

# How can I turn a solar oven into a refrigerator?



## Overview

A solar oven is designed to capture solar energy to heat things inside to a higher temperature than the surrounding air. You put an object in a mirrored box with a glass lid. Solar radiation comes in, reflects off the sides of the box, and strikes the object in the box, warming it up. Basically, the object “sees” more light from the sun than it otherwise would. The glass top keeps thermal radiation inside the box.

But suppose we turned this idea around — if we put an object in the solar oven, but replaced the top with a material that transmits thermal radiation. Then we put the box out at night and point the top at open sky.

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

## Theory

All objects radiate electromagnetic waves. Increasing an object’s temperature increases the total amount of energy radiated; hot objects “glow” more brightly than cool ones.

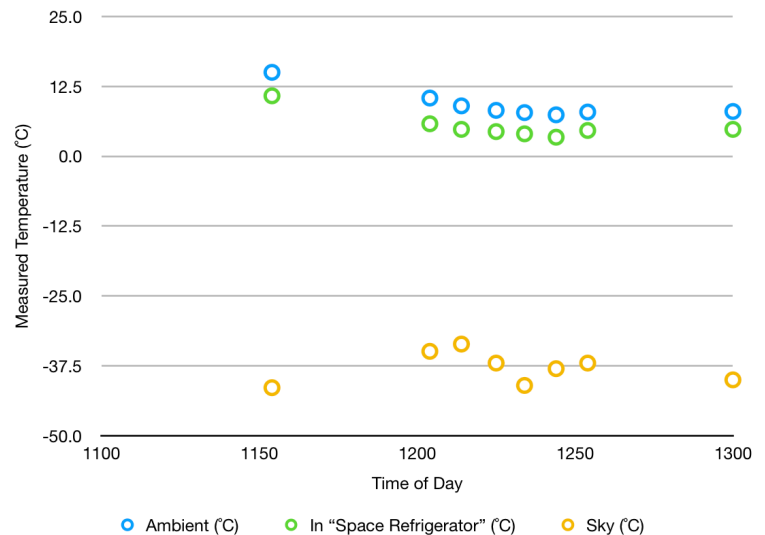
Increasing the temperature also decreases the peak wavelength of the emitted radiation. The sun gives off visible light. You are cooler than the sun, so you emit less energy, and you emit it at a longer wavelength, in the thermal radiation region of the electromagnetic spectrum.

The sun does glow more brightly than you. But you are still pretty bright! The amount of energy you emit might come as a bit of a surprise.

Here’s a remarkable fact: An unclothed human will *emit* a significant amount of electromagnetic energy—about 850 W. Your body’s basal metabolic rate is only about 150 W, so something else must be going on. If this was all there was to the story, you’d be losing 700 W more than you generate, so you’d cool off rapidly and die.

But there is a piece we left out: The radiated energy that your body absorbs from the environment. An unclothed human in a room at about 20°C will *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 only 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



*This data was taken on a cool, mostly sunny mid-March day in Colorado. It was consistently cooler inside the “space refrigerator” than outside. It’s worth noting that the measured temperature of the sky varied quite a bit over the course of the trial. (This isn’t really the temperature of the sky — it’s an approximation based on some assumptions the thermal radiation sensor makes — so it’s most useful for comparison with other sky “temperatures” you measure.) Why might this be? How might it affect your results? These can be good questions for students to consider. (One thing that can make a big difference: clouds! Clouds are generally much warmer than the sky.)*

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.

An object on the ground radiatively “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.

## Doing the experiment

Once you’ve assembled the materials, this one is pretty quick and easy to set up. Insert the thermometer probe inside the cotton ball (or whatever low-mass, high-surface area object you decide to use); this will increase the rate at which energy radiates away from the probe, so the experiment will run more quickly. Now, put the probe in the ice bucket and cover the top of the bucket with clear plastic food wrap (or thermal radiation-transmitting material of your choice). Position the bucket so there’s clear sky overhead, but avoid placing it in direct sunlight. Have your students monitor the ambient temperature and the temperature inside the space fridge for a while, then discuss the findings.

A few additional questions your students can explore:

- Experiment with the top covering. A material that transmits thermal radiation nicely but gives some insulation against conduction and convection will be best. You can test materials using an thermal radiation sensor (“infrared thermometer”) — if you place the material between the sensor and a hot object and read a temperature close to what you find if the material isn’t there, you’ve found a good transmitter of thermal radiation.
- While you’re thinking about the material you use on the top of the fridge... How could you turn your fridge into an oven? It might be interesting to test a fridge and an oven side-by-side.
- Try the fridge on different days, or at different times of day (or night!). What time and weather conditions give the best results? Why doesn’t the fridge work in some weather conditions?
- Try the fridge at different altitudes. At higher elevations, the layers of the atmosphere the fridge “sees” will be colder, resulting in 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!

### Necessary materials:

- metal ice bucket with shiny interior (ours is 3 liters)
- clear plastic food wrap (or other transparent material that does not interact with thermal radiation)
- electronic thermometer with two leads (for example, one meant to measure indoor/outdoor temperatures simultaneously); it’s nice but not necessary if the thermometer has a max-min recording function
- cotton balls (or another object with low mass and large surface area that can fit over the thermometer probe that will be inside the space fridge)
- thermal radiation sensor (“infrared thermometer”) — this is optional, but nice

**For more information**

Colorado State University College of Natural Sciences: <http://www.natsci.colostate.edu>

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