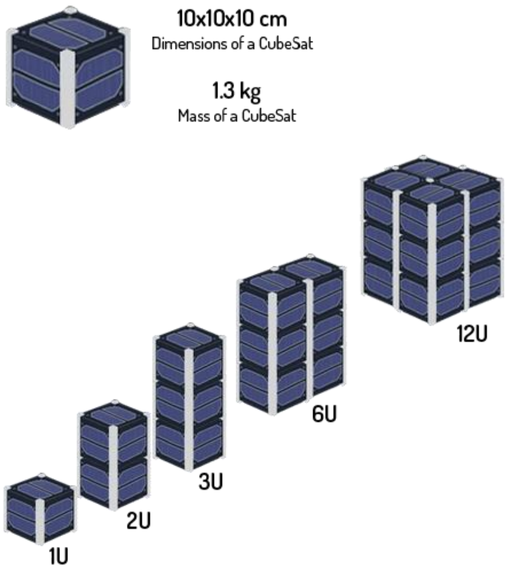
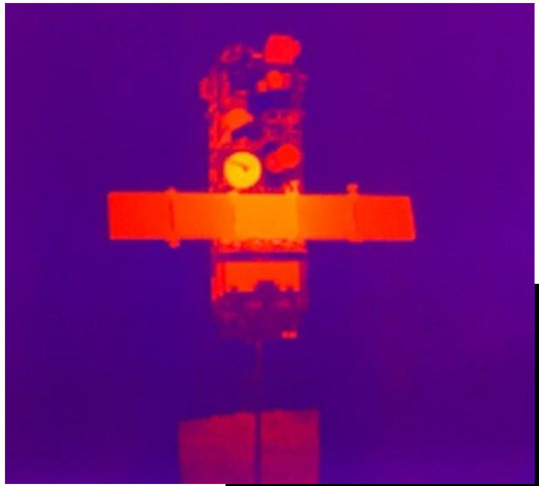
Cube Sat Heat Transfer project

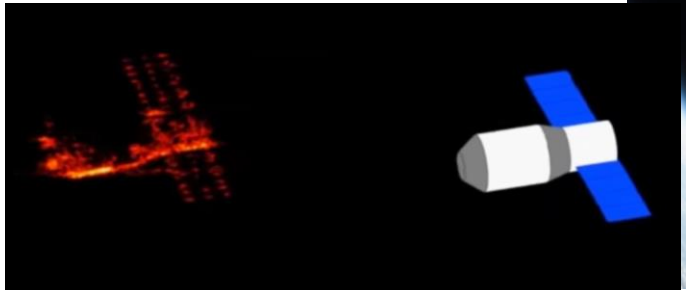
Cube Sats are small satellites that can be flown to the ISS and ejected from the Space Station using the robotic arm. They are being made by small and large companies, universities and even high schools. They can have a wide variety of uses and made in several different sizes. Because they are operating in the vacuum of space, the more power a satellite uses, the more heat that can build up inside from the electronics. This is a problem in all satellites. Removing the heat prevents the processing chip from being damaged and the battery from rupturing through the many cycles it will be going through. The sun is also a contributor to the amount of heat in a satellite. Temperatures in space can be +250F in the sun to -250F in the shade. Without air there isn't any convective cooling and the only conduction is to the shell of the satellite. This leaves only radiation to remove the heat from the satellite.





Design, build and test a thermal system for a 2U (10cmx 10cmx20cm) Cube Sat that will:

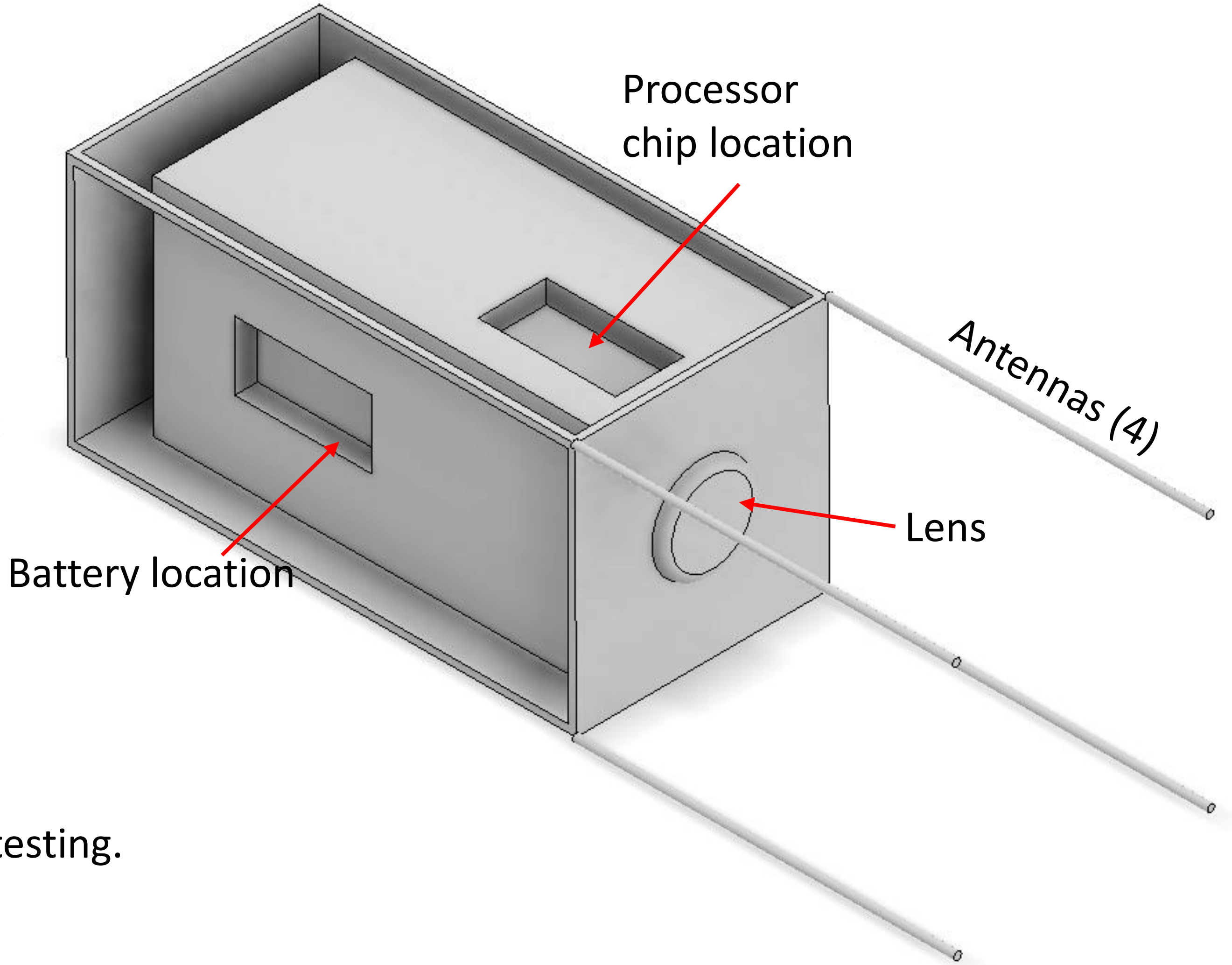
- transfer the heat from the internal electronics to the skin of the aluminum casing and beyond
- operate in vacuum of space without convective cooling
- minimize heating from solar radiation



Location of thermal sources in cube sat

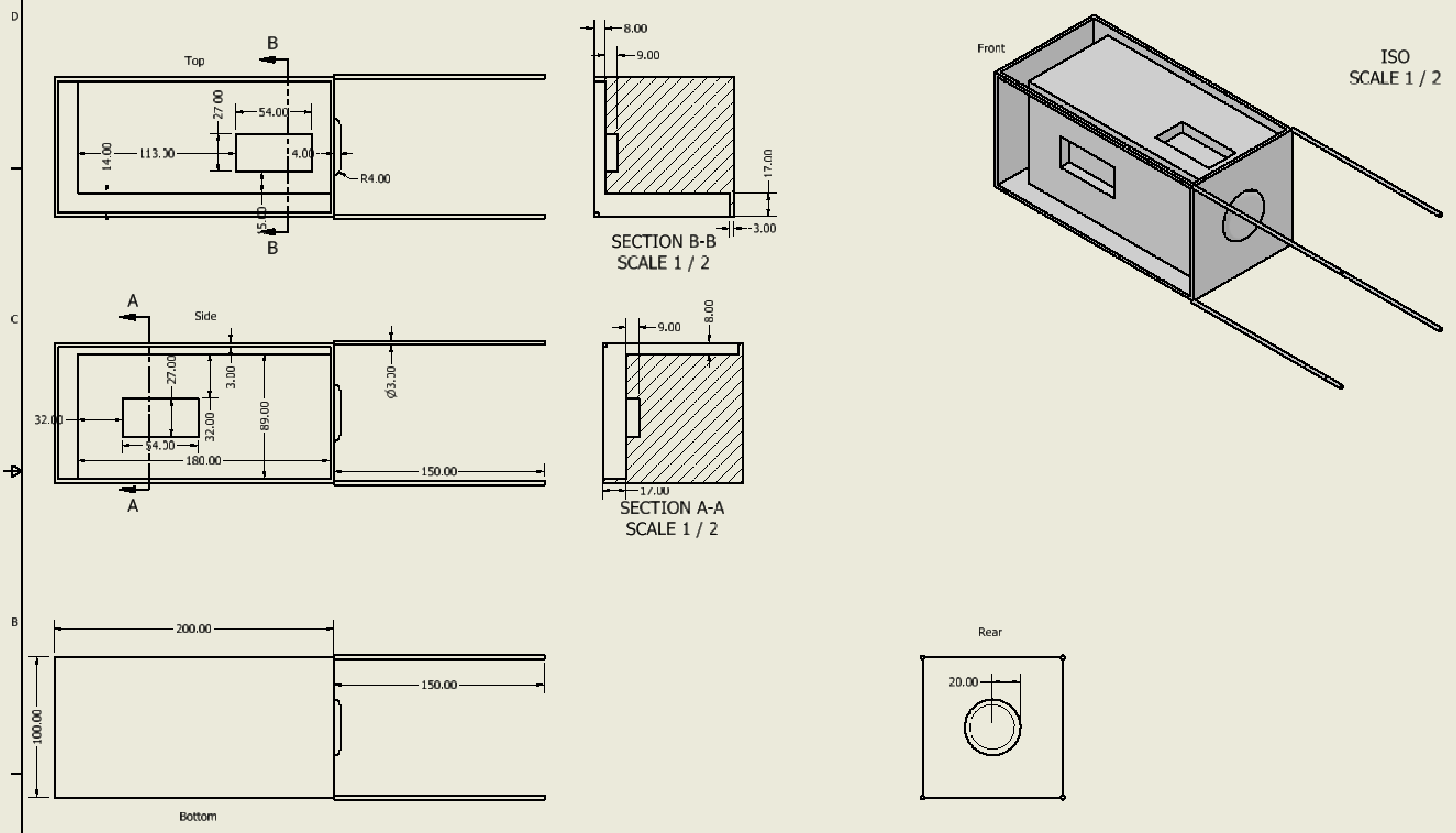
The electronics for the satellite fit inside an extruded, aluminum, rectangular tube with 3mm thick walls. The two components that get hot are the processor chip and a battery pack located on the picture below. The battery is on the side location and the processor chip is on the top. Notice that neither one is in contact with the wall of the cube sat but only in contact with the internal components. This would allow the heat to build up inside the cube sat and damage electronic components—especially when it is in the sun. Your team needs to come up with methods to make contact with the hot components and dissipate as much of the heat to space as possible. The cube sat is not sealed so there isn't any air inside that would help with cooling. You only have the one side of each component for dissipating the heat.

(2 sides were removed for visibility of the heat locations)



Two 5W Fish tank warmers are the heat sources for testing.

54mm x 9mmx 27 mm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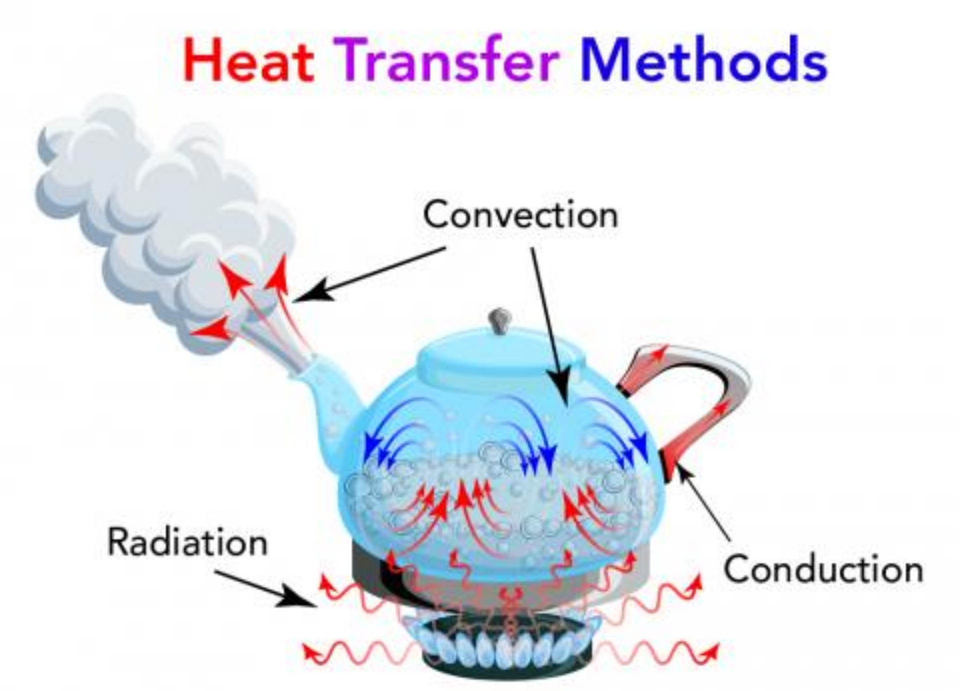
Heat Transfer

- Conduction—heat transfer by contact—like grabbing the hot handle on the tea kettle, the heat transfers to your hand by contact https://houstonpbs.pbslearningmedia.org/resource/conduction-heat-transfer-animation/unc-tv-science/

- Convection—heat transfer by flow of hot and cold fluid (air or liquid) currents. Colder and denser materials fall and warmer less dense materials rise. Like the hot water on the bottom of the kettle rising to the top of the kettle and the colder water falling down to the bottom to get heated. https://houstonpbs.pbslearningmedia.org/resource/convection-heat-transfer-animation/unc-tv-science/

- Radiation– heat transfer by electromagnetic radiation—like feeling the heat (infrared) from the sides of the kettle and the sides of the stove without coming in contact with the materials. https://houstonpbs.pbslearningmedia.org/resource/thermal-radiation-heat-transfer-animation/unc-tv-science/flame



Testing

- To simulate the processor chip and the battery we are using two 5W fish tank warmers.
- Notice that the surface is not smooth and it radiates heat from all sides.
- The more heat you can pull from one or more sides, the more heat you can remove from the satellite.
- At first this won’t seem very complicated. The difficulty comes from the vacuum of space that can act as a very good insulator. One way to test this is to put your box into an insulated bag and turn on both heaters. Without air convection, the heat builds up. After two hours or more, open the bag and measure the temperature on the satellite surfaces. If this were a satellite, all the heat will have built up inside and cooked any electronics that were inside. If you have a physics teacher with a bell jar and vacuum pump, you might be able to test it in a vacuum—it gets hot. This would be best because it would still allow for radiation to escape.

Example

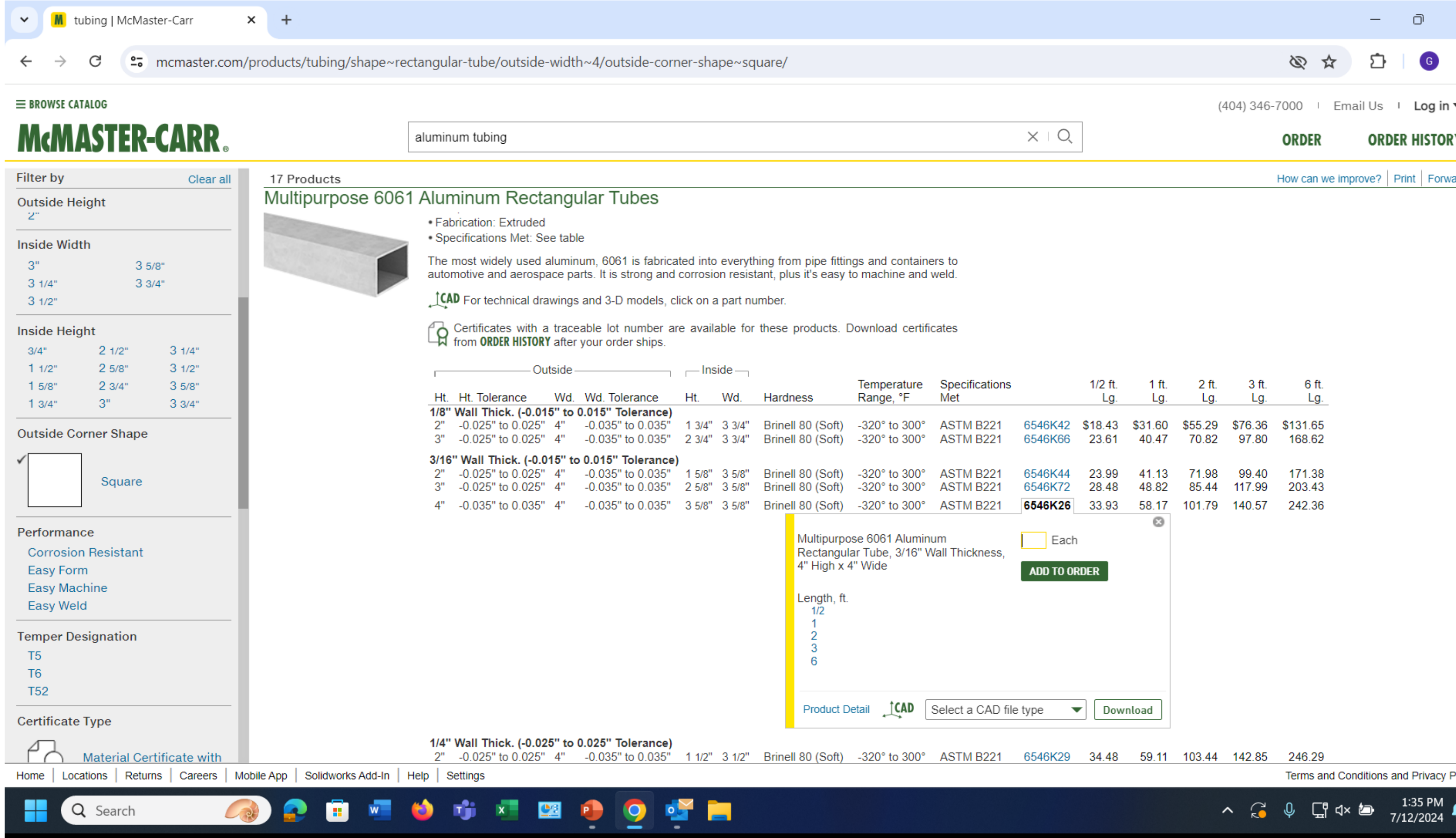
I was on a team developing a portable LED light for inside use on the ISS. I thought because it was LEDs and only 11 or 12W and had a heat sink that it wouldn’t get hot. One test was to put it in a bag and leave it on for a few hours to see how hot it would get (like if someone had stowed it but didn’t turn it off)---134 degrees F after 2 ½ hours. That was beyond the touch temperature requirements. If I had to put it in a vacuum, it probably would have been hotter.

Nearly any kind of insulated bag will work. Keep it small so you are not heating up a lot of air. Little contact with the bag is also helpful.

$12 on amazon

Rectangular Aluminum tubing—outside of cube sat

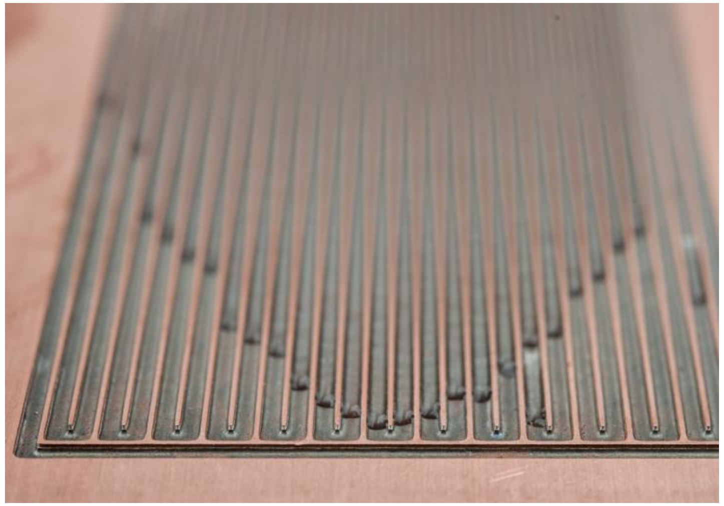
You can go to McMaster-Car and get 1ft of 4”x4” aluminum tubing for $58. I was at a metal shop and they had a 11 ¾” piece for only $12, just lucky but it’s worth checking at the metal shop near you.



Thermal spreader

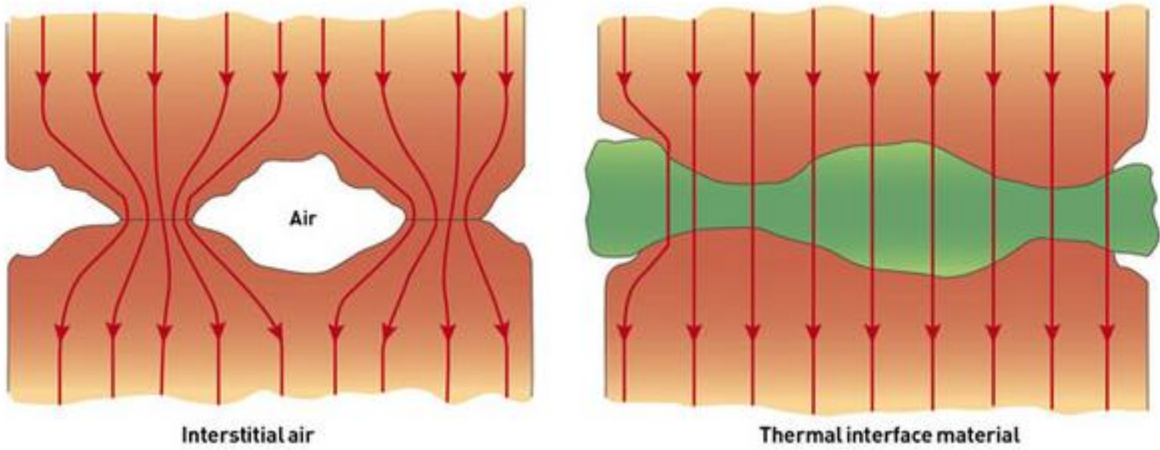
- A thermal spreader is to move the heat out from a small hotter object to a larger surface area so that the heat can be removed more easily using other components. They are usually a good thermally conductive metal that is placed in contact with a heat source (like a computer chip) using a thermal paste to ensure an even contact surface.

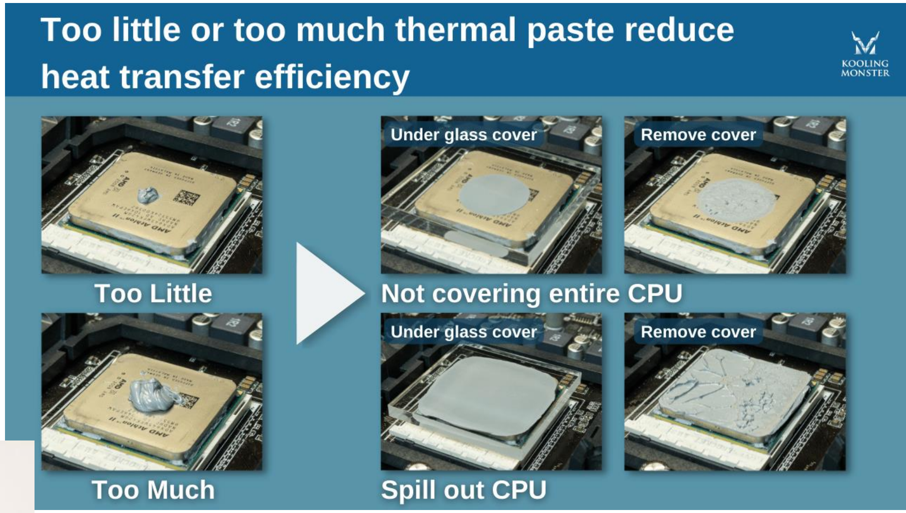
A computer chip on the left where the heat spreader has been removed where the one on the right is still in place.

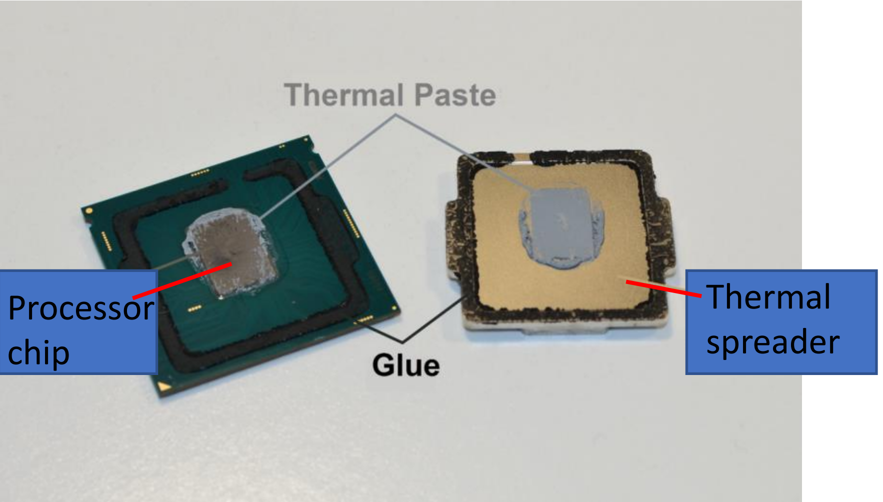


Thermal Paste

- Thermal paste is a material used to ensure good contact between a heat source and heat conductors. When two flat surfaces are placed together, any small defect or dust particles can prevent even contact between the two surfaces, causing uneven heating and cooling. A thermal paste takes up any small spaces between and gives more even cooling across the full contact area.





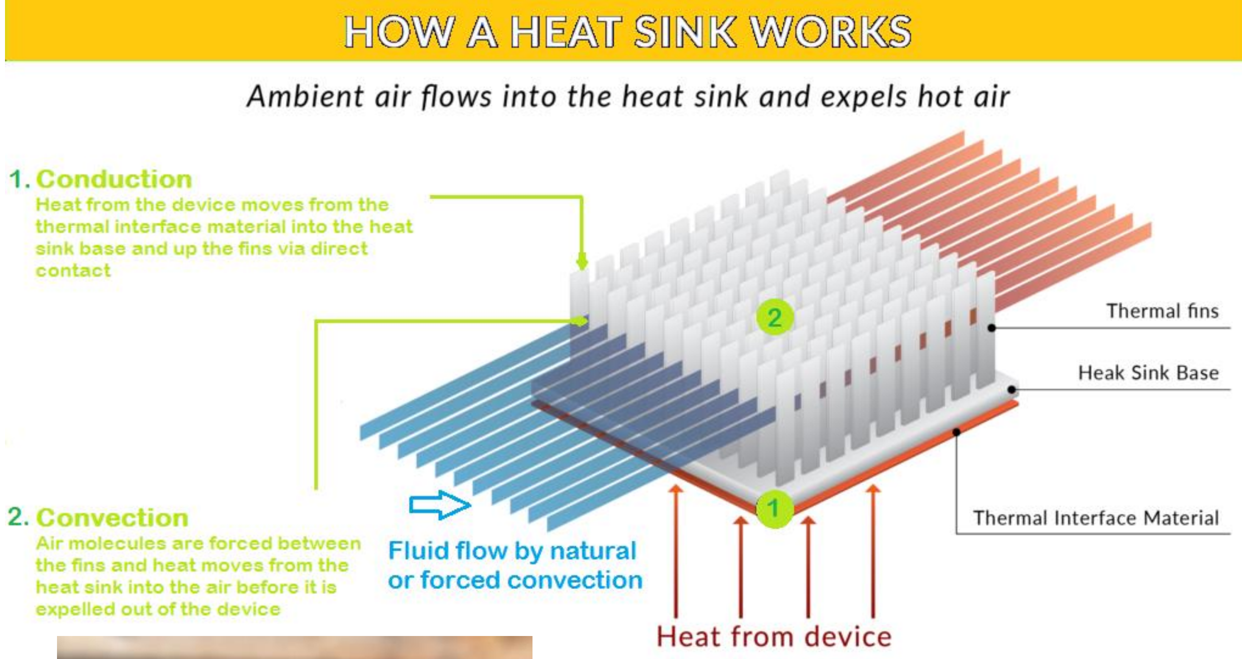


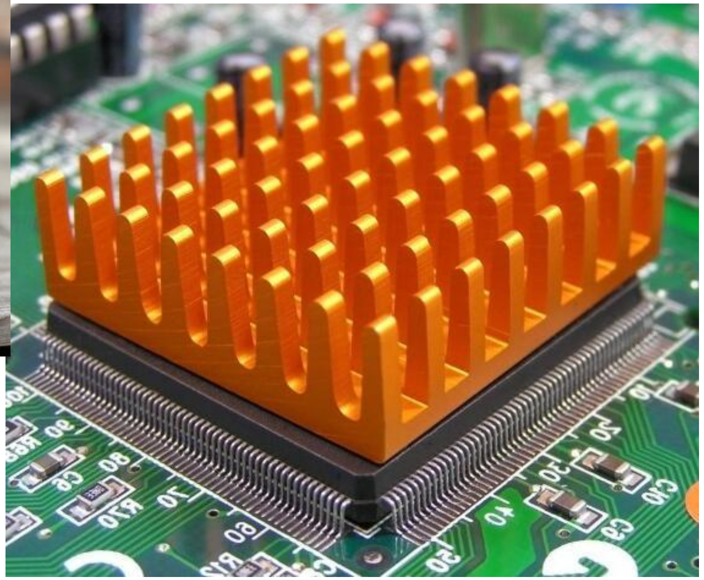
Heat sinks

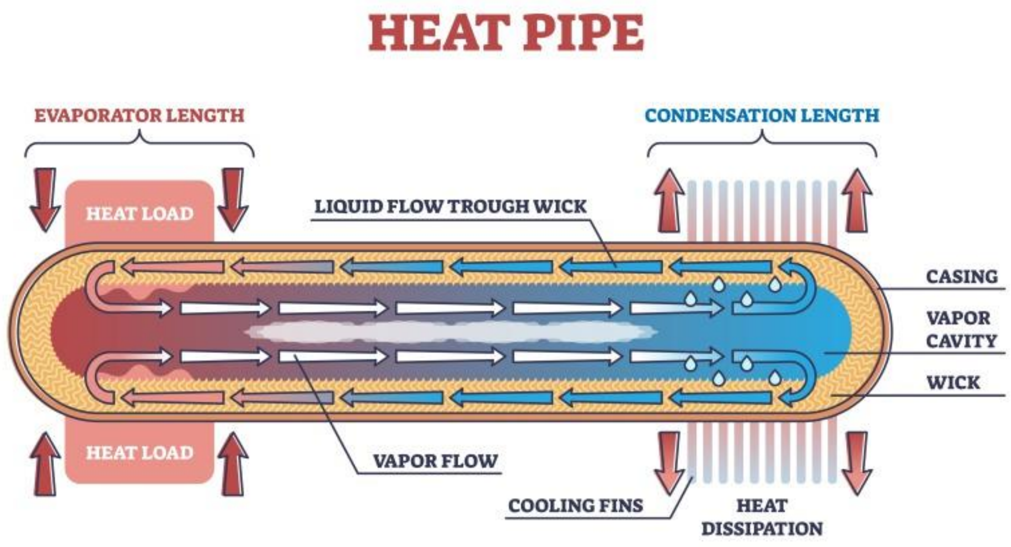
- Heat sinks can be big blocks of metal (good conductors of heat) that absorb heat by being in contact with a hot object and dissipate it slowly through conduction to another object, or they can have fins cut into to them to increase the surface area and dissipate more heat. Most computers use a combination of heat sinks, heat pipes and fans.
- Although fans turn in the vacuum of space, there isn’t any air for them to blow around to aid with cooling.
- Heat sinks with fins are not as effect in space but they are used sometimes. What is the cooling mechanism?

Testing

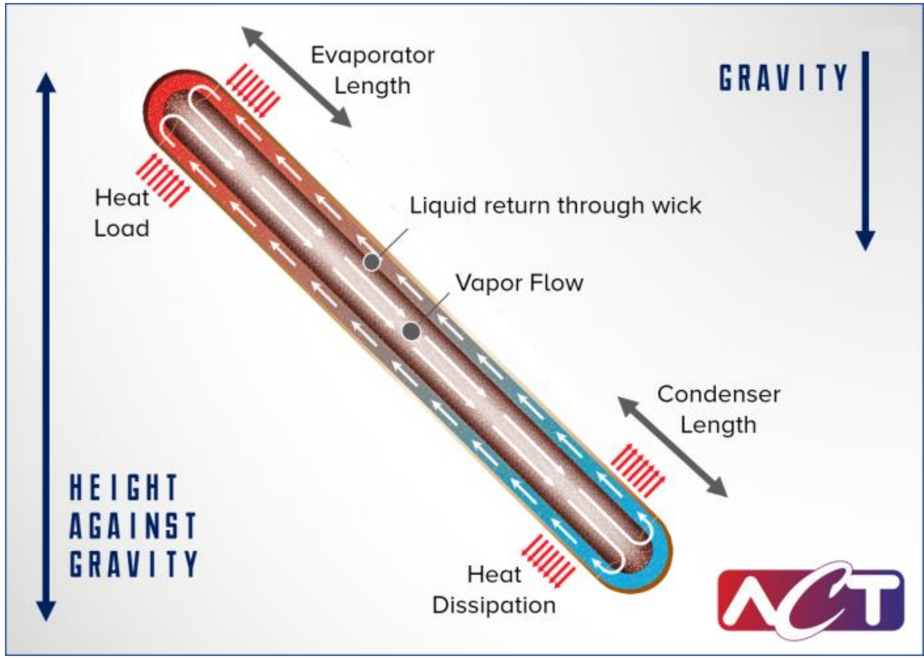
- Your physics teacher may have a bell jar and vacuum pump so you could place the 5W fish tank warmer inside the bell jar and pull out the air. Watch how the heat goes up when there is no air to help take away the heat. Use your ideas and materials to remove the heat from the chip and/or battery pack and see how your team can prevent the heat from getting too high that would damage electronics.

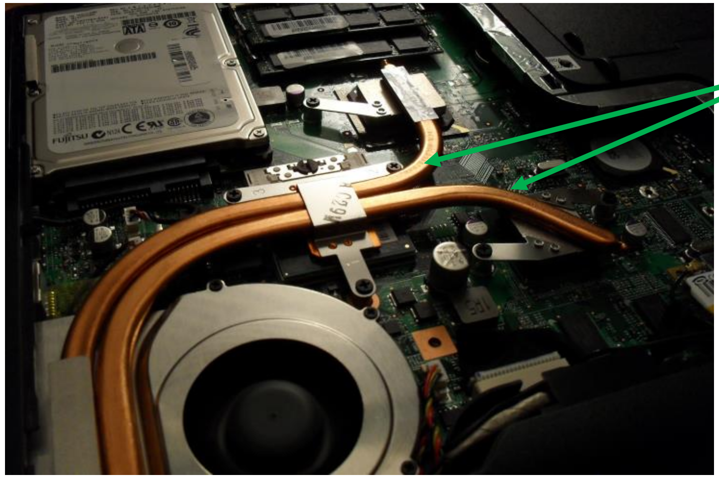






Heat Pipes





Heat pipes

Copper heat pipes in computers to cool of processors with minimal heating up the other components—not just copper bars.

Heat pipes are the most efficient method for transferring heat for many applications. They are copper tubes with a small amount of water inside (they can use other materials for specialize needs). As the water evaporates from the hot location, it carries the heat away and cools off and condenses on the cooler side of the tube. The condensed water is then drawn back to the hot side by way of the wicking action of the copper mesh on the inside walls and then the cycle happens again. Space craft have used heat pipes since the 1960s. Some are available on the internet. If you have an old laptop that no longer works, it may have some heat pipes inside.

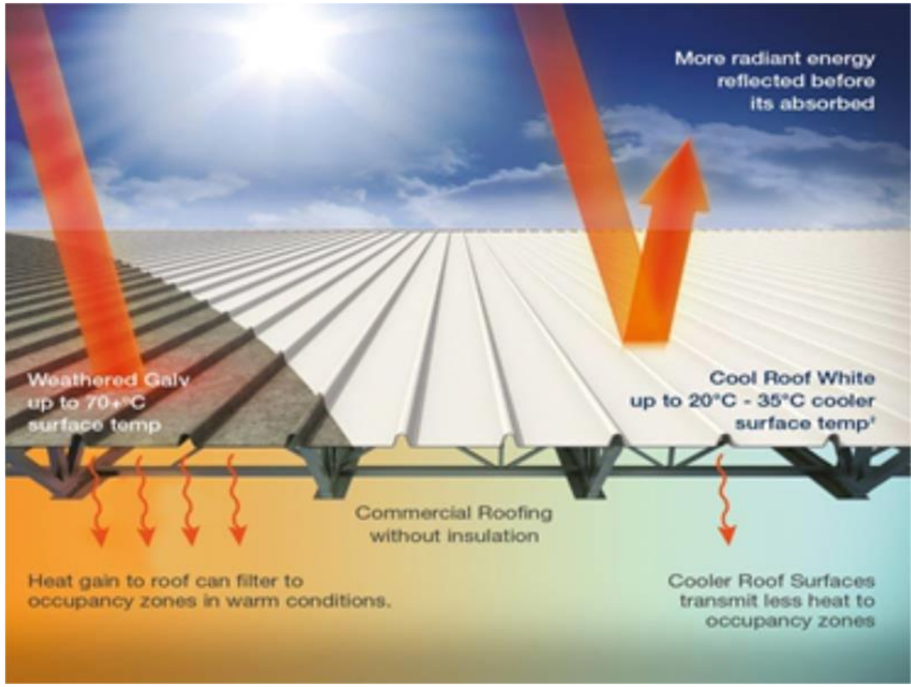
Action Labs
https://www.youtube.com/watch?v=OR8u__Hcb3k

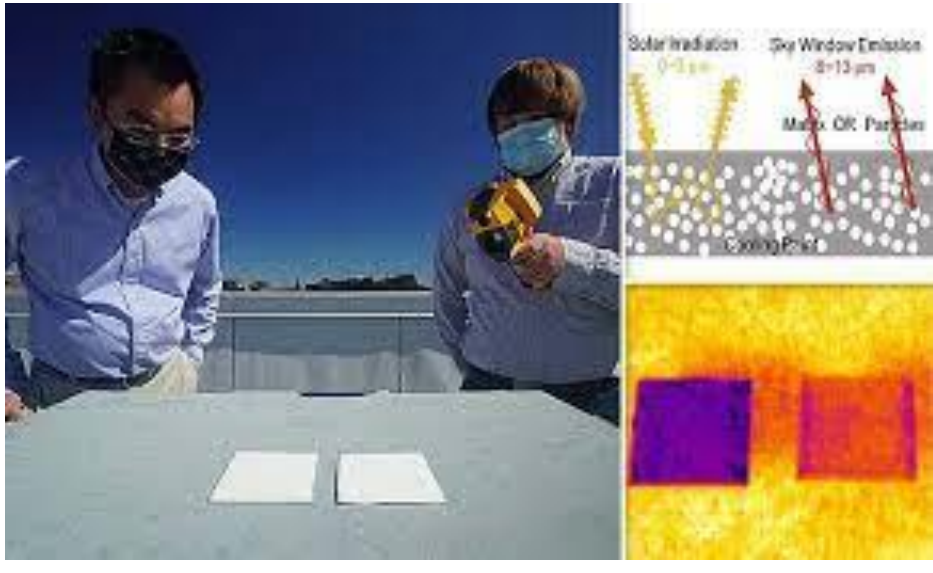
Heat pipe in laptop

- https://www.google.com/search?q=heat+pipes+&sca_esv=5da6c0e4b63a9ce6&rlz=1C1GCEA_enUS1104US1104&biw=1536&bih=730&tbm=vid&ei=9YB1ZoTpMavVp84P1_KUsAg&ved=0ahUKEwjEt5u45-yGAxWr6skDHVc5BYYQ4dUDCA0&uact=5&oq=heat+pipes+&gs_lp=Eg1nd3Mtd2l6LXZpZGVvIgtoZWF0IHBpcGVzIDIFEAAYgAQyBRAAGIAEMgUQABiABDILEAAYgAQYkQIYigUyBRAAGIAEMgUQABiABDIFEAAYgAQyBRAAGIAEMgUQABiABDIFEAAYgARI1iBQlhNYlhNwAHgAkAEAmAHHAaAB5QKqAQMwLjK4AQPIAQD4AQGYAgKgAvICwgIFECEYoAHCAgUQIRifBZgDAIgGAZIHBTAuMS4xoAfADw&sclient=gws-wiz-video#fpstate=ive&vld=cid:130842f8,vid:Qf0JShqNFME,st:0

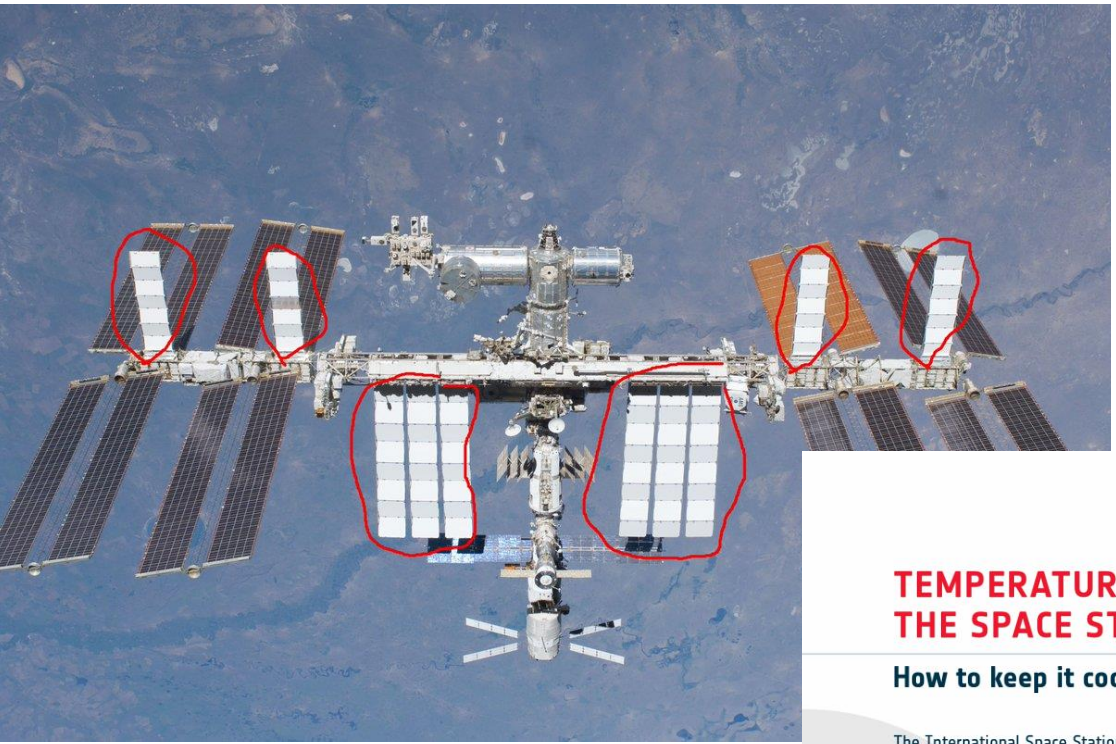
Paint?

- Heat reflecting paint—there are some paints that are very good at reflecting heat and can make a big difference in keeping metal objects from getting too hot from the sun. NASA uses them for lots of different equipment on the outside of the Space Station including cameras and different antennas.





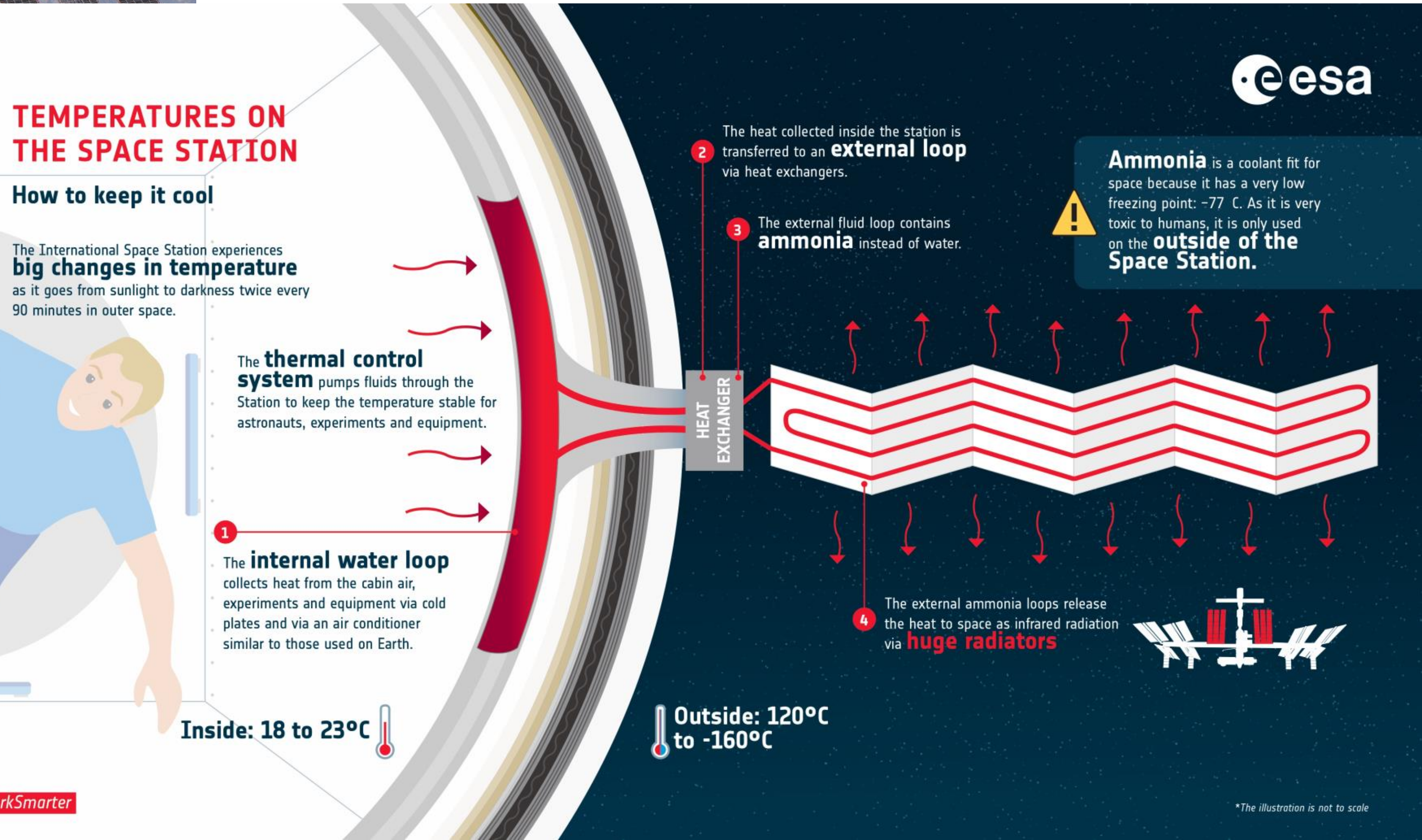
Thermal Radiators on the ISS



There are 4 thermal radiators that keep the batteries for the solar panels cool. There are another 6 that remove the heat from the inside of the space station.

https://marketing.nitrexo.com/blog-for-engineering-learners/why-thermal-engineering-is-critical-for-the-success-of-space-missions-10-issues-you-should-know

Motors, experiments, equipment and people all contribute to heating up the inside of the ISS. Air flow and water cooled plates transfer heat to the internal water loop that takes the heat outside to the heat exchanger. The heat exchanger is kind of like a car radiator where water from the hot engine flows through small tubes and the ammonia acts like the wind blowing through the radiator to remove the heat from the water. The cooled water then flows back into the station to remove more heat. The ammonia flows through tubing on flat aluminum panels that radiate the heat to space as infrared radiation.



Solar Panel Battery Packs on the International Space Station

This is one of the new battery packs on the Space Station. When in the sun, the solar panels charge up the lithium ion batteries inside the protective boxes that help dissipate the heat from charging and discharging. This one is an engineering development unit so it was never flown but is on display at Johnson Space Center.

The cooling fins are in contact with a cold plate that pulls the heat away from the whole pack and transfers the heat to the larger thermal radiators.

The white blankets are a fiber glass material with reflective mylar on the inside that helps the battery pack from absorbing solar heat when in the sun.