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Design and Simulation-Based Evaluation of a Solar-Powered LoRa Mesh Network for Urban Heat Monitoring

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Abstract

In a real life two places in same city have a different temperature like Garden and parks have a lower temperature comparatively to areas of buildings, streets,offices , industries etc .Basically in same city area can have have a different temperature based on its environ mental conditions and various human activities like urbanization . Due these differences in tempera-ture variation , the problem arises where local sensors aren't useful to state the live temperature of different places precisely which causes Urban Heat Island Effect (UHI) like Tokyo in Japan ,London Heatwaves , Mumbai,Delhi in India has a majoraly affected by these . To resolve Ur-ban Heat Island Effect (UHI) Distributed Internet of Things (IoT) sensors can help to observe the live temperatures changes at local places.Along with those IOT integration we have LoRa mesh networking and solar energy harvesting as a tech nical approaches to become practical monitoring of temperature reliable communication, available energy, maintenance needs, and energy-efficient operations.This paper describes a Python-based simulation study of three con-figurations for urban heat monitoring : I)a solar-powered mesh network II) a mesh network without solar energy harvesting III) a solar-powered direct-communication network.

These configurations are compared at different sensor-node counts using the perfor mance metrics produced by the performing simulation . The results are based on the as sumptions used in the model for implementation and are not real-world readings or data from physical sensors, a deployed LoRa network, or on field implementation.

Keywords: UHI,Lora Mesh Networking ,Solar Energy ,IOT ,Python Simulation,urban heat monitoring ,wireless sensors ,Temperture

1. Introduction

The temperature in same city varies at a short distances ,for Example the parks feels slightly cold than a streets or two buildings in same society may have different temperatures because of their surface materials, height, sunlight appearance , and surrounding.These differences in local temperatures becomes important when we are studying urban heat and being in such a temperatures fluations which can impacts lives and biodiversity present their . However,getting measurements from a limited installed weather stations may not

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represent the temperatures of a all local areas .These local differences are important when sit becomes significant for UHI.AI Mode conversation: uhi urban heat island effect

The Urban Heat Island (UHI) effect is a natural phenomenon where urban local areas feels higher temperature then a nearby rural areas it can be 1˚C to 7˚C to nearby areas.which con-tributes to urban heat increment where lots of countries like Japan,India are facing UHI and heatwaves cause of UHI and rapid Urbanization .UHI becomes Significant to manage in terms of urban heat cause it effects worsens the frequency ,duration,occurrence ,and intensity of heat waves.

For these Internet of Things (IoT) network would becomes a one of the possible way to collect the temperature data from each and every local location /area rather than relying on a one common established weather station .Each node of sensor will record a temperature regarding data and sends it to a gateway for a further processing , storage and analysis .This network system will become usefull cause its not dependent of number of sensors connected to it and but also along with a wether the packets reach to the gateway takes how long to transmit and howmuch energy it consumed for it . Long Range Area (LoRa)communication will supports to communicates with system over a long distances depending on a radio settings and deployement conditions of it for a performance .

The study of python simulation compares a three configurations a solar-powered mesh net work, a mesh network without solar harvesting, and a solar-powered direct-communication network.The configurations are evaluated at 10, 20, 30, and 40 sensor nodes. The main aim of the evaluation is to examine how those configurations based metrics are produced by the designed model, and changes with the node count and with thw ways of communication.The simulation is a just a graphically ploted study of thosse defined configurations based on suitable assumptions not an intended to reproduce each behaviour of a deployed Loa network.

These study has a main three contibutions.Firstly ,it states that the performance metrics and configurations used in performed simulation.Secondly, it checks for the changes in results at different node counts and based on scenarios.Thirdly, it describes the limatation and what actual results mean in the reseach angle which includes the simplified treatment of radio connectivity and solar energy harvesting.

2. Related Work

2.1 LoRa and Low Power Communication

There has been research into using LoRa/LoRaWAN for low power communication. Current surveys have discussed the operation of LoRa and issues which should be considered when designing a system such as coverage, data rates and energy consumption [18, 20]. Commonly, LoRaWAN is deployed in a star-of-stars topology; however this can differ from a multi hop mesh topology. There has been reviews of the limitations of LoRaWAN and mesh based systems considering radio parameters, routing, topology and overhead [6, 15, 19].

2.2 Mesh Routing

Nodes within a mesh network can relay packets for one another if there is no direct route to the gateway. This can improve connectivity in certain topologies. However, relaying increases the amount of transmit/receive activity. Recent research has looked at energy aware routing and choosing topologies for the network [1, 2]. Previous work has also looked at LoRa scalability and hybrid Wireless Sensor Networks

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[13, 14, 21].

2.3 Energy Harvesting

Using solar energy can be used to top up the energy stored in a node. However this depends on several factors such as sunlight, shading, panel angle, conversion efficiency and energy loss. Research has been done on energy harvesting sensor systems and low power wireless systems [3, 8, 16].

2.4 Urban Heat Monitoring

The placement and number of sensors used will impact urban heat monitoring. Research has been carried out on sensor placement strategies and coverage of weather stations which has highlighted that it is important to capture local spatial variation [4, 5, 9]. Research has also been carried out on heat mitigation at a street level, environmental sensor data sets and urban data analysis systems [7, 10, 12, 17, 22].

2.5 Gap In Research

There has been research carried out on low power communication, mesh routing, energy har-vesting and urban heat monitoring. However, each of these are often looked at with different assumptions and aims. This paper looks at a small number of scenarios with one set of assump-tions using Python simulations.

3. System Model

3.1 Configurations

There are 3 configurations within the simulation:

1. Solar powered mesh: Nodes will be communicating using the mesh routing described in the model. They will receive the energy harvesting input defined.
2. Mesh: Nodes will be using the same general mesh setup without any energy harvesting.
3. Solar direct communication: Nodes will try to directly communicate with the gateway. They will receive the defined energy harvesting input.

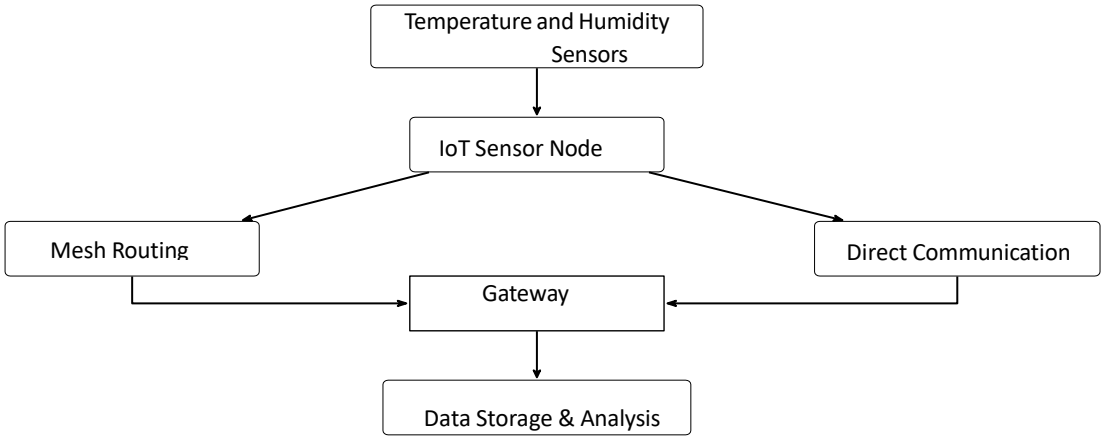


Figure 1: Conceptual network architecture.

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Table 1: Simulation Parameters

Parameter	Value
Number of Nodes	10, 20, 30, 40
Number of Runs	20
Time	24 Hours
Sense Interval	300 Seconds
Packet Size	24 Bytes
Area	1000 × 1000 m
Gateway Position	Centre of Field
Range	300 m
Energy Harvesting Input	2 J per node per hour

3.2 Network Architecture

3.3 Simulation Parameters

The simulation has looked at 10, 20, 30 and 40 sensor nodes. Each scenario and node count has been run 20 times. The area is 1000x1000m, the gateway is in the centre. The sense interval is 300 seconds and packet size is 24 bytes.

3.4 Performance Metrics

Packet Delivery Ratio (PDR):

$$PDR(\%) = \frac{N_{received}}{N_{Generated}} \times 100$$

Average End-toEnd Latency:

$$\bar{L} = \frac{1}{N_{\text{delivered}}} \sum_{i=1}^{N_{\text{delivered}}} (t_{rx,i} - t_{tx,i})$$

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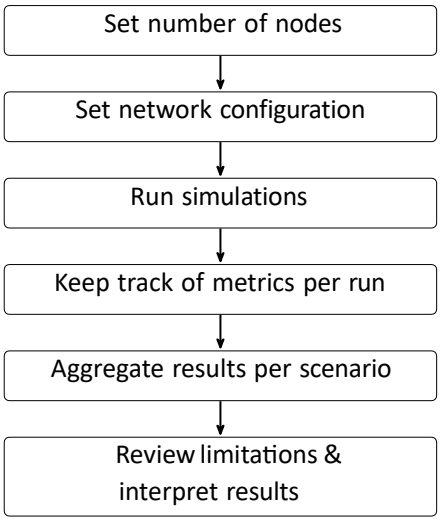


Figure 2: Evaluation process.

4. Simulation Process

A summary of the evaluation process can be seen in Figure 2. For each scenario and node amount simulations are run multiple times. Metrics are kept track of and aggregated.

5. Results & Discussion

All results were gained from running a Python simulation with the scenario summary output. They do not reflect actual sensor values from temperature, battery, or the LoRa network. The The simulation was run 240 times in total with 3 different configurations and 4 different quan-tities. of nodes and 20 simulations per configuration and quantity of nodes.

6. Packet Delivery Ratio

Mesh configurations all have identical values for the packet delivery ratio shown in the sce-nario summary. The average increases from 58.22% for 10 nodes up to 87.63% for 30 nodes. However, there then is a slight drop down to 86.07%. Solar-powered direct has a lower average PDR, ranging from 25.00% to 28.85%.

6.1 Average Latency

The average latency for mesh ranged between 54.11 ms and 67.64 ms. However, the average Latency for direct is lower, ranging between 33.25 ms and 35.00 ms.

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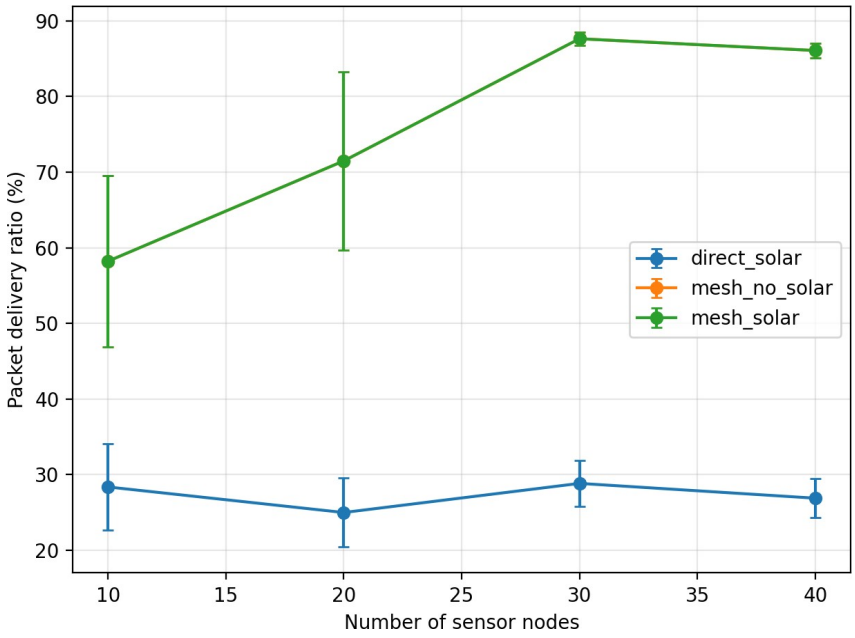


Figure 3: Packet Delivery Ratio against the number of sensor nodes.

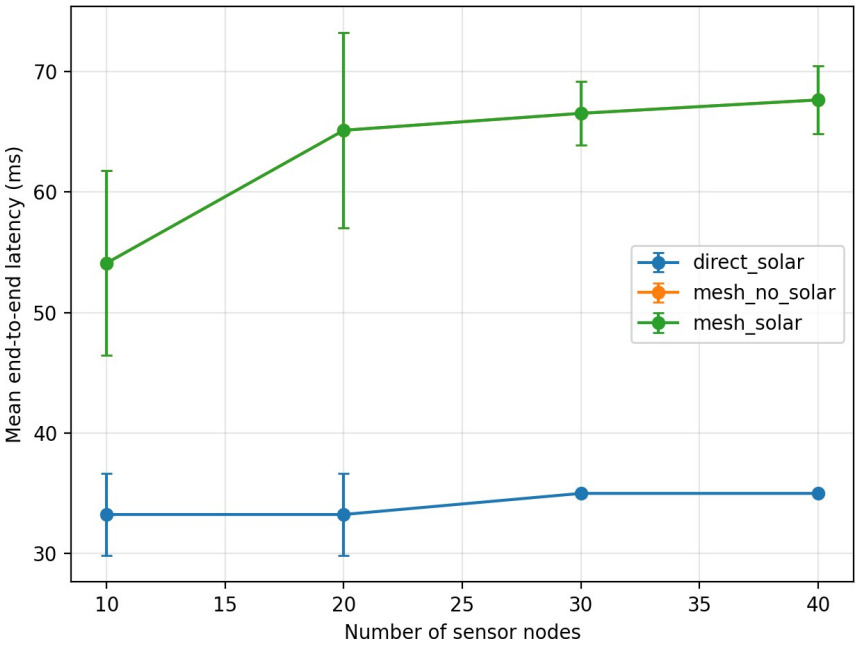


Figure 4: Average End-to-End Latency against Number of Sensor Nodes.

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6.2 Battery Depletion Proxy

Mesh without solar harvesting had an average battery depletion proxy of around 39.329 J to 40.186J. Mesh with solar had very low values ranging from 0.000J to 0.086J. Direct with solar had zero values.

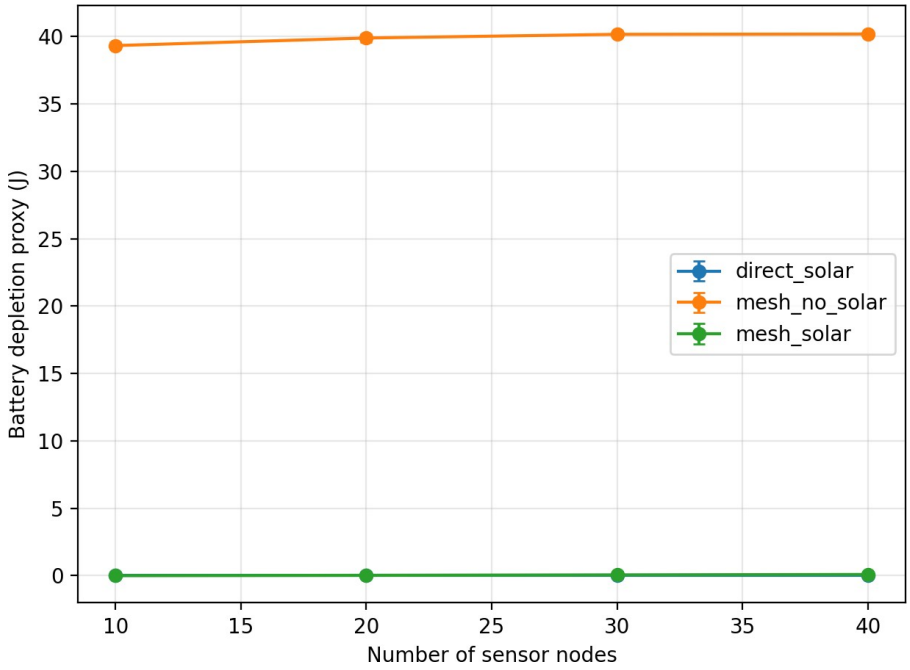


Figure 5: Battery Depletion Proxy against the number of sensor nodes.

6.3 First Node Depletion Time

All configurations had a depletion time of 24 hrs for the first node. This was due to the The simulation is only running for 24 hrs.

6.4 General Analysis

Overall it can be seen there is a trade-off in results between mesh and direct. Mesh had higher values for PDR but a higher average latency. The PDR increased between 10 and 30 nodes but then dropped slightly for 40 nodes.

7. Limitations and Validity

The results are limited by how accurate the simulation is. The communication radius has been set to a nominal value meaning the connection rule has been simplified and may not represent urban radio wave propagation. The solar harvesting input has been set as a constant, so this does not take into account day and night, shadows, weather, panel orientation and storage losses.

There are also a limited amount of random simulations. Without hardware testing we cannot prove how accurate the sensors are, how accurate they would be in the field and how accurately They can predict urban

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heat.

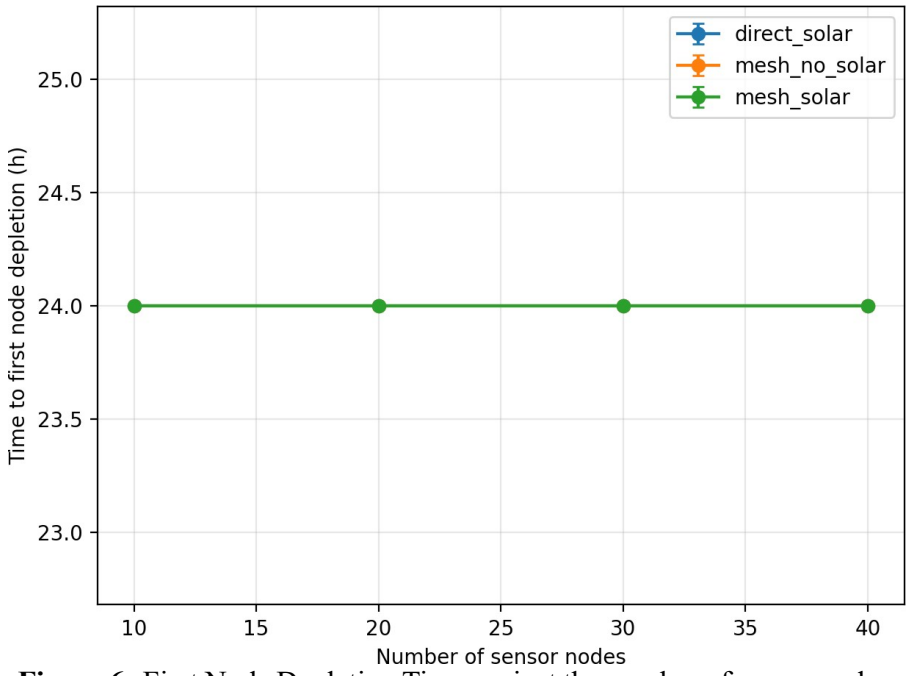


Figure 6: First Node Depletion Time against the number of sensor nodes.

8. Conclusion and Future Work

In this paper, Solar Powered Mesh, Mesh without Solar Harvesting and Solar Powered Direct Communication has been compared for urban heat monitoring through a Python simulation. The results should be analysed with consideration of the assumptions made.

In the future the energy model can be improved to include dynamic solar input, losses with conversion and storage, and consumption at the component level. The communication model can be improved to include relevant LoRa parameters, interference, collisions, re-transmissions and urban propagation. Finally, a prototype should be tested in the field with calibrated tem-perature and humidity sensors, known deployment sites and reference data.

References

[1] M. Tang, X. Li, and J. Shang, "Data-Driven Energy-Saving Methods Based on LoRa-Mesh Hierarchical Network," *Sensors*, 2026, doi: 10.3390/s26072226. Metadata should be verified before submission.

[2] M. Piechowiak et al., "Multi-Criteria Optimization Mechanisms for LoRa Network Topologies," *Electronics*, 2026, doi: 10.3390/electronics15091872. Metadata should be verified before submission.

[3] "Solar-Charged Supercapacitor Powering of Wireless Sensor Network Nodes for Environmental Monitoring," 2025, doi: 10.1155/dsn/4253030. Author list and publication meta-data require

BODHIVRUKSHA JOURNAL OF DIVERSE DISCIPLINE
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verification.
[4] P. Sakthivel and R. Sengupta, "Spatial bias in placement of citizen and conventional weather stations," *Urban Climate*, 2025, doi: 10.1016/j.uclim.2024.102280. Verify ex-act title and metadata.
[5] "Comparing Monitoring Networks to Assess Urban Heat Islands in Smart Cities," *Applied Sciences*, 2025, Art. no. 6100. Authors and DOI require verification.
[6] S. Fattah et al., "Multi-Hop and Mesh for LoRa Networks: Recent Advance-ments, Issues, and Recommended Applications," *ACM Computing Surveys*, 2024, doi: 10.1145/3638241.
[7] S. Jang, J. Bae, and Y. Kim, "Street-level urban heat island mitigation," *Sustainable Cities and Society*, 2024, doi: 10.1016/j.scs.2023.105007. Verify exact title and metadata.
[8] "Low-power wireless sensor design for LoRa-based distributed energy harvesting sys-tem," *Energy Reports*, 2023, doi: 10.1016/j.egyr.2023.08.056. Author list and exact title require verification.
[9] P. Pathak et al., "A Sensor Placement Strategy for Comprehensive Urban Heat Island Mon-itoring," *ISPRS International Journal of Geo-Information*, vol. 12, no. 1, Art. no. 11, 2023, doi: 10.3390/ijgi12010011.
[10] G. Visvanathan et al., "Sensor based dataset to assess the impact," *Data in Brief*, 2023, doi: 10.1016/j.dib.2023.109431. Full title and metadata require verification.
[11] "A Hierarchy-Based Energy-Efficient Routing Protocol for LoRa-Mesh Network," *IEEE Internet of Things Journal*, 2022, doi: 10.1109/JIOT.2022.3185619. Author list and meta-data require verification.
[12] "An integrated cyberGIS and machine learning framework," *Urban Informatics*, 2022, doi: 10.1007/s44212-022-00002-4. Full title and author list require verification.
[13] J. Bravo-Arrabal et al., "Development and Implementation of a Hybrid Wireless Sensor Network," *Sensors*, 2021, doi: 10.3390/s21020567. Verify exact title and metadata.
[14] P. J. Basford et al., "LoRaWAN for Smart City IoT Deployments: A Long Term Evalua-tion," *Sensors*, vol. 20, no. 3, Art. no. 648, 2020, doi: 10.3390/s20030648.
[15] J. R. Cotrim and J. H. Kleinschmidt, "LoRaWAN Mesh Networks: A Review and Classi-fication of Multihop Communication," *Sensors*, vol. 20, no. 15, Art. no. 4273, 2020, doi: 10.3390/s20154273.
[16] "Review of Energy Harvesting in LoRa Based Wireless Sensor Network," conference paper, 2020, doi: 10.1109/ICACCCN51052.2020.9362892. Author list and proceedings metadata require verification.
[17] N. Bebelaar et al., "Monitoring urban environmental phenomena through a wireless distributed sensor network," *Smart and Sustainable Built Environment*, 2018, doi: 10.1108/SASBE-10-2017-0046.
[18] U. Raza, P. Kulkarni, and M. Sooriyabandara, "Low Power Wide Area Networks: An Overview," *IEEE Communications Surveys & Tutorials*, vol. 19, no. 2, pp. 855–873, 2017, doi: 10.1109/COMST.2017.2652320.
[19] F. Adelantado et al., "Understanding the Limits of LoRaWAN," *IEEE Communications Magazine*, vol. 55, no. 9, pp. 34–40, 2017, doi: 10.1109/MCOM.2017.1600613.
[20] A. Augustin, J. Yi, T. Clausen, and W. M. Townsley, "A Study of LoRa: Long Range & Low Power Networks for the Internet of Things," *Sensors*, vol. 16, no. 9, Art. no. 1466, 2016, doi: 10.3390/s16091466.
[21] M. Bor et al., "Do LoRa Low-Power Wide-Area Networks Scale?" in *Proceedings of the ACM International Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems*, 2016, doi: 10.1145/2988287.2989163.
[22] T. R. Oke, "The energetic basis of the urban heat island," *Quarterly Journal of the Royal*

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Meteorological Society, vol. 108, no. 455, 1982, doi: 10.1002/qj.49710845502.