Evapotranspiration in the Urban Heat Island

Objectives:

Students will be able to:

- observe and explain transpiration.
- explain evapotranspiration in the environment
- measure and compare changes in air temperature due to evaporation from a wet surface vs. a dry one.
- understand that evapotranspiration cools the air around plants.
- relate evapotranspiration to desert landscaping choices in an urban heat island.

Author:

Ecology Explorers
Education team

Time:

1-2 50 min. class periods

Grade Level:

5-12

Standards:

AZ Science Strands
Inquiry, Nature of Science, Personal and Social Perspectives, Life Sciences, Water, Earth's Processes

NGSS - Core Ideas
Energy, Matter, Ecosystems, Water, Humans, Solutions
Practices - Multiple
Crosscutting Concepts - Multiple

Specific AZ, Common Core, and NGSS standards on page 4.

Background:

Living in the desert has always been a challenge for people and other living organisms. There is too little water and, in most cases, too much heat. As Phoenix has grown, the natural environment has been transformed from the native desert vegetation into a diverse assemblage of built materials, from buildings, to parking lots, to roadways. Concrete and asphalt increase mass density and heat-storage capacity. This in turn means that heat collected during the day is slowly radiated back into the environment at night. The average nighttime low temperature in Phoenix has increased by **8°F** over the last 30 years. For the months of May through September, the average number of hours per day with temperatures over **100°F has doubled** since 1948.

Some researchers have found that the density and diversity of plants moderate temperatures in neighborhoods (Stabler et al., 2005). Landscaping appears to be one way to mitigate the UHI effects. But plants need water. As the temperature increases, so dose evaporation. For example, in Phoenix, a swimming pool loses the equivalent of its total volume every year through evaporation. Pools lose almost **½ inch of water per day** in June and July.

How do plants use water? Water makes up most of every living creature. Every cell in an organism needs water for important processes, such as turning food into usable energy. Plants are special because they make their own food through photosynthesis in the cells of their leaves. The process of photosynthesis requires water.

Plants move water from their roots to their leaves and this water evaporates from the leaf through small pores called stomata. Most stomata in terrestrial plants are on the underside of leaves. This evaporation into the air is the force that draws water upward against gravity. Water molecules cling to each other through weak attractive forces and they move upward along the inside walls of the plants' vascular tubes (xylem) due to cohesion. This water transport through the plant due to evaporation from leaves is called transpiration. Heat held in the water molecules leaves the plant as the liquid water turns to vapor, which cools the plant and the air around it. So plants cool the environment by providing both shade and evaporative cooling.

Stabler, L.B., C.A. Martin and A.J. Brazel. 2005. Microclimates in a desert city were related to land use and vegetation index. Urban Forestry & Urban Greening 3:137-147.

Vocabulary:

condensation - liquid that forms when a vapor cools or changes pressure

ecosystems - communities of organisms interacting with nonliving aspects of the environment to form a unit in a geographical area, e.g. Sonoran desert

evapotranspiration—transpiration from leaves and evaporation from soil

organisms - living things such as plants, animals, fungi and bacteria

photosynthesis - the process by which plants and algae convert energy from the sun's radiation into chemical energy in sugars

rural - outside cities, of or in the countryside

stomata - openings on the surface of leaves that are controlled by guard cells and allow gas exchange with the atmosphere

transpiration - the process by which plants release water from their leaves into the atmosphere

urban - of or in cities

Advanced Preparation:
Students should have some prior familiarity with desert ecosystems, Urban Heat Island and the water cycle.

Materials:

- plastic whirl bags (1/student) or baggies with ties
- clip boards
- thermometers
- small terra cotta flower pots with drainage holes large enough to hold thermometers (2/group)
- plastic tray (1/group)
- spray bottle or tub of water
- timer (1/group - optional)
- Student Worksheets

Recommended Procedure:
Engagement:

1) Review the concept and consequences of the Urban Heat Island. Review evaporation and condensation. How are these affected by increased urban temperatures?

2) Ask students: how do living things survive in hot environments? Brainstorm some ideas. What happens to us when we get hot? We sweat ...or perspire. Water and salts come out of the pores in our skin and the evaporation of this water cools our bodies. How do we avoid getting dehydrated while we are perspiring? (Drink water)

3) Ask: What is unique about deserts? Review water scarcity in deserts. What challenges do plants face to survive and reproduce in an urban desert environment? What extra challenges arise with Urban Heat Island conditions?

4) Tell students they will be exploring how plants use water in nature. Explain how to tie bags over stems and leaves, emphasize that the bag must be wrapped tightly.

5) Assist students to answer the THINK questions:

What will the bag do?

What evidence should we look for in the bags?

6) Prepare to go outside and collect data. Will it matter if the leaves are in the sun or the shade? To answer this question the group may choose to use both sunny and shady plants for comparison. (The sunny ones will show more water vapor.)

7) Go outside and assist each student to "bag" one plant of their choice.

Exploration:

8) Back inside pass out the Student Worksheet: How Plants Use Water and introduce the background questions:

-How do plants use water?

-Where does the water go?

9) Using arrows, ask students to draw the pathway of water into, through and out of a plant using the diagram on their worksheet. Label the water as liquid or vapor in the soil, in the plant, and in the air.

10) Tell students plants don't perspire, but they transpire. These words rhyme. Compare pores in human skin with stomata on leaves. Introduce the term transpiration. Have students write the word on their worksheet.

11) Ask students: do you feel cooler standing in the sun or under a tree? Do you feel cooler standing under a tree or under a cement roof like a park picnic ramada? Ask them to offer some explanations for their answers. Introduce the term evapotranspiration.

12) Tell students they are going to simulate how a tree canopy affects the air temperature. They can roughly compare the effects of the shade of a tree with the shade of a built structure.

13) Give each student group two identical terra cotta flower pots marked A and B upside down on a plastic tray. Ask the students to guess what they are made of (baked clay that comes from the ground). Ask the students to name one main difference between the shade of a built structure and the shade of a tree (a tree's leaves release water vapor through evapotranspiration). Ask students what they could do to the pots to simulate this difference (make one wet).

14) Provide students with a spray bottle or small tub of water, two thermometers and a piece of cotton or paper towel. Instruct students to saturate only pot B with water, keeping the other dry.

15) Ask students, what do these pots represent in our test? (A = a dry built canopy, such as a concrete or adobe roof, B = an evaporating canopy, much like a tree).

16) Hand out Student Worksheet: Evapotranspiration Experiment Data Collection. Have students read the scientific question: How will evaporating water affect the air temperature inside the pot?

17) Record the air temperature on both thermometers, then wedge them carefully into the pot holes with a bit of cotton or paper. Make sure the thermometer is readable above the pot and the bulb is suspended the same distance from the table surface. Place the trays in the sun for observation and data collection.

18) Explain that the shady underside of the pot is protected from the sun. Ask students: Will the temperature differ in the shade of pot A vs. the shade of pot B? Why? Have students make a prediction for the temperatures at 5 min and at 10 min. and record it on the data collection worksheet.

19) Using a timer or the classroom clock, observe and record the temperatures every minute for 10-20 minutes. Record on the data collection worksheet. Calculate the average for each pot for each group.

20) At this point if time is limited, students may retrieve their bags from the leaves outside and continue with data analysis in another class session. Skip to step 25.

Explanation:

21) Ask students: how did the temperature change over time? Assist students to graph their group data on the Student Worksheet: Evapotranspiration Experiment Data Analysis. Have students decide on the scales for temperature on the x axis and time on the y axis and write in the appropriate numbers. Make two line plots, one for pot A and one for pot B.

22) Ask students: which pot had more stable air temperatures under it? How long did the wet pot "resist" heating up in the sun? How long would it take for the two pots to reach the same temperature?

23) Ask students, was there a difference in the average temperature under the two pots? Discuss the importance of variation in nature and in experiments. Did all the groups get the same averages? Why or why not? Each group got an answer for two pots, but to answer the question in general, the class needs to replicate the experiment. Explain that each group provides one replicate. With more replicates the class can compensate for the individual variation to find a general answer to the question: How will evaporating water affect the air temperature inside the pot?.

Expansion:

Analyze class data. The worksheet provides a table to calculate the average and range for pots A and B across all class groups. The graph below it can be used to plot temperatures for each pot across time, either for individual or class data. To make a class graph, students can compile their average temperatures in a table on the board for particular intervals (e.g. 5, 10, 15, and 20 min.). Then, these data can be used to create a class graph, plotting the A and B pots on two separate lines for comparison.

24) Based on the data analysis, what is the class conclusion? Did the results support their predictions? Why or why not?

25) Return to bagged leaves and observe. Ask students what they see. Why do some bags have water in them? Remove bags carefully without loosing condensation.

26) Ask students to describe the process by which the water gets into the bags. Where does the water go when there is no bag? What does it become? Ask students: what do you think the affect of this water vapor is on the air temperature? (Water vapor provides a cool barrier around plants - it eventually condenses into clouds in the atmosphere and becomes precipitation. The bags are trapping the water vapor causing them to form tiny "clouds".)

27) To synthesize, have students draw their ideal Urban Heat Island landscaping. They may choose to represent part of their own yard or school yard. Encourage them to think about the effects of the UHI on plants and the effects of plants on UHI. Which types of plants would they choose to plant? Where would they locate them. What other types of built structures could improve the landscaping to reduce the effects of UHI? Have students label their drawings with the types of plants. Label the cooler places and explain what makes them cool. Have students provide a caption description explaining their choices.

Evaluation:
Students will participate in the discussion, investigation and complete worksheets.

Extensions:
Read the articles related to urban plants in the ASU Chain Reaction magazine, volume 4:

"A Shady Situation" http://chainreactionkids.org/files/issues/4/chreact4_p18_19.pdf

"Planting Water-Wise" http://chainreactionkids.org/files/issues/4/chreact4_p20_21.pdf

"Where does our water come from?" http://chainreactionkids.org/files/issues/4/chreact4_master.pdf (p 21).

Have students discuss the articles in small groups. Ask students to explain how understanding evapotranspiration helped the scientists to do their research.

Standards:
Arizona Science Standards
S1-C1-GR3-PO2
S1-C1-GR-4-PO3
S1-C1-GR-5-PO2
S1-C1-GR-6-PO1
S1-C1-GR-8-PO2
S1-C1-GRHS-PO2, PO4
S1-C2-GR4-HS-PO1
S1-C2-GR3-8-PO4
S1-C2-GR3-8-PO5
S1-C2-GRHS-PO4, PO5
S1-C3-GR3-8-PO1
S1-C3-GR3-5-PO2
S1-C3-GR3-6-PO3
S1-C3-GR4-PO4
S1-C3-GR7-PO5
S1-C3-GRHS-PO1, PO2, PO6
S1-C4-GR3-5-PO1
S1-C4-GR3-8-PO3
S1-C4-GRHS-PO2, PO3, PO4
S3-C1-GR4-5-PO1
S3-C1-GR7-8-PO1
S3-C1-GRHS-PO1, PO2, PO3, PO4, PO5
S4-C1-GR3-4-PO1
S4-C1-GR6-PO1, PO6
S4-C3-GR3-4PO4
S4-C3-GR7-PO2, PO5
S4-C3-GRHS-PO1, PO2
S4-C4-GR3-4-PO1
S4-C4-GR4-PO2
S4-C4-GR8-PO3
S4-C4-GRHS-PO4
S6-C2-GR6-PO1
S6-C1-GRHS-PO1, PO4
S6-C5-GRHS-PO1, PO3
S6-C2-GRHS-PO1, PO2, PO3

NGSS Core Ideas:
ESS2.C: The roles of water in Earth's surface processes
ESS3.C: Human impacts on Earth systems
ETS1.B: Developing Possible Solutions
LS1.C: Organization for matter and energy flow in organisms
LS2.B: Cycles of matter and energy transfer in ecosystems
LS2.C: Ecosystem dynamics, functioning, and resilience
LS4.D: Biodiversity and humans

NGSS Practices:
Planning and carrying out investigations
Analyzing and interpreting data
Using mathematics and computational thinking
Constructing explanations
Engaging in argument from evidence
Obtaining, evaluating, and communicating information

NGSS Crosscutting Concepts:
Cause and effect
Scale proportion and quantity
Systems and system models
Energy and matter: Flows, cycles, and conservation
Structure and function
Stability and change

Common Core/ELA Literacy
RST7: Integrate content from diverse formats
WHTS1: Write to support claims
WHTS2: Write to convey ideas and information
WTS4: Produce clear and coherent writing
WTS7: Research/investigate to answer a focused question
SL1: Participate in collaborations and conversations
SL2: Integrate oral information
SL4: Present effectively to listeners

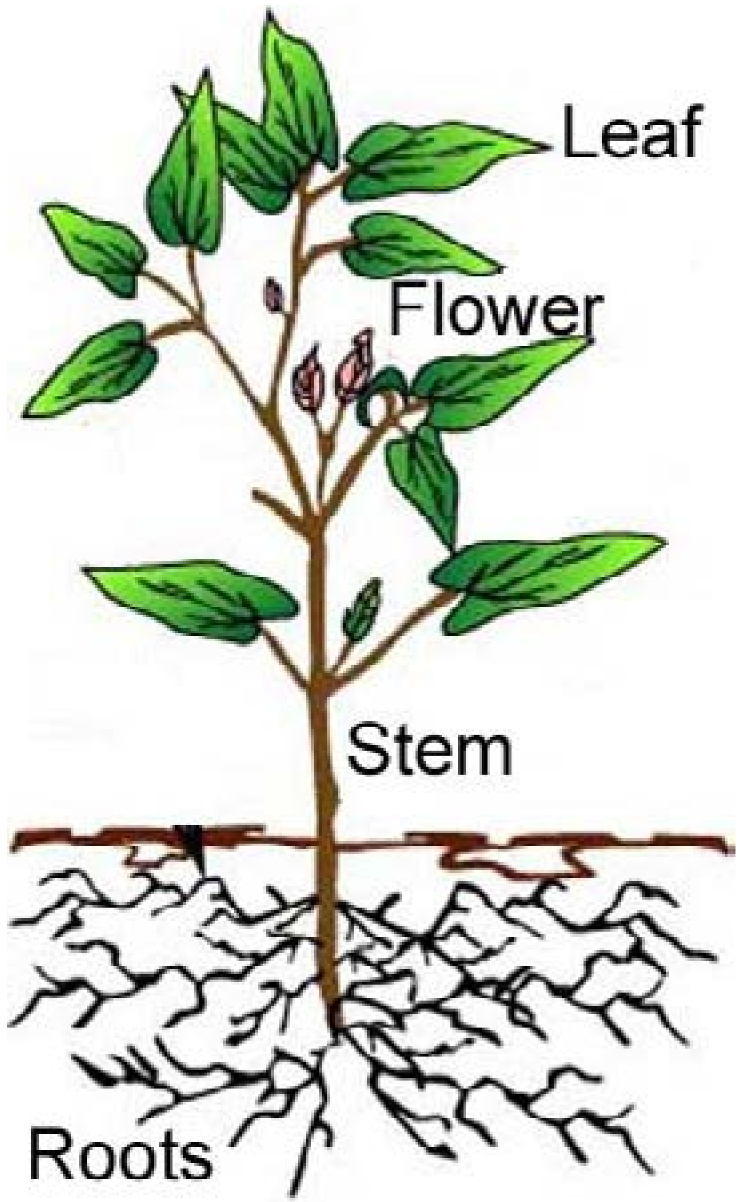
Common Core/Mathematics
Domains:
Number and Quantity
Measurement and Data
Statistics and Probability
Math Practice:
2. Reason abstractly and quantitatively.

Student Worksheet (#1)
Evapotranspiration

THINK - How do plants use water?

-Where does the water go?

DRAW the pathway of water moving into, through and out of the plant using arrows.



LABEL the water as liquid or vapor in the soil, in the plant, and in the air.

WRITE the word that describes the process above.

Student Worksheet (#2)
Evapotranspiration Experiment

Name:______________________________ group number: _____________

THINK: How will evaporating water affect the air temperature inside the pot?

RECORD: initial air temperature: A = __________________ B = __________________

PREDICT: temperatures:

5 min: A= _______________ B = __________________

10 min: A= _______________ B = __________________

Time (min)	Temp oC Pot A (Dry)	Temp oC Pot B (Wet)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		

CALCULATE average air temperature for group:

A = __________________ B = __________________

Student Handout (#3)
Evapotranspiration Data Analysis

Class Data Group #	Average Temperature oC Pot A (Dry)	Average Temperature oC Pot B (Wet)
1		
2		
3		
4		
5		
6		
7		
8		

CALCULATE the average of all replicates A = _________ B= __________

CALCULATE the range for the average A= _________ B= __________

Graph

Temperature (oC)

Time (min)

ASU JULIE ANN WRIGLEY GLOBAL INSTITUTE of SUSTAINABILITY
ARIZONA STATE UNIVERSITY

My Urban Heat Island Landscaping

Draw a picture, label the types of plants and structures you choose, label the cooler areas and explain.

Describe your picture and explain the choices you made::