

Cups 'n' Convection

What's this lesson all about?

The purpose of this lesson is to help adjust student conceptions about how heat gets transferred, focusing primarily on heat transfer through convection. Many students who take the TCE show a misconception that heat only travels upward, that "heat rises", and that heat and cold flow like liquids (Yeo & Zadnik, 2001).

- Heat only travels upward. 20
- Heat rises. 20
- Heat and cold flow like liquids. 10, 13

This lesson starts by challenging those conceptions through a discrepant event, followed by exploring three simulations involving cups and convection. By the end of this lesson students should have a much more nuanced understanding of heat transfer in fluids like air.

This lesson should take place after the [TCE Pre-Test](#) and, ideally, after [Lesson 1 - Thermal Equilibrium](#) and [Lesson 2 - "Hot" and "Cold"](#).

Quick Assessment of Student Understanding

Have students complete the three quick questions at the beginning of [this Google Doc](#).

Introductory Physical Activity/Demonstration - Convection Conundrum

This demonstration should hopefully get students thinking about how the motion of fluids is affected by temperature, as well as initiate a density-related discussion about why fluids tend to travel upwards when warmed.



Materials: 4 empty identical bottles, food coloring, playing cards, hot & cold water

- Fill two bottles with hot water and two bottles with cold water. Label the bottles “HOT” and “COLD.”
- Use yellow (or red) food coloring in the warm water and blue food coloring in the cold water. Each bottle must be filled completely.
- Place a card over the mouth of a hot water bottle (this is tricky).
- Hold the card in place as you turn the bottle upside down and place it on top of a cold water bottle (be prepared for a little mess).
- Quickly slide the card out from between the bottles. This is easiest if you hold the top bottle in place.
- Discuss what happens to the colored liquids in the two bottles.
- Repeat the above steps but this time place the cold water bottle on top of the hot water bottle.
- Discuss what happens this time. Encourage students to make connection between the temperature of the fluids and the direction of motion.

[Click here for a YouTube demonstration of the activity \(1m01s\)](#)

Activity adapted from [The Lab](#) (2018).

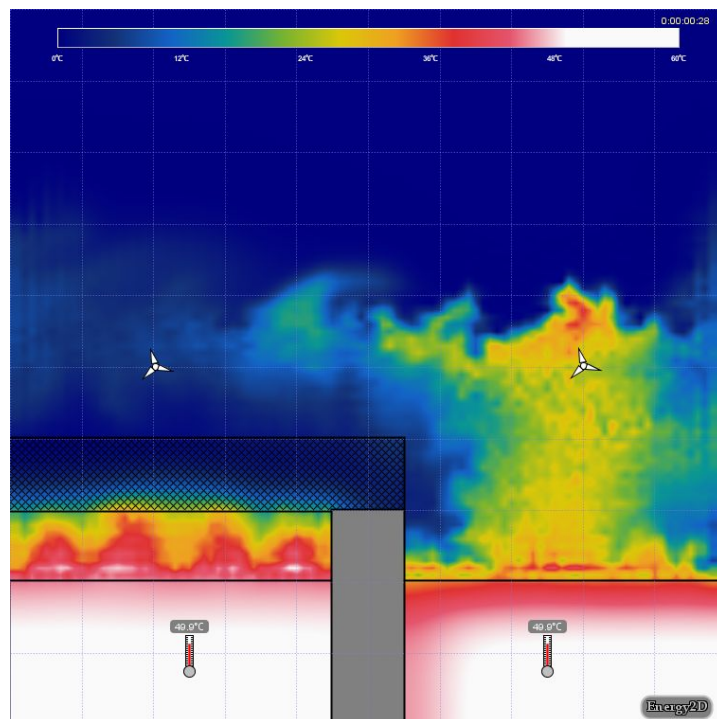
Activity - Exploring Heat Transfer using Three Energy2D Simulations of Cups

At this point students are familiar enough with Energy2D to be able to work more freely and independently with less teacher support. Facilitate students exploration of the three simulations below and encourage them to [record, reflect on and discuss their thoughts and observations in the accompanying Google Doc](#).

Note: The colouring in these simulations is the **temperature** of water or air, and not an amount of heat.

Simulation 1 - Open vs. Closed Cups

Open [hot-water-cup-open-vs-closed.e2d](#) in Energy2D. This model simulates the heat losses from two cups of hot water, one being covered the other closed. Only a part of the cups is modeled. Convection in the water is not considered.



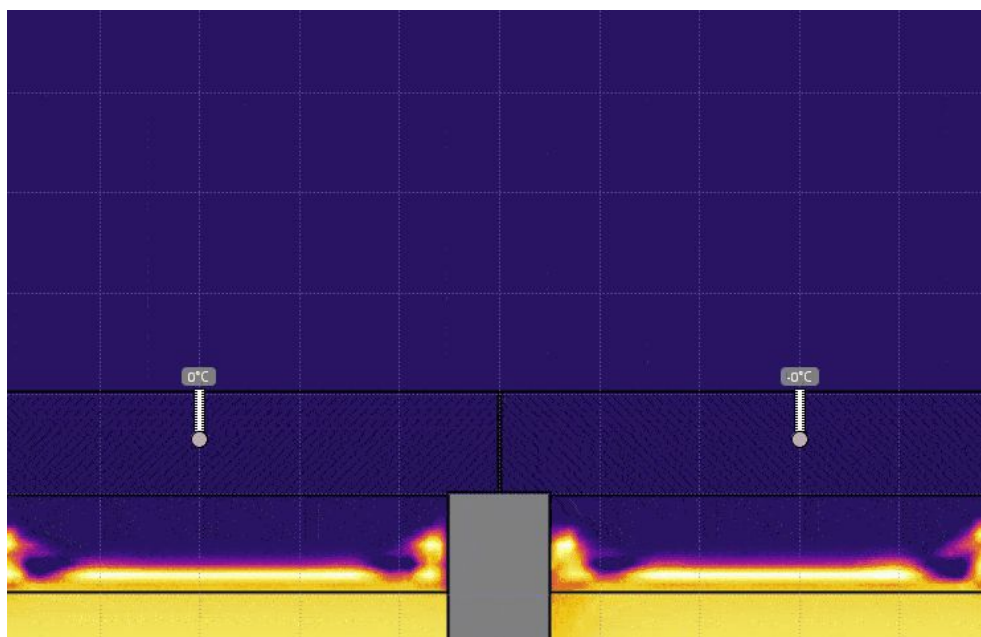
- Which cup cools the fastest? Why?
- Do the cups reach thermal equilibrium with the air? Discuss.

- Set the temperature of the water on the **right** to 0° C, keeping the temperature on the left at 50° C, and run the simulation. Discuss what has changed.
 - Consider how heat is transferred through:
 - i. the air above the cup on the left.
 - ii. the lip of the cup on the left.
 - iii. the air above the cup on the left.
- Set the temperature of the water on the **left** to 0° C and set the temperature on the right back to 50° C, and run the simulation. Discuss what has changed.
 - Consider how heat is transferred through the air above the cup on the right.
- Do you agree that “heat only travels upward”? Why or why not?
- Suppose you are told “heat flows like a liquid through all materials”. Would you agree, or disagree? Support your argument with reference to heat transfer through air and the cup’s lid.

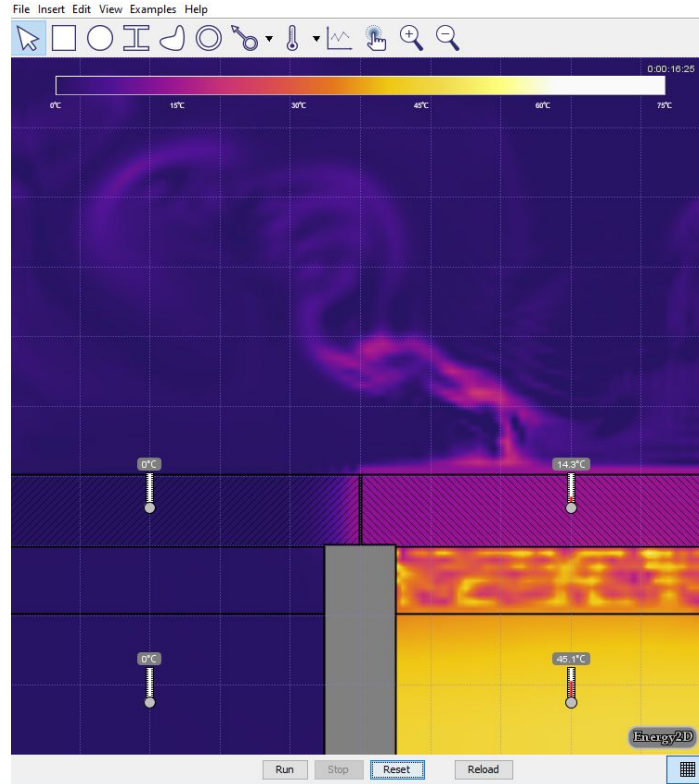
Simulation 2 - Cups with Lids of Different Thermal Conductivity

Open [hot-water-cup-conductivity.e2d](#) in Energy2D. This model simulates the heat losses from two cups of hot water covered by two sheets of materials that have different thermal conductivity. Convection in water is not considered.

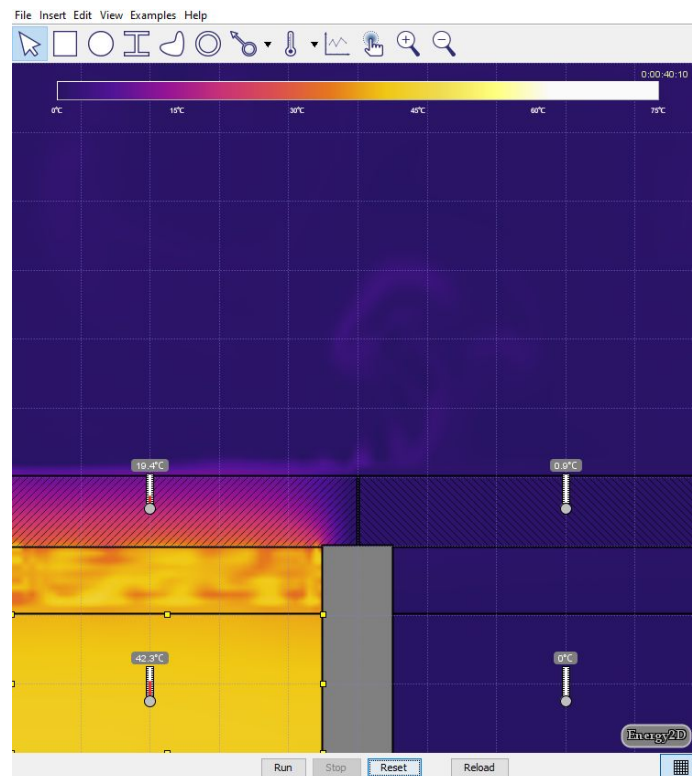
- Which cup of water cools more quickly, the cup on the left or the right? Discuss with reference to thermal conductivity.
- Which lid conducts heat energy away from the cup the quickest?



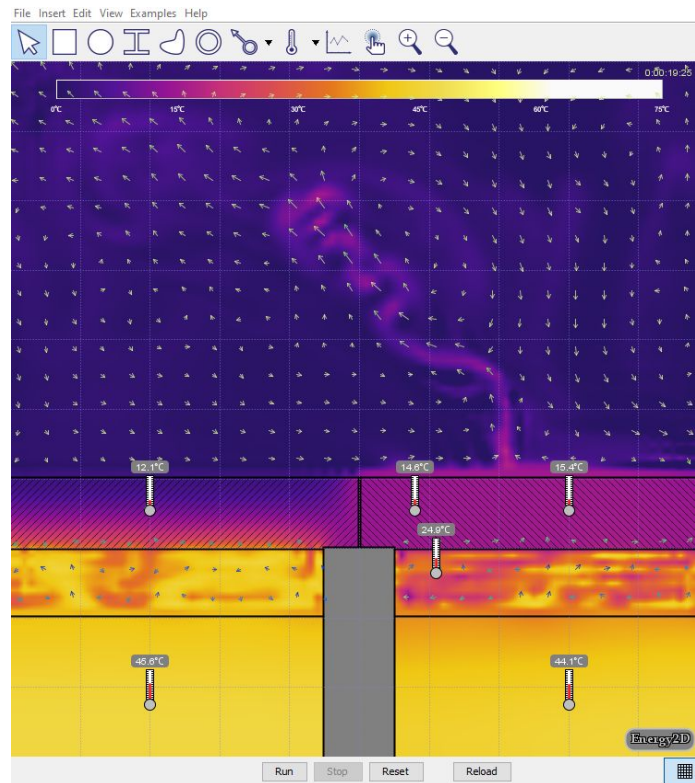
- Set the temperature of the water on the **right** to 0°C , keeping the temperature on the left at 50°C , and run the simulation (see the image below). Discuss the effect this has on the temperature, the time it takes for heat to be transferred, and motion of the air above the lids.



- Set the temperature of the water on the **left** to 0°C and set the temperature on the right back to 50°C , and run the simulation (see the image below). Discuss the effect this has on the air above the lids.



- Turn on **Velocity** in the View menu. Run the simulation for 5 or 10 seconds then click Stop (see the image below). Generate a relationship between the temperature of the air and the direction of travel.

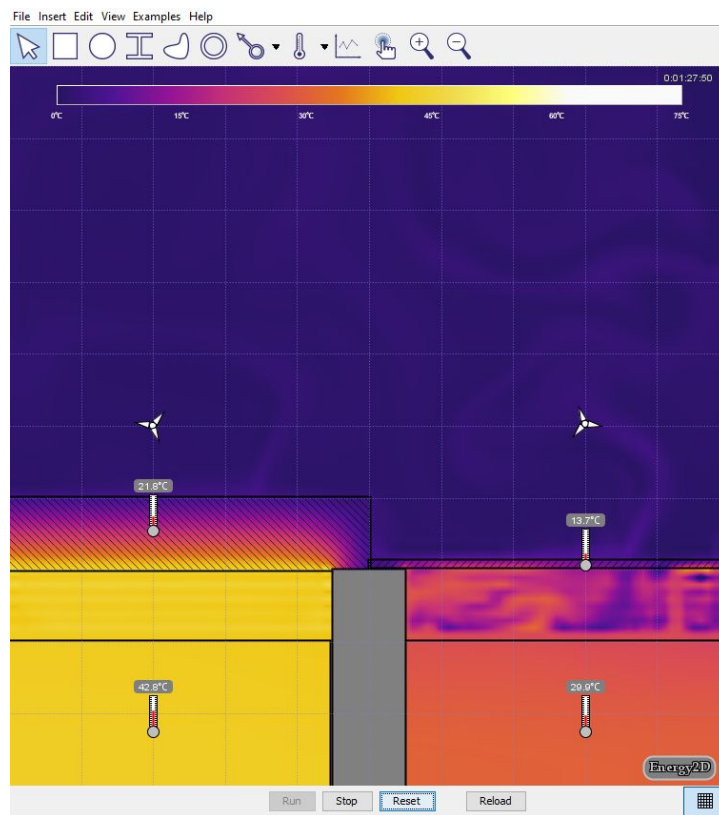


- Set both water temperatures back to 50° C, turn on **Heat Flux Arrows** and run the simulation. Make at least 3 conclusions about heat transfer and the motion of air at different temperatures. Turning on graphs may help. Compare these conclusions with at least one other student, and present your most interesting conclusion to the class.

Simulation 3 - Cups with Lids of Different Thicknesses

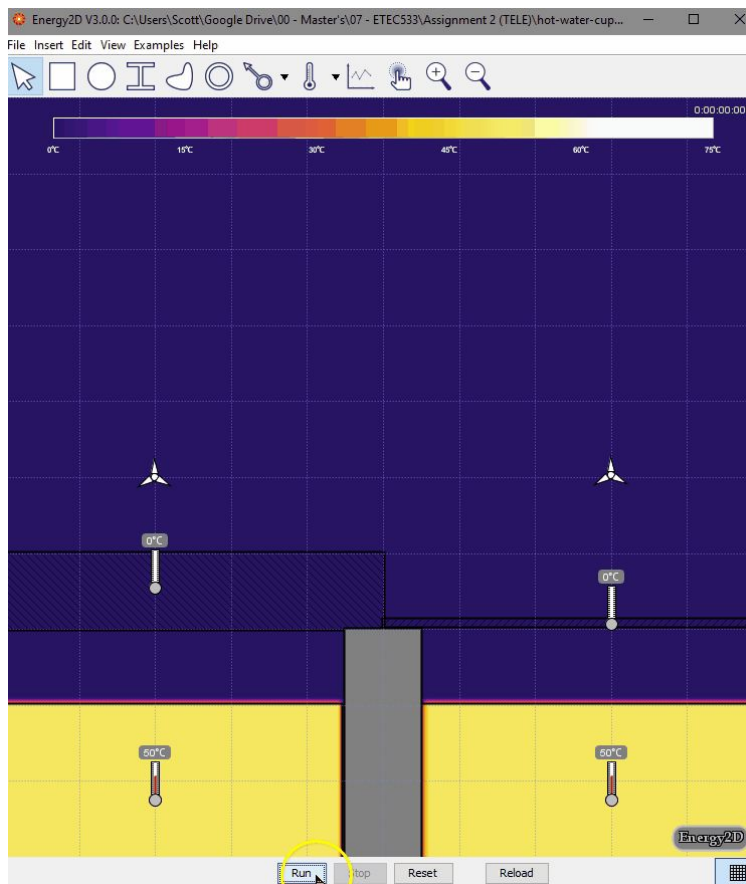
Open [hot-water-cup-thickness.e2d](#) in Energy2D. This model simulates the heat losses from two cups of hot water covered by two sheets of identical materials that have different thickness. Only a part of the cups is modeled. Convection in the water is not considered.

- Which cup cools the fastest? Why?
- How is the air next to each lid affected? Does it always travel straight up?
- Which fan turns the quickest? What causes this?
- Discuss the difference in the air trapped under the thick lid compared to the air trapped under the thin lid (see first image below). Turning on **Isotherm** in **View Options** may help (see second image below).



Suggested Exploration for All Simulations

Explore View options such as “Heat Flux Arrows”, “Streamlines”, “Isotherm”, and “Velocity”.



Summary Discussion Questions

State whether you agree or disagree with the following statements, and explain your answer with reference to an example from the simulations. If using Google Docs, screenshots are helpful.

1. "**Heat** doesn't rise, because heat is not a substance. **Hot air** rises because it is pushed upwards by cooler, denser air."
 2. "Heat is only ever transferred upward."
 3. "Heat and cold flow like liquids."
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And... you've reached the end!

This concludes all three lessons.

Please have your students take the TCE Post-Test to see how they've improved.

Thanks so much for visiting and I hope these lessons have been helpful.

Final Notes:

- Please forward any feedback you have on this lesson to scottskanes@gmail.com. I'd love to hear what you liked, what you didn't, what worked, what didn't, or any modifications you've made!