Surface Materials and Temperature Change: How Does the Type of Surface Material Covering a Specific Location Affect Heating and Cooling Rates at That Location?

Introduction
Inner cities and suburbs tend to be much warmer than rural areas as a result of land use and human activities. Scientists call this phenomenon the urban heat island effect. Take Atlanta, Georgia, as an example. The figure below shows two satellite images of Atlanta taken on September 28, 2000. Image A is a true-color picture of Atlanta, where trees and other vegetation are dark green and roads or buildings are different shades of gray. Image B, in contrast, is a map of land surface temperature. In image B, cooler temperatures are yellow and hotter temperatures are red. Downtown Atlanta is in the center of both images. On this day in 2000, the temperature in the areas in and around downtown Atlanta reached 30°C (86°F), while some of the less densely developed areas outside of the city only reached 20°C (68°F). Las Vegas, Nevada, also experiences a significant urban heat island effect. On hot summer days, it can be 13°C (24°F) warmer in downtown Las Vegas than it is in the surrounding desert. Downtown Las Vegas also has, on average, 22 more days that are above 32°C (90°F) each year when compared with the surrounding rural areas. Most major cities in the United States, including Dallas, Phoenix, New York, Los Angeles, Denver, and Washington, D.C., experience a significant urban heat island effect.

Two Landsat satellite images of Atlanta: (a) a true-color picture of the city and (b) an image showing the differences in temperature for the city and areas around the city in the afternoon

In our everyday conversations, we often use the terms temperature and heat interchangeably. In science, however, these two terms have different meanings. Temperature is used to describe the average kinetic energy of the atoms or molecules that make up an object. Heat, on the other hand, is the transfer of thermal energy into, within, or out of an object. There are three ways thermal energy can transfer into, within, or out of an object: conduction, convection, and radiation.

- **Conduction** is the transfer of thermal energy due to the collision of the molecules within an object or between two objects in contact. Thermal energy always transfers from an object or area of higher temperature to an object or area of lower temperature.

- **Convection** is the transfer of thermal energy due to the mass movement or circulation of particles within a fluid. Fluids are liquids (like lakes or oceans) and gases (such as air).

- **Radiation** is the transfer of thermal energy through electromagnetic waves. An example of radiation is what happens to a car when it sits in the sunlight on a hot summer day. The car absorbs sunlight, and the temperature of the car increases. As more sunlight is absorbed over time, the temperature of the car increases as well.
When thermal energy transfers into an object, the temperature of the object will increase; when heat transfers out of an object, the temperature will decrease. However, not all objects will undergo the same change in temperature when the same amount of thermal energy is added to them. For example, adding 1 joule (J) of thermal energy to a 1-kilogram (kg) sample of lead will cause the piece of lead to increase in temperature by about 8°C. Adding 1 J of thermal energy to a 1 kg sample of water, however, will only increase the temperature of the water by approximately 0.2°C.

There are many potential explanations for the urban heat island effect. First, cities have more people living in them. Some scientists have therefore speculated that a higher concentration of people using air conditioners may be causing the urban heat island effect because air conditioners remove heat from the air in buildings and transfer it outside. Other scientists have suggested that car exhaust is causing the urban heat island effect because the gases in exhaust can trap thermal energy, and there are many more cars in cities than there are in rural areas. Finally, other scientists suggest that the materials we use to build roads, homes, and other buildings are the source of the urban heat island effect. Scientists studying this possibility note that in cities that experience an urban heat island effect, there tends to be a much higher concentration of concrete inside the city when compared with the area surrounding the city, which tends to be covered by naturally occurring materials such as plants, sand, or water.

Your Task
Use what you know about heat and temperature, cause-and-effect relationships, and stability and change in systems to plan and carry out an investigation that will allow you to determine the relationship between the materials covering an area and the rate at which the temperature of that area changes over time. This investigation will aid you in understanding the underlying cause of urban heat islands.

The guiding question of this investigation is: **How does the type of surface material covering a specific location affect heating and cooling rates at that location?**

Materials
You may use any of the following materials during your investigation:

- Water
- Soil
- Dark sand
- Light sand
- Concrete
- Sod
- Styrofoam cups
- Balance
- Heat lamp
- Thermometers
- Laser thermometer (optional)
- Graduated cylinder
- Support stand
- Ruler

Getting Started
To answer the guiding question, you will need to design and carry out an experiment. The figure to the right shows how you can use a heat lamp to warm different types of materials, such as soil, water, sand, concrete, or sod (grass).

Before you begin to design your experiment using this equipment, think about what type of data you need to collect, how you will collect the data, and how you will analyze the data.
To determine what type of data you need to collect, think about the following questions:
● What are the components of the system you are studying?
● Which factor(s) might control the rate of change in this system?
● How will you measure how quickly the materials heat up (or rate of change)?
● How will you measure how quickly the materials cool down (or rate of change)?

To determine how you will collect the data, think about the following questions:
● What conditions need to be satisfied to establish a cause-and-effect relationship?
● What will serve as your independent variable and dependent variables?
● How will you vary the independent variable while holding the other variables constant?
● How will you make sure the amount of each material is the same?
● How will you make sure that your data are of high quality (i.e., how will you reduce error)?
● How will you keep track of and organize the data you collect?

To determine how you will analyze the data, think about the following questions:
● What type of calculations will you need to make?
● How could you use mathematics to document a difference between conditions?
● What type of table or graph could you create to help make sense of your data?
● How will you determine if rates of change are the same or different?

Report
Once you have completed your research, you will need to prepare an investigation report that consists of four sections (be sure to have section headings):
1. Introduction: Give some background information on the topic. Explain what question you were trying to answer and include a hypothesis. (Background info, research question and hypothesis)
2. Procedure: What did you do during your investigation and why did you conduct your investigation in this way? (How you collected and analyzed data)
3. Data: Include a data table and/or graph to show your results. Be sure to include a title for your table or graph with labels for the variables.
4. Conclusion: What is your argument? (Claim - Evidence - Reasoning)

Your report should answer these questions in two pages or less. The report must be typed, and any diagrams, figures, or tables should be embedded into the document. Type your report on Google Docs (12 point font, double-spaced) and share it with your teacher. Your report will be graded based on the rubric in the class syllabus.