How can I turn a solar oven into a refrigerator?

A laboratory experiment from the Little Shop of Physics at Colorado State University

Overview

A solar oven is designed to capture solar energy to heat something to a higher temperature than the surrounding air. You put an object in a mirrored box with a glass lid. Radiation comes in, reflects, and strikes the object in the box, warming it up. Basically, the object "sees" more light from the sun than it otherwise would.

But suppose we turned this idea around. If you put an object in the solar oven but replace the top with something that transmits infrared. Then we put the box out at night and point it at open sky.

What happens? It makes a refrigerator—a "space refrigerator." The object cools to a lower temperature than the surrounding air!

Necessary materials:

- Box
- Electronic thermometer

We use a thermometer with two leads. It's meant to do inside and outside temperatures. And it does, measuring temperatures inside and outside the box.

A max-min recording function is nice too.

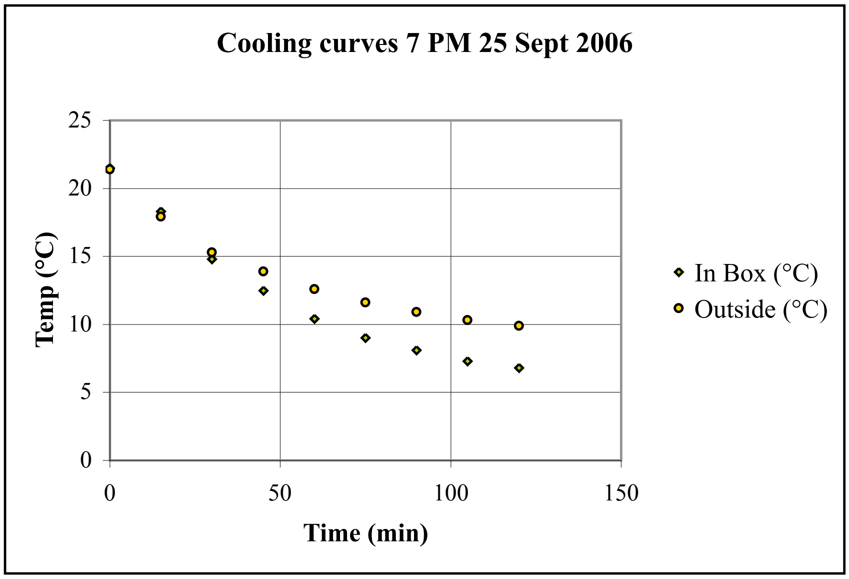
Theory

You know that all objects radiate electromagnetic waves. You also know that increasing an objects temperature increases the total amount of energy radiated and the decreases the peak wavelength of the emitted radiation. Your body radiates energy in the infrared region of the spectrum—this you know. But the amount of the emitted radiation might come as a bit of a surprise.

Oven by day, fridge by night.

Here's a remarkable fact: An unclothed human will radiate a significant amount of electromagnetic energy—about 850 W. Now, your body's basal metabolic rate is only about 150 W, so if this was all there was to the story, your body's thermal radiation would cause your body to cool catastrophically.

But there is more to the story: The radiated energy that your body absorbs from the environment. An unclothed human in a room at about 20°C will your absorb about 750 W of thermal energy that is emitted by the walls, floor and ceiling of the room. The net loss of energy is about 100 W—enough that you will feel chilly, but not so much that you will develop hypothermia.



If the walls of the room you are in are cold, you will radiate just as much, but you will get less back. If the walls are warm, you will get more back. The temperature of the walls, ceiling and floor in a room are every bit as important to your comfort as the temperature of the air.

A object on the ground "sees" the earth below and the sky above. The sky is cool, the earth is (relatively) warm. The object will cool, because it will emit more than it receives—only half of what it "sees" gives significant infrared back. But an object in the "space refrigerator" doesn't "see" anything warm. The solar oven collects radiation from above—but above is the sky, and the sky is cool. So the object in the box gives off as much energy as an object on the ground, but it gets much less back. It cools more rapidly.

Some sample data for a cool fall evening are above. The box had a bag of sand in it; a similar bag of sand was on the ground next to it. As you can see, the sand in the box cooled off much more quickly. After two hours, it was at a frosty 7°C, while the sand on the ground was a much warmer 10°C.

Doing the Experiment

This is a good idea for a student project. It would be interesting to see how good a "space refrigerator" one can make. Some things to try:

- Optimize the device as if you were optimizing a solar oven. Use shiny material in the box, adjust the sides so that incoming radiation has a clear focus, and place the object right at the focal point. The better an oven the box is, the better a fridge it will be.
- Experiment with the covering. If you have material that transmits infrared nicely but gives some insulation against conduction and convection, that will be best.
- Try the fridge on different nights. What type of night works best?
- Try the fridge at different altitudes. At higher elevations, the layers of the atmosphere the fridge "sees" will be colder, meaning more effective cooling.

Summing Up

This experiment would be a great one to couple with a unit on solar energy. The earth gives off as much radiant energy as it takes in, and this experiment makes that point quite nicely!

For More Information

CMMAP, the Center for Multi-Scale Modeling of Atmospheric Processes: http://cmmap.colostate.edu

Little Shop of Physics: http://littleshop.physics.colostate.edu