Document ID: 08_03_15_1
Date Received: 2015-08-03 **Date Revised:** 2015-11-09 **Date Accepted:** 2015-11-20
Curriculum Topic Benchmarks: M4.2.3, M6.2.2, M6.2.5, M6.2.8, S1.2.1, S1.2.6, S14.2.1, S15.2.4, S15.2.5
Grade Level: Upper Elementary (3-5)
Subject Keywords environment, Hands-on, Measurement, Urban Heat Island, thermometer, heat

What makes cities hot?
An urban heat island activity

By: Anna Scott, Johns Hopkins University. email: ascott47@jhu.edu

From: The PUMAS Collection http://pumas.nasa.gov

Overview

The primary source of heat on Earth is the Sun. When sunlight reaches the Earth's atmosphere, most of it passes through the air and warms the surface. The surface then radiates energy back into the air, causing the atmosphere to heat up. How warm the surface becomes depends on the material that the surface is made of-–this is why standing barefoot in a parking lot is uncomfortable in the summertime but walking on the grass in a park is tolerable. This is also why cities and urbanized areas are generally hotter than rural areas, a phenomenon that scientists call the urban heat island effect. We can explore these ideas by testing the temperatures of different locations and materials outdoors (or indoors, using a lamp with a tungsten bulb instead of the sun for a heat source) using thermometers.

Objective: Students will understand that heat is transmitted from the sun, the difference between surface and air temperature and the relationship between surface and building materials and temperature.

Materials: You will need thermometers (consider paper thermometers*) and a variety of solid materials: aluminum foil, sand, black construction paper, white

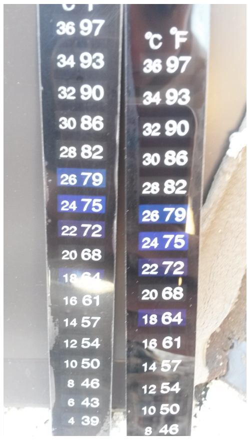

Figure 2 Liquid crystal thermometers indicating the temperature is between 75 and 79 degrees.

construction paper, soil, and two green sponges (sod, moss, or potted wheatgrass or grass would be a great substitute if available).

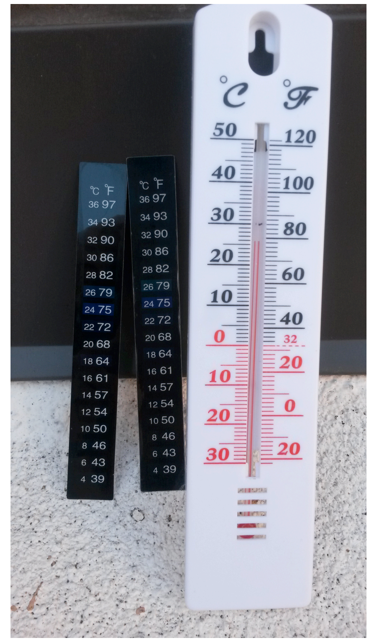

Figure 1 Liquid crystal paper thermometers next to a traditional alcohol thermometer.

Optional: heat sensitive paper or liquid crystal paper. Additionally, students should have pencils and paper, and the teacher should have a blackboard/whiteboard or notepad or large piece of paper to compute results. If there isn't enough sun outside, then substitute a lamp with a heat bulb or any non-LED and non-fluorescent bulb.

*A note on paper thermometers: paper liquid crystal thermometers take quantitative temperature measurements with a fairly large range of uncertainty, but are inexpensive, contain no breakable parts, and allow the measurement of surfaces as well as air. They contain strips of liquid crystals that are sensitive to different temperatures, and change color to indicate that the current temperature is within a given range. For a more thorough explanation, see: http://www.sisweb.com/art/pdf/liquid-crystal-thermometer-strip-product-info.pdf . Paper thermometers can be found at a local beer-brewing store for around $2-3 per thermometer as well as on the internet (for example, http://www.amazon.com/Exo-Terra-Liquid-Crystal-Thermometer/dp/B00026Z4PS). A sensitivity of 2 degrees Celsius (3-4 degrees Fahrenheit) is sufficient for the exercise if done during sunny conditions or if using a lamp.

Setup

Lay out the different materials in the light. Slightly moisten one of the sponges. Place thermometers on top of each material, as well as a thermometer above the material that is reading air temperature.

Figure 3: Sample setup.

Activity

Show the students the setup, explain how to read a thermometer, and ask them to read off the temperatures. Demonstrate the difference between the temperature taken in the air, and the temperature taken of a hot object. See if the demonstration thermometers are getting similar measurements, and if not, discuss. If thermometers have Fahrenheit and Celsius scales, ask them to read off both and translate between them.

Once students are familiar with the thermometers, ask them to identify the hottest and coolest objects. After a brief discussion (see Discussion section), give the students thermometers, and a pencil and paper. Ask students to record the hottest and coolest air temperatures around the site. If you are outside, let students explore beyond the demonstration materials and ask them to find the hottest and coolest materials around the site, recording their temperatures and locations.

Students should notice that sunny areas are hotter than shaded ones, concrete and brick tend to be hotter than grassy areas, and that unobstructed walls facing the sun are hotter. (Often–but not always – in the Northern Hemisphere, the warmer walls are likely to be south-facing.)

Note: this activity works particularly well if the site includes a concrete sidewalk as well as vegetation and walls or any variety of land covers and materials, so students can focus on measuring the different objects available. If not, then focus may be directed toward how much sunlight each area receives: walls that receive more sunlight are generally warmer, and walls that receive less sunlight are generally cooler. However, some materials warm or cool faster than others.

Substitutions for older/more advanced students:

While students are measuring temperature, draw a map that roughly illustrates the ground (demarcating grass and asphalt or other land cover classes) and a table to record their results. Compute statistics as appropriate for the students' level (mean, range, max, min, etc.) and make a map marking land temperatures in one color and air temperatures in another color. This could also lead to a lesson about measurement uncertainty.

Substitutions for younger/less advanced students:

Ask students to touch the various materials and ask which are hotter. Explain how to use a thermometer, and then ask them to measure which material is hottest. Discuss.

These general concepts can be illustrated without the use of formal measurements as well: wetting heat-sensitive paper or liquid crystal paper results in a dramatic color change. Demonstrate and explain how the paper thermometer's color changes when exposed to different temperatures. Take the wet sponge and the dry sponge, and ask which one the students think is hotter and which is cooler. To test this, wipe the sponges on the heat sensitive or liquid crystal paper thermometers (or use a spray bottle to wet one of the thermometers). For the dry sponge, no temperature change will occur, because the sponge will be at the temperature of the surroundings. For the wet sponge, the paper color should change instantly. Explain how when we sweat, we cool off by evaporation, and similarly, the paper thermometer is cooling off by evaporation.

Discussion – What are we seeing, and why?

1) Differences between the ground and the air:

The black piece of paper is warmer than the air above it. This is because the paper is an opaque solid that absorbs sunlight, and the air is a gas that is transparent to sunlight. Gases have molecules that are farther apart than those of solids, meaning that gases generally hold less heat than solids and liquids and it takes more energy to heat them up. Not all gases are transparent to sunlight (for example, air containing the pollutant gas NO_2 is brownish), not all solids are opaque (consider clear plastic or glass), and some solids reflect rather than absorb sunlight (white paper and clean snow, for example). The gasses in our atmosphere are mostly transparent to the visible light we see, so when light passes through our air it doesn't interact with the molecules very much, leaving its energy to be passed to the Earth's surface.

2) Differences between temperatures of materials:

The different materials have different reflective and absorption properties, and some are more transparent than others. This is why the paper's color makes a difference: white paper reflects sunlight better than black paper. Energy is conserved, so the more energy a material reflects or transmits, the less it is able to absorb and re-emit as heat energy. Materials also absorb heat differently due to their conductivity, which is why denser materials such as metals become hotter than paper under similar external conditions (metal has a higher conductivity than paper).

Another factor that affects the way materials change temperature is evaporation. Water can also play a role in this: when water heats up, it evaporates. Evaporation requires a lot of energy, and when the water goes from liquid to gas form it absorbs energy. Evaporation is why the ocean is cooler than land during the summer.

3) Differences between site locations:

Different site locations receive different amounts of sunlight. In particular, sunlit walls receive more energy, and all else being equal tend to be warmer.

5) How does this affect our city?

Parks and green spaces cool the city. Trees that offer shade can reduce the amount of sunlight that reaches the ground and will reduce the air temperature below. Building cities out of materials that reflect light rather than absorb it can help lower temperatures as well; one example is painting roofs white.