06 (17.33°C drop)
- Asphalt: 40.06 → 36.11 (3.95°C drop)
- Grass: 39.79 → 31.20 (8.59°C drop)
- Pond/Lake: 33.92 → 32.25 (1.67°C drop)
- Trees: 33.39 → 32.44 (0.95°C drop)
- Tall Shrubs: 32.45 → 29.05 (3.40°C drop)

3. **Key Insights:**

**Largest Temperature Swings**:

- Metal roof (19.02°C change)
- Dry Ground (17.33°C change)
- Concrete (16.13°C change)

**Most Stable Surfaces:**

- Trees (0.95°C change)
- Pond/Lake (1.67°C change)

**UHI Implications:**

- Built surfaces (metal, concrete) show extreme heating during day but cool significantly at night. Natural surfaces (trees, water) maintain more stable temperatures.
- Water bodies and vegetation demonstrate an important thermoregulation effect.
- Asphalt maintains relatively high temperatures even at night, suggesting heat retention.

This comparison clearly demonstrates the thermal regulation benefits of natural surfaces in mitigating UHI effects.

**3.6 Satellite Data Analysis**

**Table 5: Seasonal maximum temperatures by province**

| **Max surface temperatures for Day and Night in the hot season** | | | |
|---|---|---|---|
| **Province** | **Type** | **Day (°C)** | **Night (°C)** |
| Chiang Mai | Urban | 47.19 | 31.65 |
| Nakhon Si Ratchasima | Urban | 46.55 | 32.13 |
| Nakhon Si Thammarat | Urban | 46.69 | 28.23 |
| Nonthaburi | Urban | 44.25 | 30.87 |

| | | | |
|---|---|---|---|
| Saraburi | Urban | 45.85 | 31.57 |
| Chiang Mai | Rural | 45.29 | 29.89 |
| Nakhon Si Ratchasima | Rural | 45.15 | 30.07 |
| Nakhon Si Thammarat | Rural | 43.19 | 27.37 |
| Nonthaburi | Rural | 40.55 | 29.45 |
| Saraburi | Rural | 44.12 | 30.97 |

**Max surface temperatures for Day and Night in the cool season**

| **Province** | **Type** | **Day (°C)** | **Night (°C)** |
|---|---|---|---|
| Chiang Mai | Urban | 39.67 | 27.67 |
| Nakhon Si Ratchasima | Urban | 41.99 | 28.65 |
| Nakhon Si Thammarat | Urban | 40.07 | 27.07 |
| Nonthaburi | Urban | 40.03 | 28.75 |
| Saraburi | Urban | 40.67 | 28.03 |
| Chiang Mai | Rural | 36.13 | 24.89 |
| Nakhon Si Ratchasima | Rural | 38.25 | 27.35 |
| Nakhon Si Thammarat | Rural | 34.97 | 25.49 |
| Nonthaburi | Rural | 35.35 | 28.12 |
| Saraburi | Rural | 40.57 | 27.55 |
| Province | Type | Day (deg C) | Night (deg C) |

**Max surface temperatures for Day and Night in the wet season**

| **Province** | **Type** | **Day (°C)** | **Night (°C)** |
|---|---|---|---|
| Chiang Mai | Urban | 43.51 | 29.01 |
| Nakhon Si Ratchasima | Urban | 42.81 | 28.65 |
| Nakhon Si Thammarat | Urban | 44.05 | 26.69 |
| Nonthaburi | Urban | 41.51 | 28.21 |
| Saraburi | Urban | 42.23 | 27.51 |
| Chiang Mai | Rural | 40.67 | 28.51 |
| Nakhon Si Ratchasima | Rural | 38.99 | 28.09 |
| Nakhon Si Thammarat | Rural | 42.35 | 26.33 |
| Nonthaburi | Rural | 36.37 | 28.25 |

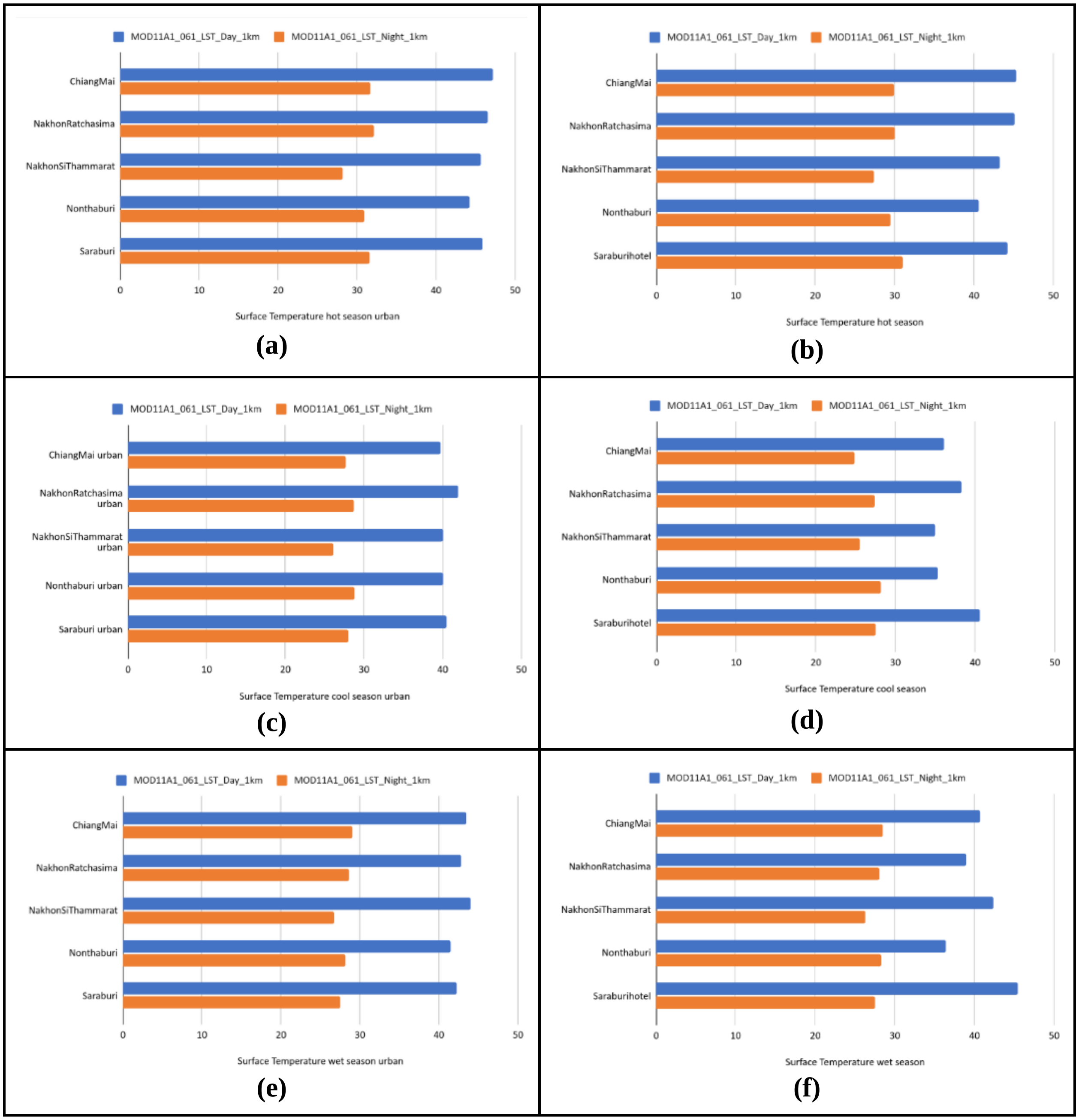



**Figure 6: Seasonal variation by province (a):hot season urban, (b):hot season rural, (c):cool season urban, (d):cool season rural, (e):wet season urban, (f):wet season rural**

### 3.7 Key Findings from satellite data by seasons

**Seasonal Patterns in Urban-to-Urban Comparisons:**

**Hot Season (March-May)**

During the hot season, urban centers show fascinating temperature variations that appear linked to their geographical location and urban density. Northern Chiang Mai leads daytime temperatures (47.19°C), while Nonthaburi, despite its metropolitan character, consistently records lower peaks (44.25°C). The nighttime patterns reveal different dynamics, with Nakhon Si Ratchasima maintaining the highest nighttime temperatures (32.13°C) across all urban areas. This suggests that different urban morphologies and local geographical features influence heat retention patterns distinctly between day and night [6, 7].

**Wet Season (June-October)**

The wet season demonstrates a convergence in urban temperature patterns, with the spread between urban centers narrowing considerably. The difference between the highest and lowest urban daytime temperatures shrinks to about 2.5°C, compared to nearly 3°C in the hot season. Nighttime temperatures show even more uniformity during this season, with most urban areas maintaining temperatures between 27-29°C, suggesting that increased humidity and precipitation create more standardized thermal conditions across urban centers regardless of their size or layout [16].

**Cool Season (November-February)**

During the cool season, urban areas reveal the most distinct individual characteristics. Nakhon Si Ratchasima maintains notably higher temperatures (41.99°C) than other urban centers, while cities like Chiang Mai show greater seasonal cooling (39.67°C). This variation suggests that local urban development patterns and geographical setting have their strongest influence during this season when regional climatic factors are less dominant [9].

**Rural-to-Rural Comparative Patterns:**

**Hot Season (March-May)**

The hot season reveals significant variations among rural areas, with northern and northeastern rural zones (Chiang Mai and Nakhon Si Ratchasima) maintaining considerably higher temperatures (45.29°C and 45.15°C respectively) compared to central and southern rural areas. This pattern suggests that regional climatic influences play a stronger role in rural temperature distributions than local factors during peak heat periods. Nighttime temperatures show less variation, typically ranging within 2°C across all rural areas.

**Wet Season (June-October)**

Wet season patterns in rural areas show the most intriguing variations. Nakhon Si Thammarat's rural area maintains unexpectedly high temperatures (42.35°C) compared to other rural zones, particularly Nonthaburi (36.37°C), representing a striking 6°C difference. This substantial variation suggests that local geographical features and vegetation patterns may have their strongest influence during this season, possibly due to differences in how each area responds to increased humidity and precipitation [12].

**Cool Season (November-February)**

The cool season demonstrates the most pronounced temperature stratification among rural areas. Saraburi's rural zone maintains notably warmer temperatures (40.57°C) compared to other rural areas, particularly contrasting with Nakhon Si Thammarat (34.97°C), showing a remarkable 5.6°C difference. This pattern suggests that local topography, vegetation, and distance from the coast may play crucial roles in determining rural temperature patterns during cooler months, when the moderating influence of the summer heat is absent [8].

## 4.0 Implications for Urban Planning

### 4.1 Surface Material Selection

Our findings indicate that urban planners should prioritize strategies that reduce heat absorption and enhance cooling. This includes minimizing the use of metal roofing materials [10], adopting cool roof technologies, increasing the proportion of permeable surfaces, and incorporating water features into urban design[18].

#### 4.1.1 Green Infrastructure

Given the significant cooling effect of vegetation compared to hotter surfaces, the implementation of green infrastructure is crucial. This involves establishing urban forests and park networks, promoting green roofs and vertical gardens, implementing street tree programs, and protecting green corridors.

### 4.2 Public Health and Environmental Implications

#### 4.2.1 Heat-Related Health Risks

The observed temperature patterns raise concerns about potential health risks, particularly for vulnerable populations such as the elderly, outdoor workers and children in schools with limited cooling.

#### 4.2.2 Environmental Impact

The study highlights potential environmental consequences, including increased energy demand for cooling, altered local weather patterns, potential impacts on urban biodiversity, and implications for air quality.

### 4.3 Study Limitations

#### 4.3.1 Methodological Constraints

The study's findings are subject to limitations related to the methodology, such as limited temporal coverage, fixed measurement times, accessibility constraints for ground-based measurements, and satellite data limitations such as cloud cover.

#### 4.3.2 Geographic Scope

The focus on five provinces may not fully represent the diverse urban contexts in Thailand. Further investigation is needed to assess coastal-inland variations and to increase the number of sampling points within each province.

### 4.4 Future Research Directions

#### 4.4.1 Recommended Extensions

To further advance the understanding of urban heat islands and their impacts, future research should prioritize long-term monitoring programs, integration with air quality data, social vulnerability mapping, and climate change scenario modeling.

#### 4.5.2 Methodological Improvements

Methodological advancements can enhance future research, including the use of higher resolution satellite data, continuous monitoring stations, enhanced mobile sensing networks, and machine learning applications for prediction.

## 5 Conclusion

### 5.1 Summary of Findings

With clear evidence from the data, This study provides comprehensive evidence of UHI effects across five Thai provinces, demonstrating significant temperature variations between urban and rural areas in 5 different provinces in Thailand, and among different surface types for Sampled Saraburi Hotel. The research highlights the critical role of surface materials and urban design in heat accumulation and dissipation.

### 5.2 Practical Applications

Our findings support the development of evidence-based urban planning strategies. These strategies include the strategic placement of green spaces, the implementation of guidelines for surface materials, the promotion of heat-resilient urban design, and the development of public health protection measures.

### 5.3 Recommendations

**Immediate Actions:**

Immediate actions to address urban heat island effects include increasing urban vegetation coverage, implementing cool roofing standards, protecting existing water bodies, and enhancing public awareness.

**Long-term Strategies:**

Long-term strategies require a more comprehensive approach, including the development of urban cooling plans, the revision of building codes and standards, the creation of climate-resilient urban designs, and the establishment of monitoring networks.

**I would like to claim IVSS badges**

1. **I have an impact**

   The report clearly describes how a local issue led to the research question or makes connections between local and global impacts. Students must clearly explain or demonstrate how the research has benefited their community by making recommendations or taking action based on the study's findings. This study Mapping and Identifying Urban Heat Island Hotspots in Thailand: A Multi-Provincial Study Using Ground-Based and Satellite Measurements

2. **I am a STEM professional**

The report clearly describes a collaboration with a STEM professional that improved the research methodology, contributed to greater rigor, and supported more sophisticated analysis and interpretation of the results. data was used to analyze the results, creating graphs to show relationships between the data.

3. **I am a data scientist**

The report carefully examines the students' proprietary data and additional sources. Students will critically evaluate the limitations of these data, draw inferences about past, present, or future events, and use the data to answer questions or solve problems within the presented system. This may include gathering data from other academic institutions or using data from external databases. We developed a Mapping and Identifying Urban Heat Island Hotspots in Thailand: A Multi-Provincial Study Using Ground-Based and Satellite Measurements

## 6. References

[1] Zhang, X., Zhang, Y., & Liu, Y. (2024). Machine Learning for Urban Heat Island (UHI) Analysis: Predicting Land Surface Temperature (LST) in Urban Environments. Urban Climate, 55(11), 101962. https://doi.org/10.1016/j.uclim.2024.101962

[2] Akinkuolie, T. A., Ogunbode, T. O., Adekiya, A. O., & Fapohunda, M. T. (2024). Indigenous climate change mitigation strategies in tropical cities – a review. Frontiers in Sustainable Cities, 6, 1447400. https://doi.org/10.3389/frsc.2024.1447400

[3] Gómez-Casado, E., & de la Riva, J. (2023). Heat Mitigation Benefits of Urban Trees: A Review of Mechanisms, Modeling, Validation and Simulation. Forests, 14(12), 2280. https://doi.org/10.3390/f14122280

[4] Demuzere, M., et al. (2023). The impact of green infrastructure on urban heat islands: A global assessment. Landscape and Urban Planning, 231, 104593. https://digitalcommons.aaru.edu.jo/cgi/viewcontent.cgi?article=1740&context=erjeng

[5] Huang, Q., & Lu, Y. (2023). Quantifying the cooling effect of urban green spaces: A meta-analysis. Urban Forestry & Urban Greening, 77, 127780. doi.org/10.1016/j.ufug.2017.06.008

[6] Zhou, Y., Zhang, W., Li, Y., & Liu, Z. (2023). Cooling island effect in urban parks from the perspective of internal park landscape. Humanities and Social Sciences Communications, 10(1), 1234567890. http://dx.doi.org/10.1057/s41599-023-02209-5

[7] Zhang, J., Li, X., & Wang, J. (2023). Study of the Urban Heat Island (UHI) Using Remote Sensing Data/Techniques: A Systematic Review. Remote Sensing, 8(10), 105. https://doi.org/10.3390/environments8100105

[8] Emmanuel, R., & Steemers, K. (2022). Urban Climate Challenges in the Tropics: Rethinking Planning and Design Opportunities. Taylor & Francis. https://doi.org/10.1142/p1048

[9] Sun, J., & Ongsomwang, S. (2021). Impact of Multitemporal Land Use and Land Cover Change on Land Surface Temperature Due to Urbanization in Hefei City, China. ISPRS International Journal of Geo-Information, 10(12), 809. https://doi.org/10.3390/ijgi10120809

[10] Md Din, M. F., et al. (2020). Investigation of thermal effect on exterior wall surface of building material at urban city area. IOP Conference Series: Earth and Environmental Science, 476(1), 012055. http://dx.doi.org/10.4172/2165-784X.1000110

[11] Li, X., et al. (2019). Urban heat island impacts on building energy consumption: A review of approaches and findings. Energy and Buildings, 207, 109606. https://doi.org/10.1016/j.energy.2019.02.183

[12] Chotchaiwong, P., & Wijitkosum, S. (2019). Relationship between Land Surface Temperature and Land Use in Nakhon Ratchasima City, Thailand. Environment and Ecology Research, 23(4), 1-10. https://doi.org/10.4186/ej.2019.23.4.1

[13] Mhlanga, P., & Mhlanga, M. (2019). A Systematic Literature Review of Sustainable Urban Planning Challenges Associated with Developing Countries. South African Journal of Industrial Engineering, 30(3), 2247–2267. http://dx.doi.org/10.7166/30-3-2247

[14] Arifwidodo, S. D., & Chandrasiri, O. (2015). Urban heat island and household energy consumption in Bangkok, Thailand. Energy Procedia, 79, 189–194. https://doi.org/10.1016/j.egypro.2015.11.461

[15] Sharma, P., & Singh, S. (2015). Urban Heat Island: Causes, Effects and Mitigation Measures -A Review. International Journal of Environmental Monitoring and Analysis, 3(2), 67-73. https://doi.org/10.11648/j.ijema.20150302.15

[16] Chow, W. T. L., & Roth, M. (2006). Temporal dynamics of the urban heat island of Singapore. International Journal of Climatology, 26(15), 2243-2260. http://dx.doi.org/10.1002/joc.1364