Portions excerpted from: Environmental Literacy and Inquiry Working Group at Lehigh University (2011)

Learning Objective: Students will understand the concept of albedo and how it affects radiant heat transfer and the subsequent temperature of an object.

Curriculum Standards:

- NGSS HS-ESS3-6. Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity
- NGSS HS-ESS3.C Human Impacts on Earths Systems
- MD E-Lit Standard 1 Topic A: Environmental Issue Investigation
    - Indicator 4: Design and conduct the research
    - Indicator 5: Use data and reference to interpret findings to form conclusions
- MD E-Lit Standard 3 Topic B: Energy Distribution through Earth Systems
    - Indicator 2: Explain that transfer of thermal energy between the atmosphere and the land or oceans produces temperature and density gradients.

Introduction: The albedo of an object is a measure of how strongly it reflects light from radiant sources such as the sun. Albedo is the percentage of incoming light that is reflected rather than absorbed. It is thought that the earth's average albedo is around 30%. Energy in the form of visible radiation (light) from the sun warms the earth. Some of the energy from the sun is reflected back into space while some of the energy is absorbed. All materials, including man-

The term "**heat island**" describes built up areas that are hotter than nearby rural areas. The annual mean air temperature of a city with 1 million people or more can be 1.8–5.4°F (1–3°C) warmer than its surroundings. In the evening, the difference can be as high as 22°F (12°C). Heat islands can affect communities by increasing summertime peak energy demand, air conditioning costs, air pollution and greenhouse gas emissions, heat-related illness and mortality, and water quality. – *USEPA (www.epa.gov/heat-islands)*

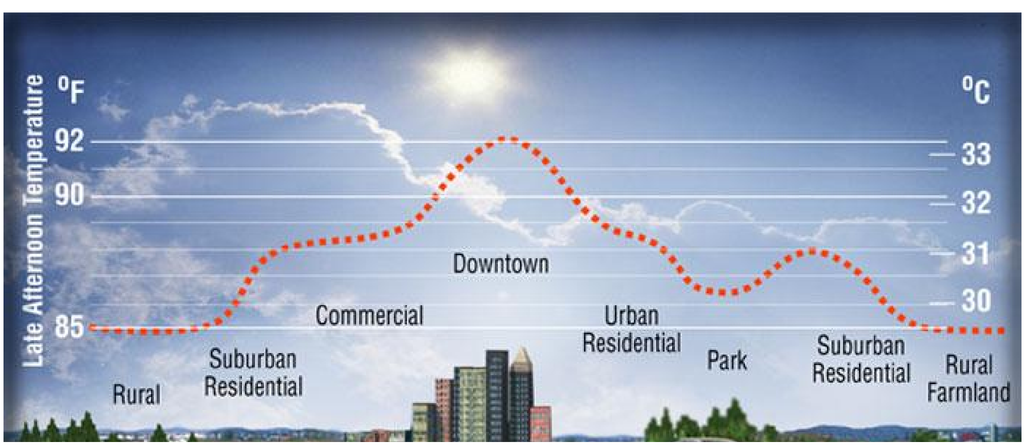

Image credit: Heat Island Group, Berkley Lab, www.heatgroup.lbl.gov made structures, can absorb radiant energy or reflect this energy back into space. The absorbed radiation warms objects, which subsequently re-radiate energy (infrared) back out into space (known as emissivity). The hotter the earth's surface, the more energy is radiated out. This is how heat islands form in and around urban centers.

In general, lighter colored objects tend to have a higher albedo, while darker colored objects absorb more of the sun's energy. If a locale (or the entire earth) receives more energy from the sun than it sends back to space, that locale gets warmer. If a locale reflects more of the sun's energy than it absorbs, the locale gets colder.

The classic example of albedo effect is the snow-temperature feedback. If a snow-covered parking lot warms and the snow melts, the albedo decreases, more sunlight is absorbed, and the temperature of the asphalt tends to increase. The converse is true: if snow forms, a cooling cycle occurs. Below are some examples of objects and their albedo ratings. Numbers closer to 1 are considered to have a higher albedo, while numbers closer to 0 have a lower albedo. A high albedo means that material has a more reflective surface and can reflect much of the sun's energy away.

Surface	Typical Albedo
Conifer Forest (summer)	0.09-0.15
Deciduous Trees	0.15-0.18
Fresh Asphalt	0.04
Black Brick	0.08
Worn Asphalt	0.12
Bare Soil	0.17
Green grass	0.25
Red brick	0.36
Desert Sand	0.40
Ocean Ice	0.5-0.7
New Concrete	0.55
White brick	0.72
Fresh Snow	0.80-0.90

Terms to Know

>Albedo: *a measure of how much light that hits a surface is reflected without being absorbed. A white object with high albedo, reflects most light that hits it and a dark object of low albedo absorbs most of the light that hits it.*

>Emissivity*: the measure of an object's ability to emit infrared energy. Emitted energy indicates the temperature of the object. Emissivity can have a value from 0 (shiny mirror) to 1.0 (blackbody).*

Possible Class Discussions:

1. If global climate change has already been introduced to the class in another portion of the course, a discussion of albedo's effect on natural surfaces may be appropriate. *What natural surfaces have the highest and lowest albedo? How does the decrease in polar ice coverage affect overall global thermal energy absorption of the sun's radiant energy?* The melting of the polar ice could cause a positive feedback loop with regard to global thermal absorption. *What is a positive feedback loop? Explain why the melting of polar ice is or is not a positive feedback loop.*

2. *Using your understanding of the concept of albedo, what activities might we use to mitigate the absorption of thermal energy in man-made environments? Consider alterations to parking lots, rooftops, sidewalks, turf, or other surfaces.*

Two differentiated labs are provided. Lab B allows students to observe how materials of different albedo warm at varying rates and retains heat when the radiant heat source is removed. Lab A is a shortened version in which students take multiple measurements of the three albedo sources, calculate the averages and compare the differences in both sunny and shade environments. Students can also make a prediction of surrounding surface temperatures.

STUDENT LABS

STUDENT LAB OPTION A

(Total Time: Part 1: 25 minutes, Part 2: 15-20 minutes)
Objective: Students will identify surfaces that have higher and lower albedo effect.

Background: Albedo is the reflectiveness of a surface. In general, light colors have high albedo, and dark colors have low albedo.

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Conifer Forest (summer)	0.09-0.15
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Part 1: Measuring temperature difference of same materials with different colors

Directions:

1. Place bricks outside on insulated material in the sun for approximately 10 minutes.
2. Complete the table below by entering the information and temperatures.
3. To measure temperature: Hold infrared thermometer (IRT) at arm's length aimed straight down at one of the bricks. Press and release the temperature button to display the temperature.
4. Record temperature in the data table for the appropriate brick.
5. Repeat for each brick type 3 times.
6. Calculate and average surface temperature for each brick type.

Data from Sunny location:

Brick color	Approximate Albedo	Trial 1	Trial 2	Trial 3	Average Surface Temperature

Analysis:

1. Put the bricks in order from coolest surface temperature to warmest.

2. Based on the coolest temperature indicating the greatest albedo, put the bricks in order from lowest albedo to greatest albedo.

3. Make a prediction of how air temperature above EACH individual surfaces might be different.

Now move the bricks to a location in the shade. Using your watch/phone clock, wait the number of minutes in the table and record each brick's temperatures.

Data from Shade location:

	Brick color:				
Temperature after time				**Which color is warmest?**	**Which color is coolest?**
3 minutes					
8 minutes					
13 minutes					

1. Describe the differences between sun and shade results?

2. Explain why the temperatures might different between the different color bricks.

3. Thinking of the surfaces currently on your schoolyard, how has the albedo of the land surface changed when the school was built there?

Part 2. Exploring the albedo effect.

1. Select 3 surfaces in the vicinity and **make a prediction** for the order of albedo, lowest to highest.
   1) *Lowest:*____
   2) ____
   3) *Highest:*____

2. With at least 3 trials, create a data table below to test your prediction in #1. Record data, calculate averages.

Surface	Trial 1	Trial 2	Trial 3	Average Surface Temperature

3. Based on the averages, put the surface types in order from lowest albedo to highest albedo.

4. Do the results support your hypothesis?

STUDENT LAB OPTION B:

(Total time: 80 minutes, plus additional time to complete questions)
This experiment investigates how the color of a surface influences its ability to reflect or absorb heat. Students use a non-contact infrared thermometer to measure the temperature of different color bricks. They measure and compare changes in temperature as bricks are heated with a high intensity lamp (or outdoors in sunlight).

LAB MATERIALS

For each laboratory team –

1. One non-contact infrared thermometer
2. Styrofoam or other insulated material to set bricks upon
3. Three bricks, one of each color: white, tan, and black
4. Outside to sunlit area or a heat intensive lamp
5. Stopwatch
6. Lab notebook to record readings

Experimental Design:
Before beginning the experiment, as a class discuss the following questions and have the students reach consensus:

1. What is the dependent (measurement) variable in our experiment?
2. What is the independent variable in our experiment?
3. What factors must be held constant during the experiment?
4. What is the reason for including replication in an experiment? How will this experiment be replicated?
5. What is the reason for including a control in an experiment? What is an appropriate control for this experiment?

Laboratory Protocol:

1. Place the bricks side-by-side (but not touching) on an insulated surface (possibly Styrofoam). Why? *(This will cut down the chances of heat conduction from the material below the bricks during the experiment.)* If an artificial light is being used, be sure that the lights are at a constant distance from the bricks in each replicate. If sunlight is being used, be sure that the bricks are NOT exposed to the sunlight before the beginning of the experiment.

2. Measure and record the temperature of each color of brick. This indicates the temperature BEFORE the beginning of the experiment.

3. Turn on the light or begin exposing the bricks to sunlight. Begin the stopwatch. Measure and record the temperature of each brick. This is time 0.

4. Measure and record the temperature of each brick at 5-minute intervals for 30 minutes.

5. Turn the light off (or shade the bricks from sunlight) and record the temperature of each brick after an additional 10 minutes (40 minutes total).

6. Collate the class data and determine the <u>average</u> temperature change for each color brick at each time point.

7. Using the temperature measurements from the first 30 minutes: Which color brick has the lowest albedo (i.e. which brick appears to have absorbed the most heat) and which color brick has the highest albedo (i.e. which brick appears to have absorbed the least heat). Prompt students to record this information and rank the albedo of all three bricks.

8. [Optional – Have students graph the average change in temperature of each color brick at 5-minute intervals. Is temperature gain linear for each color over the 30-minute observation? If not, why?]

9. Compare the average temperature change over the final 10 minute period (from the 30-minute to 40-minute time interval). Do all brick colors respond similarly over this period? What does this tell us about the retention of thermal energy for bricks of different colors? Are the bricks re-radiating thermal energy?

Optional Modification of the Activity:

Instead of only looking at temperature changes during this experiment, actual thermal energy absorption and re-radiation can be calculated by applying the specific heat of the brick material. A brick has a specific heat of approximately 920.5 J/kg ^{o}C. Weigh the brick at the beginning of the activity and determine the increase in thermal energy content of each color brick as it absorbs radiant energy. Similarly, students can calculate the re-radiation of thermal energy during the final 10 minutes of the experiment.