LESSON 6:

THERMAL RADIATION

Specific Heat of Building Materials

Material	C_p in J/g·K
Aluminum	0.897
Asphalt	0.920
Brick	0.840
Concrete	0.880
Glass, silica	0.840
Granite	0.790
Gypsum (in wallboard)	1.090
Marble, mica	0.880
Sand	0.835
Soil	0.800
Steel	0.466
Water	4.1813
Wood	1.7 (1.2 to 2.9)

Source: https://en.wikipedia.org/wiki/Heat_capacity

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The following lesson and associated materials are part of the Integrating Chemistry and Earth science (ICE) Urban Heat Island Module. The Module brings together important concepts from Earth science and chemistry to help students build an understanding of why urban areas have higher temperatures both during the day and at night, than their rural counterparts.

ICE Partners

Cary Institute of Ecosystem Studies

BALTIMORE CITY PUBLIC SCHOOLS

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Lesson 6: Thermal Radiation (2 Days)

Driving Question: *How does Earth's surface cool?*

Summary: The objective of this lesson is for students to understand that materials differ not only in how much energy they can reflect, but also in how much absorbed energy is needed to increase their temperature (Specific Heat). This property also influences the rate at which materials lose heat when exposed to a cooler medium. The stored heat is referred to as Heat Capacity. The Specific Heat/Heat Capacity of building materials in an urban area can contribute to their role in influencing the temperature of the City in terms of excess heat stored in structures. The differences in Heat Capacity of materials could result in differences in when and how much the air is heated over a day/night cycle.
Teacher Note: You have two scheduled days for this topic.

Activity Description:

Day I

- **Opening Activity:** Engage student's prior experiences with heat waves by having them read a news article about heat advisories in Baltimore.
    - Students will read, annotate and answer the questions for the close reading activity *News Excerpts: Heat advisory continues in Baltimore area, as temperatures surge and cooling centers stay packed*
    - Use this reading activity to lead students to wonder how the materials in the urban environment affect the temperature on a hot (or cold) day.
- **Investigation:** Students will investigate how common building materials react when heated.
    - *Heat Energy and Urban Materials Lab*
        - Pre-Lab Preparation-The teacher will need to have enough containers with boiling water for heating each of the 4 rock sample types. These will need to be boiling for at least 20 minutes prior to the activity to insure the rock samples have come to equilibrium with the boiling water. Be sure to have enough samples in each hot water bath for the groups to have 2 samples - one for each part of the activity.
            - It is suggested that each group only test 2 rock types and then share their findings with another group.
            - When you are finished with the rock samples, they can be reheated for each subsequent class.
        - At the end of the activity, save the rocks to be reused.
        - Have students share their Specific Heat data on a class summary chart on the board so that the whole class can compare the heat capacities of all the materials.
            - Discuss the lab results with students. Possible discussion points:
                - Which building materials hold the most heat?
                - Do all the rock types give off their heat at the same rate?

    - How might these properties affect the temperature in our neighborhoods? (Day? Night?)
    - What properties emerge from interaction of components in the system that can't be seen just by looking at the interactions?
  - **Teacher Notes: Key points:**
    - The urban building materials in the environment are being heated and cooled throughout a daily cycle.
    - Heating from absorption of radiation is a function of Albedo
    - Surfaces lose energy by emitting long wave (heat) radiation
    - Different materials store and lose heat differently depending on the chemistry of the materials.
    - *Chart of Specific Heat of Building Materials*
- **Updating Models:** Students will update/edit/modify their models based on today's lesson.
  - Have students edit their heat models to incorporate the concepts from today's lesson.
  - Discussion Prompt: How do the different components of the system interact? What feedback loops are affecting the system?
  - Add to the class model based on student input.
- **Homework:** If more time is needed, allow student to complete the model as homework.

Day II

- **Opening Activity:** Ask students to discuss the design of the lab activities from the previous day and what might have been caused the differences in the heat capacity and cooling times of the man-made materials (Note: wet materials cool faster than dry materials due to the evaporative cooling).
- **Further exploration:** Students will explore the effect of evaporative cooling on surfaces.
  - Students return outside with the IR thermometers and spray bottles.
  - At each location students will take the measurement of the dry surface, spray the surface, and measure the temperature of the wet surface.
  - *Thermal Exploration Data Table 2*
- **Updating Models:** Students will update/edit/modify their models based on today's lesson.
  - Students will update and finalize their Baltimore heat model to incorporate the concepts from today's lesson.
  - At this time, they should complete the explanation portion of the model sheet.
  - Update the Class Model
- **Homework:** Complete the model if extra time is needed.

News Excerpts: Heat advisory continues in Baltimore area, as temperatures surge and cooling centers stay packed

Sarah Meehan and Scott Dance July 2, 018 *The Baltimore Sun*

Chilled water bottles were in high demand Monday morning at the Northern Community Action Partnership Center. The building on York Road was doubling as a cooling center for neighbors seeking a reprieve from Monday's oppressive heat. While most people there were clients waiting to see caseworkers about housing, energy assistance and other needs, others visited strictly to keep cool. By 11:30 a.m., the center had handed out at least 100 water bottles, said its manager, Fernando Moore. And the day was only getting hotter.	1. Explain the need for water bottles on Monday July 2, 2018.
The heat index surged toward 110 degrees Monday afternoon in Baltimore as the sun baked the Northeast. The National Weather Service issued an "excessive heat warning" Monday with the possibility of "dangerously high temperatures and humidity" for Baltimore and southern Baltimore County into the evening. A heat advisory was in effect across Central Maryland for Tuesday, too. Temperatures reached at least 98 degrees at BWI-Thurgood Marshall Airport on Monday, where the uncomfortably high humidity made it feel like 109 degrees. At the Inner Harbor, humidity was still more intense, with temperatures of at least 97 degrees and a heat index up to 111 degrees.	2. What were the temperatures and heat indexes at A. BWI: B. Inner Harbor:

Baltimore Health Commissioner Dr. Leana S. Wen issued the city's first "Code Red" heat advisory of the season for Sunday and extended it through Tuesday. The alert led the city to open cooling centers at four Community Action Partnership Centers and several senior centers. The centers are open on Code Red days from 8:30 a.m. to 4:30 p.m. during the week, and 11 a.m. to 7 p.m. on weekends. "If anyone is in the area and wants to stop in, they can," said Ebony Wilder, a spokeswoman for the Mayor's Office of Human Services. Wen encouraged residents to protect against hyperthermia and dehydration by limiting outdoor activity, drinking plenty of clear, non-alcoholic liquids, and keeping a close eye on children and the elderly, who are most vulnerable to heat stroke and other heat-related illnesses. "This is a chance for us to all watch out for those who are most vulnerable," Wen said. Chronic illnesses can also be worsened by extreme heat.	3. What did the issuing of a Code Red heat advisory lead the city to do? 4. What are some physical effects of intense heat that people need to be aware of in children, elderly and those most vulnerable to heat?

Heat Energy and Urban Materials

How do building materials affect the temperature of the environment in Baltimore?

Recall the observations you made with infrared thermometers for different surfaces (light surfaces, dark surfaces, grassy etc.). Based on what you recall from this activity, rank the following urban building materials on which will hold heat the longest (Brick, Marble, Cement and Granite) in a calorimeter. Explain your reasoning.

Material	**Ranking (1- shortest 4- longest)**	
	Rank	*Reasoning*
Brick		
Marble		
Cement		
Granite		

Materials:

- **Teacher Station:**
- Hot Plates
- Large Beakers for heating rocks
- Coffee cup calorimeter
- Concrete
- Marble
- Brick
- Granite
- Tongs
- **Student Stations:**
- Water
- Graduated cylinder
- LabQuest
- Temperature probe
- IR Thermometers
- Stop watch
- Balance
- Paper Towels

Procedures:

Part 1-Measuring the amount of energy released by urban building materials

1. Set up your coffee cup calorimeter.
2. You will be testing two of the sample types. Be sure to record in the appropriate columns on the data table
    a. Type A:
    b. Type B:
3. Pour 100 mL of cold water into the calorimeter. (D_{H2O}=1g/mL) Record the mass in the data table.
4. Take the initial temperature of the water and record it in your data table. Record the initial temperature of your first rock sample) in your data table, based on the temperature of the hot water bath. (Your teacher will have pre-heated these for you.)
5. Place the first rock sample in the water, place the cover and temperature probe back on the calorimeter.
6. Start the LabQuest recording. Continue collecting data until the system comes to equilibrium.
7. Record the final temperature.
8. Remove the sample from the calorimeter, dry with a paper towel, and find the mass of the rock.
9. Record the mass.
10. Repeat the process with the other sample making sure to record your data.
11. Exchange data with other groups to fill your data table.

Part 2- Observing thermal radiation

1. Obtain a freshly heated sample of your first rock type from your teacher.
2. Use your IR thermometer to test the temperature of your rock every 5 seconds for a 2-minute period.
3. Record your observations.
4. Repeat process with the other rock type.

Observations/Data

Part 1:

	Test 1		Test 2		Test 3		Test 4	
	Cement	**Water**	**Brick**	**Water**	**Marble**	**Water**	**Granite**	**Water**
Mass								
Initial Temperature								
Final Temperature								
Time to Equilibrium (s)								

Specific Heat (Calculated)								

Part 2:

Time (s)	Cement (^{O}C)	Brick (^{O}C)	Marble(^{O}C)	Granite(^{O}C))
5				
10				
15				
20				
25				
30				
35				
40				
45				
50				
55				
60				
65				
70				
75				
80				
85				
90				
95				
100				
105				
110				
115				
120				

Analysis

Part 1

1. How did your actual results compare to your predictions for each of the urban building materials?

2. Using the $q=mc\triangle T$ and $q_A=-q_B$ equations, determine the specific heat of each of the building materials. (Remember specific heat of water = 4.18 J / g ^{o}C) Show your work below. Record your findings in the data table.

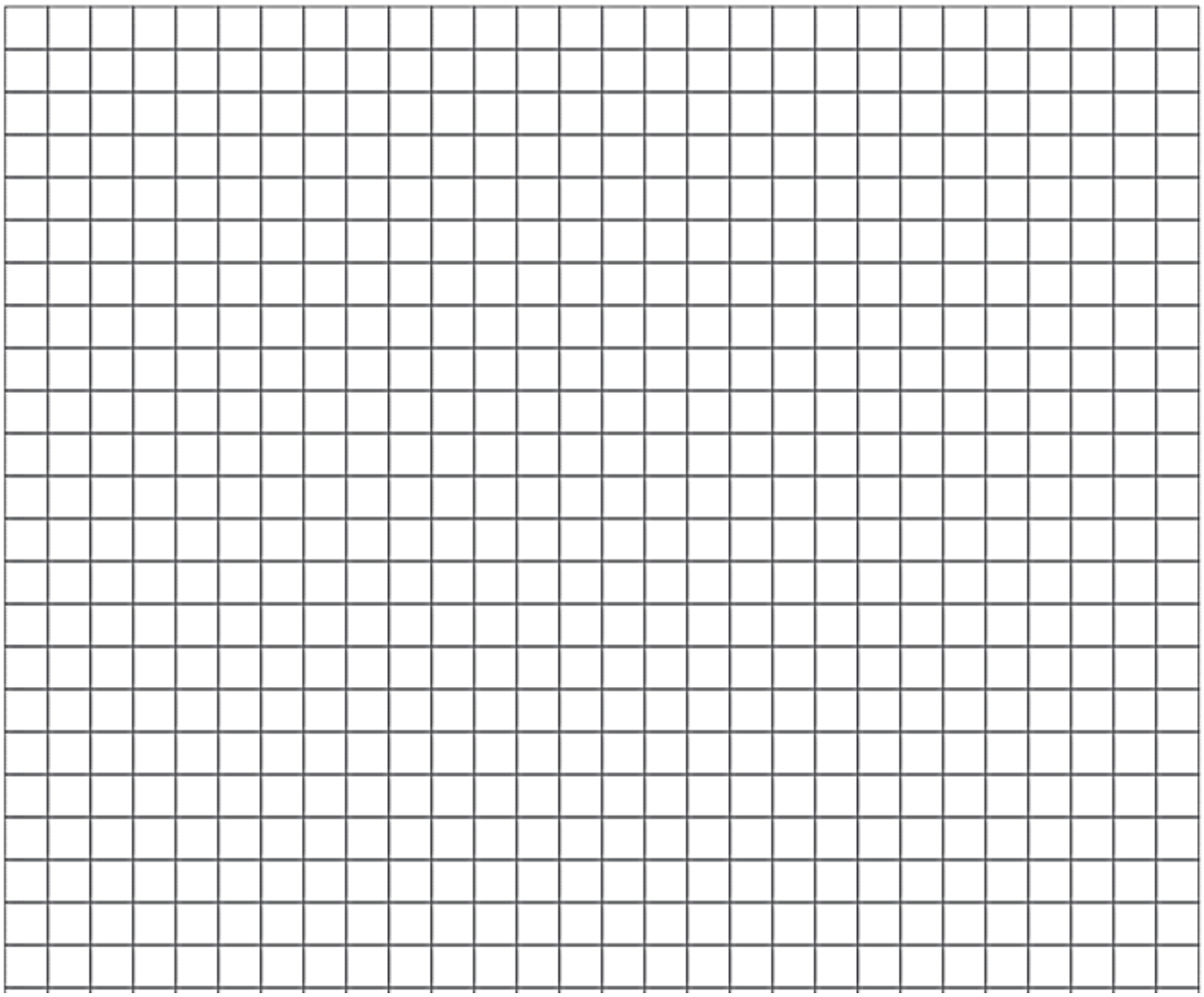
3. How does heat capacity of the materials affect your results? How would this affect the temperature of city in the summer? winter?

4. Water has a heat capacity of 4.18 J/g^{o}C. Would you expect water to absorb more or less heat from the environment than the rocks we tested? How might being near a large body of water effect the overall temperature of the environment?

5. Provide real world examples for your reasoning for both numbers 3 and 4.

Part 2

1. Create a line graph illustrating the temperature change of all four rock types. (be sure to include a key, title, and appropriately numbered and labeled axis.)



2. How do the patterns differ between the different types of materials?

3. How did the cooling patterns of materials compare when cooling happened in water vs. air.

4. How do your observations relate to what happens to air temperature in highly developed areas?

Conclusion:

List the pros and cons of using this type of lab experiment to represent the real-world thermal radiation process.

Specific heat capacity of building materials

Do these vary much from each other?
Higher values mean they change temperature slowly: e.g., heat up slowly but then retain the heat longer.
What will this mean if there is a large mass of buildings concentrated together, such as a city?

Material	C_p in J/g·K
Aluminum	0.897
Asphalt	0.920
Brick	0.840
Concrete	0.880
Glass, silica	0.840
Granite	0.790
Gypsum (in wallboard)	1.090
Marble, mica	0.880
Sand	0.835
Soil	0.800
Steel	0.466
Water	4.1813
Wood	1.7 (1.2 to 2.9)

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Thermal Exploration Data Table 2

Building Material	Location	Temperature (°C)	
		Dry	Wet