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**Principal Investigator:** Wenwen Cheng, the University of Oklahoma

**Project Title:**

A spatial decision support system for identifying heat vulnerability based on a comprehensive energy budget model and multi-criteria decision analysis in Oklahoma City, OK

Annual Report

August 30th, 2023

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# Table of Contents:

1. Project Summary
   1. Project Goals and Objectives
   2. Executive Summary of Project Progression
2. Activities & Outcomes
   1. Project Advancements
   2. Community Engagement Activities
   3. Calendar of Milestones Achieved
   4. ARL Reporting (*Data Integration Projects only*)
3. Inclusion Plan Reporting
   1. Metrics Tracked
   2. Progress Narrative
4. Budget
   1. Year’s Costing
   2. Adjustments Made (if needed)
5. Appendix
   1. Communications & Publications
   2. Miscellaneous

# Project Summary

## Project Goals & Objectives

With global warming, the average annual temperature in Oklahoma City is predicted to increase by 2.6°F -5.2°F by mid-century (2036 -2065) and exacerbate the effects of the existing urban heat island. Mitigating the effects of extreme heat is particularly listed as one of the planning goals in Oklahoma City’s first sustainability plan for 2020-2025 and its initiative for developing methods to measure, monitor, and report local urban heat island conditions.

Heat exposure is a severe public health concern as exposure to heat usually has adverse impacts on a population’s health outcomes. However, most previous heat exposure studies have focused only on meteorological-based metrics, which do not fully measure the physiological impact of heat stress on the human body. The Heat Vulnerability Index, as a combination of population *sensitivity, adaptive capacity,* and *exposure* to heat, has been used to describe heat vulnerability across the landscape and for different subgroups of the population. Traditional methods of HVI developed based on the “fit-for-all” principle do not allow individual types of the community’s (e.g., socially disadvantaged community) voice to be heard during the modeling process.

Although the National Aeronautics and Space Administration (NASA), among various agencies,

has provided high spatiotemporal climatic monitoring and forecasting research data, a data divide often precludes disadvantaged communities from accessing and utilizing these rich data products. There is also an urgent need to predict heat exposure levels to support sustainable planning and adaptive behavior for future scenarios. It is thus critical to provide a data pipeline that can integrate climatic data with socio-environmental data and translate those sources into heat vulnerability indices for risk communication on current and future conditions. Using Oklahoma City and selected disadvantaged communities as the testbed, the objective of this proposal is to:

1) Develop a weekly heat exposure index (HEI) by a human-environment energy budget model

using NASA-Unified Weather Research and Forecasting (NU-WRF) model simulation data as

inputs for heat exposure predictions.

2) Establish a heat vulnerability index (HVI) by considering socio-economic status, demographics, health, and environmental factors in addition to HEI.

3) Apply a collaborative spatial decision-making support tool through knowledge co-production with communities and multi-criteria decision-making (MCDM) analysis, to provide underserved community-driven HVI that heat-related policy-making process.

## Executive Summary or Project Progression

The project comprises five research team members from the University of Oklahoma and Texas A&M University (PI Cheng, Co-PI Cai, Li, Yang and Zhang), seven collaborators from the City of OKC (T.O. Bowman and Sarah Terry co-bo), OKC Beautiful (Natalie Evans), Neighborhood Alliance of Central Oklahoma (Georgie Rasco), Institute for Quality Communities (Shane Hampton), John F. Kennedy Neighborhood, Ross Heights Neighborhood and Northeast OKC (Denyvetta Davis and Wallace Johnson), and two international graduate student assistants (Sagar Singh and Anvesh Vanga).

PI Cheng oversees and manages the project and instructs graduate students on how to complete the project according to the planned timetable.

*Objective 1:Heat Exposure Index development and publication*

* September 2022- December 2022: Dr. Cheng and Dr. Cai oversaw HPC access and lab setup requirements, while they also coordinated the advertising efforts for GRA recruitment.
* January 2023- April 2023: Dr. Cai and Sagar worked on NU-WRF setup and domain simulation. HEI input data include 1) climatic data (2-meter air temperature, relative humidity, 2-meter wind speed, direct solar radiation, and the land surface temperature); 2) human physical and physiological data (metabolic rate and clothing resistance), and 3) ground albedo. Hourly predicted climatic data with a spatial resolution of 1km from 11 am – 4 pm for each day in the following week were obtained by NU-WRF. The NU-WRF model was used over the entire continental North America, nesting to the Southern Great Plains (SGP) area with a finer resolution, and further nesting to Oklahoma City with the finest resolution.
* May 2023 – August 2023: Dr. Cai and Anvesh worked on coupling NU-WRF results into the COMFA model and users’ interface development. The hourly predicted climatic data with a spatial resolution of 1km x 1km from 11 am – 4 pm for each day in the following week, together with metabolic rate and clothing resistance were put into the COMFA model. Six energy budget values (EB, W/m2) for each day will be calculated (11 am – 4 pm) while the maximum EB will be the output for daily maximum HEI. The EB was categorized into four categories: Safe (EB < 120 W/m2), Caution (121 W/m2 <EB< 200 W/m2), Dangerous (201 W/m2 < EB < 340 W/m2), and Extremely Dangerous (EB >340 W/m2).

*Objective 2:Heat Vulnerability Index development and publication*

* September 2022- December 2022: Cheng and Co-PI Yang were responsible for socioeconomic, demographic, health, and environmental data collection and the COMFA model calculation. Human vulnerability to heat stress and its impacts can be conceptualized as a combination of *sensitivity, exposure*, and *adaptive capacity*. *Sensitivity* refers to the internal characteristics of the population causing vulnerability or susceptibility to increased heat exposure, including socioeconomic and demographic factors such as age, income, employment, etc., and health conditions such as disability and specific illness. In our study, a total of 14 indicators will be included for *Sensitivity*. *Adaptive capacity* is the ability to actively adjust to increased heat exposure, usually referring to the accessibility of amenities/facilities that mitigate heat exposure, such as access to communication technologies and cooling facilities. A total of 7 indicators will be used. For *exposure*, we used the historical climatic data of the hottest day during a calendar year from GRID met and DAY met.
* January 2023- April 2023: Cheng, Yang and Co-PI Li finished HVI development in April 2023. All indicators will be prepared at the census-tract level, using geographic crosswalks. The HVI will be created using equal weights. Values were classified into six HVI categories based on the standard deviation (SD) of the yielded data: “very high” (>2SD), “high” (1–2SD), “high normal” (0–1SD), “low normal” (−1–0SD), “low” (−2–1SD), and “very low” (<−2SD).
* May 2023 – August 2023: Through communication with the City of OKC, OKC HVI 2015-2020 was published on the Open Data Portal ([Heat Vulnerability Index (arcgis.com)](https://okc.maps.arcgis.com/apps/mapviewer/index.html?webmap=98a49bfc5bba4f3dac9879c018bb022c).

*Objective 3: Community-driven HVI through MCDM and community engagement*

* November 2022- April 2023: Co-PIs Zhang instructed one graduate student from the Department of Geography at Texas A&M University (TAMU) to develop Jupyter Notebook-based MCDM tools. The interface of MCDM was developed and tested among researchers.
* February 2023 – April 2023: Meetings with the City of OKC and the Institute of Quality Community were conducted in February, March, and April about their concerns from the decision-making point when heat events come.
* May 2023 – August 2023: A combination of factors relating to heat vulnerability from researchers and decision-makers was used to develop the HVIs for OKC. Based on our analysis, twenty census tracts are under high heat vulnerability. After meeting with the City of OKC, a public workshop in the John F. Kennedy neighborhood was successfully held on July 8th, at the Auditorium at the Douglass, OKC. Attendees include the representatives from the City of OKC (T.O. Bowman), the Association of Central Oklahoma Governance (Eric Pollard), OKC Beautiful (Natalie Evans), South Central Climate Adaption Science Center (Dolly Na-Yemeh), and OKC residents.

We presented our workshop results on the Northeast OKC Neighborhood Coalition meeting on July 14th. Meetings with the representatives of Ross Heights were conducted for the preparation of our next workshop on September 5th at Northeast OKC Renaissance Inc.

* Future community engagement: A series of meetings were conducted for future community engagement workshops, including meetings with:
  + Amanda Marcott- Thottunkal, Director of Energy and Empowerment Programs, Community Development Services
  + Tracy Prather, Director of Oklahoma Area Tribal Epidemiology Center
  + Cassandra Querdibitty, Tribal Epidemiology Center Core Program Manager at Southern Plains Tribal Health Board

# Activities & Outcomes

## Project Advancements

This project was originally planned to be carried out over a period of 18 months, starting in Autumn 2022 to Spring 2024. We followed our original plan and finished most of the accomplishments.

2015– 2020 OKC HVI were published on the City of OKC open data portal [Heat Vulnerability Index (arcgis.com)](https://okc.maps.arcgis.com/apps/mapviewer/index.html?webmap=98a49bfc5bba4f3dac9879c018bb022c).

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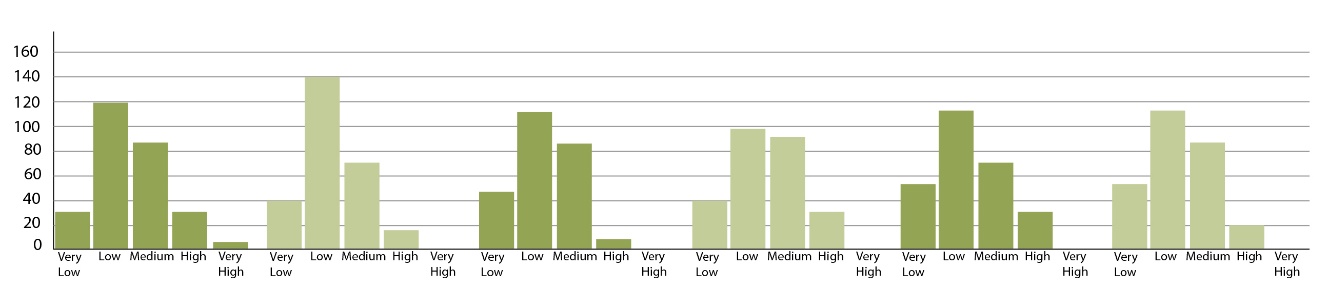
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Figure 1. OKC HVI 2015-2020.

Among 270 census tracts in OKC, Most census tracts are in the low-medium level of heat vulnerability (>80%) from 2015-2020. 15 census tracts are in a high level of heat vulnerability from 2015 – 2020. Most of the census tracts are in middle-south OKC, along Oklahoma River (NW 10TH ST to SW 59TH ST). There are no significant differences (p=0.06) in heat vulnerability in the census tract level from 2015-2020.



2015

2016

2017

2018

2019

2020

Figure 2. HVI level 2015-2020.

The multi-criteria analysis offers a rich collection of decision techniques for structuring problems that contain conflicting objectives and enabling the prioritization of decision alternatives and sensitivity analyses. MCDM analysis is a mathematical decision-making framework where many decision criteria are combined to meet one or several objectives to support decision-making. Given a set of alternatives, denoted as A1, A2, A3, … , A𝑚, and a set of n decision criteria denoted as C1, C2, C3, … , C𝑛, it is assumed that the decision-maker has to determine the performance value a𝑖𝑗 (for i = 1, 2, 3, …, m and j = 1, 2, 3, …, n ) of each alternative for each criterion. Figure 3 illustrates the TOPSIS MCDM decision support tool: the left side is the weighting slider to assign weights to the criteria that are relevant to the decision

goals. In our MCDM model, we will use the Simple Multi-Attribute Rating Techniques (SMART), where an important criterion is assigned importance of 100 points and the next-most-important criteria are assigned a number of points that reflect the ratio of their relative importance to the most important dimension.

A map of the state of oklahoma

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Figure 3. Oklahoma HVI Multi-criteria Decision Making platform

## Community Engagement Activities

Community engagement activities were conducted throughout the whole process of our project. Prior to the HVI development, meetings with the City of OKC and the Institution of Quality Community were conducted to introduce our project, to see community needs, and how our project can help both decision-makers and communities for policy-making and deployment (Figure 4 and 5).

A group of people standing on a sidewalk

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|  |  |
| --- | --- |
| Figure 5. Research Group visit Cleveland elementary school for tree planting by OKC Beautiful | Figure 6. Online meetings with the City of OKC, AARP, Neighborhood Alliance of Central Oklahoma, South Central Climate Adaptation Science Center, and OKC Beautiful. |

After we identified the high-risk area, we started to contact historically underserved communities. John F. Kennedy neighborhood is one of them. After communicating several rounds with their president, Denyvetta Davis, we attended one of their neighborhood meetings on June 10th 2023, to learn about their concerns in heat events (Figure 7).

The residents expressed their worries about the increasingly hot summers and the lack of effective measures to mitigate the heat in their community. They shared stories of discomfort, health issues, and energy bills skyrocketing due to excessive heat. This engagement with the neighborhood has made it abundantly clear that addressing heat-related challenges is a top priority. Armed with this knowledge, we are committed to working together to explore innovative solutions, such as improved insulation, tree planting initiatives, and community cooling centers, to enhance the livability and well-being of our neighborhood during hot weather A group of people posing for a photo

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Figure 7(a). Dr. Anni Yang is presenting our research to JFK neighborhood in residents meeting. (b). JFK neighborhood in residents meeting. (c). Left to right: Hongwan Li (OU), Changjie Cai (OU), Chenghao Wang (OU), Carrie Leslie (OU), Denyvetta Davis (JFK), Tiffany Legg (OU), Anni Yang (OU)

A group of people standing in a room

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Description automatically generatedOklahoma City has been selected as the heat mapping campaign city by NOAA this year. After meeting with the City’s Sustainability Department, we decided to hold two workshops together. We collaborated on contacting with neighborhoods connection, multi-stake holders and researchers meeting, as well as agenda and details about workshop. We aim to establish effective communication channels with neighborhoods, connect with multi-stakeholder groups, and facilitate meaningful interactions between researchers and local communities.

Figure 8(a). Dr. Wenwen Cheng is presenting our study in JFK neighborhood workshop. (b). Left to right: Yuhang Xie (TAMU), Changjie Cai (OUHSC), Anni Yang (OU), Hongwan Li (OUHSC), Dolly Na-Yemeh (SCCASC), T.O. Bowman (City of OKC), Wenwen Cheng (OU), Eric Pollard (ACOG) and Shu Sun (OU).

On July 8th 2023, we hold a JFK neighborhood at the Auditorium at the Douglass, OKC. After we introduced our results, we asked the residents to discuss “Is there any other factor(s) that you think are important but not listed?”; “Please circle the hottest place on the maps of JFK or OKC”; and “What facilities/spaces do you think your community is missing in mitigating heat? For example, trees, water splash pad, community garden, walking path, etc.”. The results from the residents showed that air pollution and trees are the two factors that they concern the most during heat. Pool and community gardens are the most mentioned facilities by residents from JFK neighborhood (Figure 9).

A white board with sticky notes on it

Description automatically generated A person holding a poster with post-it notes

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Figure 9. Discussion boards in workshop: “Is there any other factor(s) that you think are important but not listed?”; and “What facilities/spaces do you think your community is missing in mitigating heat? For example, trees, water splash pad, community garden, walking path, etc.”.

Another workshop focusing on the Ross Heights neighborhood will be conducted on September 5th, 2023. After these workshops, we will generate JFK-based and Ross Heights-based HVI for the City of OKC to publish.

In fall 2023, a studio class focusing on JFK neighborhood design is undergoing at the Division of Planning, Landscape Architecture and Design in the College of Architecture at OU. Through data collection in JFK, students made site analysis (Figure 10) and will do evidence-based neighborhood design for the JFK neighborhood.

A map of neighborhood heat map

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Figure 10. JFK neighborhood heat map by Natalie Young (OU student)

## Calendar of Milestones Achieved

The updated schedule, milestones, and events planned are explained below:

Phase 1: September 2022- April 2023

Milestones accomplished:

• April, 2023 - OKC HVIs (2015-2020) have been developed.

• March, 2023 - A community-driven MCDM decision support tool has been developed.

Events hold:

• Conference presentation:

o December, 2022 - AGU 2022, “A Heat Vulnerability Index based on a comprehensive energy budget model in Oklahoma City, OK”. Chicago, IL.

o March, 2023 - CELA 2023, “Development of a heat vulnerability index for Oklahoma City, OK”. San Antonio, TX.

• Presentation:

o March, 2023 - Mr. T.O. Bowman, the director of department of sustainability development, City of OKC, presented our results to his event meeting: OKC Urban Heat Island Mapping Campaign

• Meeting agenda

o February, 2023 - Meeting with Institution of Quality Community: discuss 1) HVI factor selections and other possible factors 2) possible communities that can be collaborators, 3) workshop agenda and flow

o March and April, 2023 - Meeting with the City of OKC: discuss 1) HVI factor selections and other possible factors 2) possible communities that can be collaborators, 3) present HVI for the City and publishing process 4) workshop agenda

o April, 2023 - Meeting with OKC Beautiful: 1) discuss about how our project results can help them identify vulnerable communities

o March, 2023 - Meeting with Neighborhood Alliance of Central Oklahoma: 1) possible communities that can be collaborators, 2) workshop agenda and workflow

Phase 2: May 2022- September 2023

Milestones:

• July, 2023 - OKC HVIs publishing Heat Vulnerability Index (arcgis.com).

• August, 2023 - OKC HEI development.

• July – August, 2023 - OKC vulnerable communities workshops.

Events:

• Presentation

June 10th: Mr. T.O. Bowman, the director of the department of sustainability development, City of OKC, will present our results to the City Council.

• Meeting agenda

o May, 2023 - Meeting with the City of OKC: 1) Working with IT from the City in publishing online GIS. 2) Collaborating on connecting neighborhood leaders.

o May, 2023 - Meeting with OKC Beautiful: 1) Introduce our project 2) invite OKC Beautiful to the community workshops

o June, 2023 - Meeting with John F. Kennedy Neighborhood: workshop preparation

• Community Workshops

o We conducted a workshop with JFK neighborhood in OKC. Three major parts were conducted during the workshop: a. introduction (background of the project and questions for discussion) b. “Protect Yourself From Heat” (lectures on how to protect your self during heat event and how research and the City can help you) c. “Tell Us Your Thoughts”(discussion from residents about their concerned factors during heat)

*Upcoming milestones and events:*

Phase 3: October- December 2023

The results from our community workshops will be used to generate community-driven HVIs.

Milestones:

• November, 2023 - Community driven HVIs from four communities

• December, 2023 - Publishing our results to the City of OKC

Events:

• December, 2023 - Meeting with our collaborators and present our results

Phase 4: January – August 2024

PI Cheng will act as guest lecture and guest reviewer and will work with the instructor of Landscape Architecture Studio IV (LA5545), Dr. Sarah Little at the University of Oklahoma to teach students community design in spring 2024. Two co-design workshops will be held in March (mid-term) and May (final presentation). Students will ask residents to mark their most concerned community space, their most needed space, and their least used space. Based on residents’ responses, students will conduct community design. The final project from the class will be presented in the community, as well as application materials for community place making grants applications. Two publications will also be prepared during summer 2024.

Milestones:

• May, 2024 - Community co-design by residents and students

• August, 2024 - Publishing two papers relating to 1) OKC heat vulnerability development and assessment 2) community-driven HVI development and assessment

Events:

• March (midterm), 2024 – community conceptual design

• May (final), 2024 – community design final presentation

# Inclusion Plan Narrative

## Metrics Tracked

|  |  |  |
| --- | --- | --- |
| Working environment | Student hiring | Community Outreach |
| * Promoting open communication channels * Providing equal opportunities * DEI training * Highlight socioeconomic drivers of heat vulnerability | * DEI training * Involve minority students as graduate student assistants | * Develop strong partnerships with community advocacy groups * Design activities that fit participants with various backgrounds |

## Progress Narrative

Diversity, equity, and inclusion (DEI) are important to the process and outcome of our project. This inclusion plan outlines our DEI goal and strategies for implementation. The main goal is to create and maintain an inclusive project environment that embraces diversity, engages researchers, students, partners, and community stakeholders with empathy and transparency, and promotes equitable research processes and outcomes.

* Creating and Sustaining a Positive and Inclusive Working Environment:

The primary goal of our inclusion plan is to establish and maintain a positive and inclusive working environment for the project team, community partners, and broader communities engaged in our work. We aim to foster a culture of respect, collaboration, and diversity that embraces different perspectives and values the contributions of all individuals. To achieve these goals, our activities will include:

a. Promoting open communication channels: We will encourage transparent and respectful communication within the project team and with community partners. We will create opportunities for everyone to share their ideas, concerns, and feedback openly.

b. Providing equal opportunities: We will ensure that all team members and community partners have equal access to resources, information, and opportunities for growth and development. We will strive to eliminate any barriers that could hinder equitable participation.

c. DEI training: All PIs completed DEI training to increase knowledge and competence in DEI.

d. Involve minority students as graduate student assistants and in the proposed service-learning activities. Eliminate barriers faced by traditionally underrepresented faculty members and students to opportunities and networks associated with this project.

* Community outreach working environment

As our project has strong community engagement components, we seek to have a positive impact on the vulnerable populations that we serve, train them to stand up for themselves and other disadvantaged groups, and utilize scientific data and tools to advance their missions. We achieve this goal by the following activities:

a. Develop strong partnerships with community advocacy groups that are focused on diversity and inclusion. Our PIs attended several neighborhood meetings to touch base with the communities.

b. Highlight socioeconomic drivers of heat vulnerability in our collaborative decision-making system through understanding the concerns from underrepresented groups.

c. During committee meetings, design activities that fit participants with various backgrounds and promote information exchange and positive community building in diverse small groups. Our workshop materials will be explained to residents. All the spaces that we selected for the workshop meet ADA requirements for access.

d. Train the vulnerable and at-risk members of the community to advocate for themselves.

* Addressing Barriers to Creating a Positive and Inclusive Working Environment:

We recognize that certain barriers may hinder the creation of a positive and inclusive working environment. These barriers can include unconscious biases, which may influence perceptions, judgments, and interactions among team members and community partners, as well as limited awareness and understanding of different cultures, backgrounds, and identities can lead to misunderstandings, exclusion, and inequitable treatment. To work against these barriers and create a sustainable environment, the project team conducted meetings with neighborhood leaders, the City of Oklahoma City, and other NGOs to make sure that we understand the cultural background and social needs of the communities. Also, we make sure that our workshop will be clearly explained to our participants so that they have enough understanding to make decisions.

* Metrics and Assessment of Success:

We regularly gather feedback from team members and community partners through open discussions to assess the inclusiveness of the working environment. Our final delivery products are presented through various channels (social media, webinar, workshop, lectures) to benefit minority communities and minority-serving organizations.

# Budget Narrative

## Year’s Costing

• Senior Personnel (Salaries)

The Principal Investigator, Dr. Cheng, provided management of the project and active participation at a projected effort of 100% for 1.5 summer months. Co-PI Dr. Yang was responsible for data collection and indices publishing with the effort of 100% for 0.5 summer months. Co-PI Dr. Cai worked on data collection and indices construction with the effort of 100% for 0.5 summer months. Co-PI Dr. Li was responsible for indices construction with the effort of 100% for 0.5 summer months. Co-PI Dr. Zhang was responsible for MCDM tool development and working with the community with the effort of 100% for 0.5 summer months.

• Other Personnel

Two graduate research assistants (50% FTE for 6 months) from the University of Oklahoma assisted Dr. Cheng and Dr Cai in data collection and preparation. A graduate research assistant (50% FTE for 6 months) from Texas A&M University is requested to assist Dr. Zhang.

• Travel

Domestic travel:

We budget conference presentations for 2 persons (PI Dr. Cheng and Co-Pi Dr. Yang) from the University of Oklahoma. $1,900 for AGU and CELA.

We budget $1750 for conference presentations for 2 persons (PI Co-Pis Li and Zhang) from Texas A&M University.

• Community workshops:

* July 8th, JFK workshop:

Auditorium rental fee: $1,925.95

Printing fee: $117.51

Lunch: $939.55

Materials (pens, notebooks, markers, and sticky notes): $147.33 + $23.52

Consulting fee: $200 (Denyvetta Davis, JFK neighborhood leader)

Total: $3353.86

**Upcoming events:**

* September 5th, Ross Heights workshop:

Place rental fee: $1,000

Dinner: $1,000

Consulting fee: $200 (Wallace Johanson, Ross Heights leader)

* Workshop/studio in the fall 2023:

• Shuttle rental = $360 x4 = $1,440; Lunch = $15 per person x 10 persons x 4 trips = $600; Booklet printing fee: $500

# Appendix

## Communications: Publications

Our project has been reported by:

Oklahoman

[https://www.oklahoman.com/story/news/local/oklahoma-city/2023/08/17/okc-weather-heat-mapping-extreme-temperatures-how-it-works/70546725007/](https://urldefense.com/v3/__https:/www.oklahoman.com/story/news/local/oklahoma-city/2023/08/17/okc-weather-heat-mapping-extreme-temperatures-how-it-works/70546725007/__;!!GNU8KkXDZlD12Q!5pjc6SBc3OIZgvZLQCG_-L9_HGIRoUJ5svawaRt7t7HWIFvQx_1aT12Ak0bvtUeLCTyuDfIFDeu2cTR8tA$)

Norman Transcript

[OU researchers receive grant to study heat islands in Oklahoma City | News | normantranscript.com](https://www.normantranscript.com/news/ou-researchers-receive-grant-to-study-heat-islands-in-oklahoma-city/article_9d83c906-30b2-11ee-a6ab-eb10dfe4b304.html)

The City of OKC

<https://www.okc.gov/Home/Components/News/News/4498/18>

OU VPRP

[University of Oklahoma Researchers Studying Extreme Heat (ou.edu)](https://www.ou.edu/research-norman/news-events/2023/ou-researchers-studying-extreme-heat)