Applications of Steady-State Conduction

Thermal Conductivity in Heat Transfer – Lesson 4

Ansys

An Insulated House

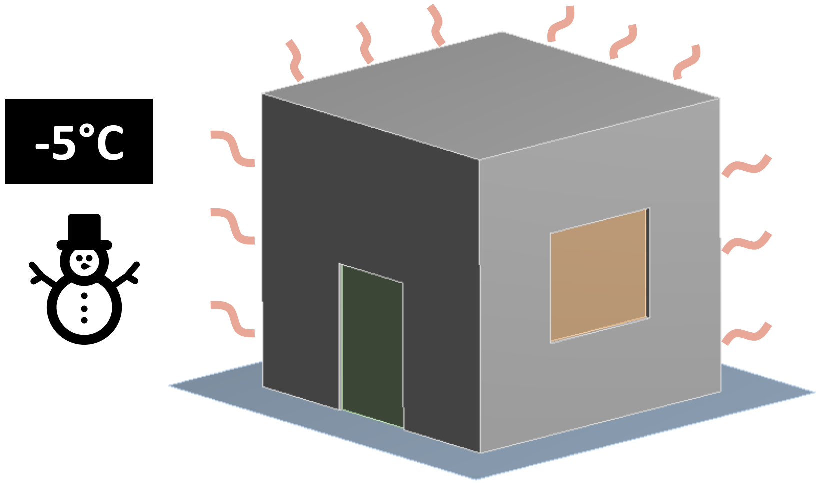
The insulation of a house provides resistance to heat flow and can significantly lower heating and cooling costs. It improves comfort and, at the same time, increases energy efficiency.

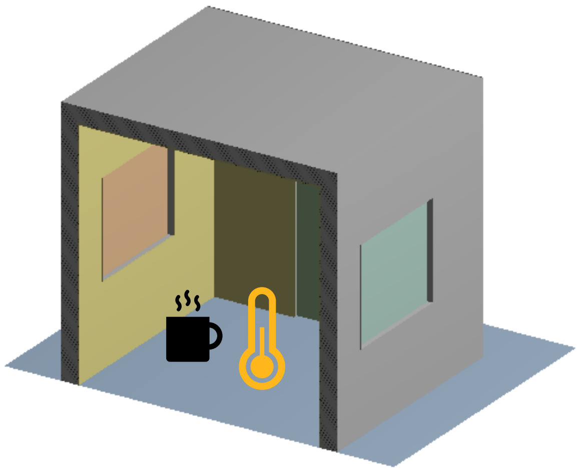
- In winter, heat flows from all heated living spaces to adjacent, unheated objects.
- Most common insulation materials work by slowing conductive heat flow. A layer of low-conductivity material is typically added to house walls.

An Insulated House

Let's conduct a steady-state thermal analysis of a simple house structure.

- The house sits in a cold environment with an outside temperature of -5°C.
- Inside the house, there is a heat source that provides constant heat flow to all internal surfaces.
- The house is assumed to be a perfect enclosure without leaks, meaning that the heat is purely transferred by conduction through the materials.
- The outside surface of the house constantly outputs heat to the cold environment by convection.



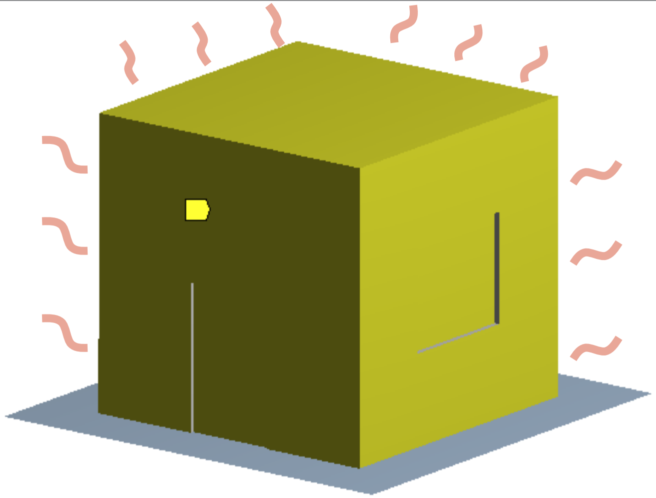


An Insulated House: Boundary Conditions

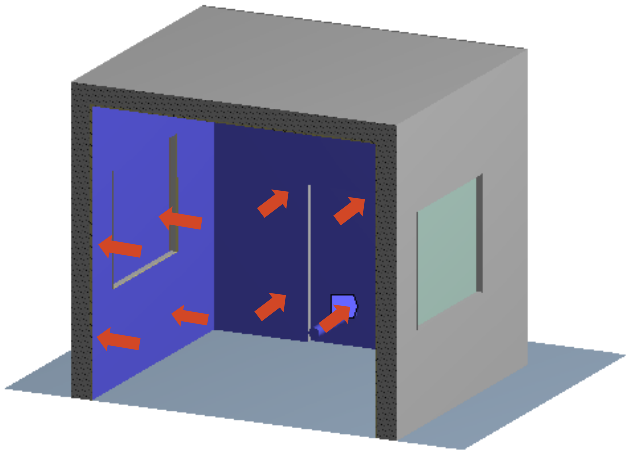
In the simulation, the boundary condition for the problem is simplified as follows:

- Constant heat flux to all interior surfaces
- Convection boundary condition for all the outside surfaces

Convection from the house surface to the outside environment

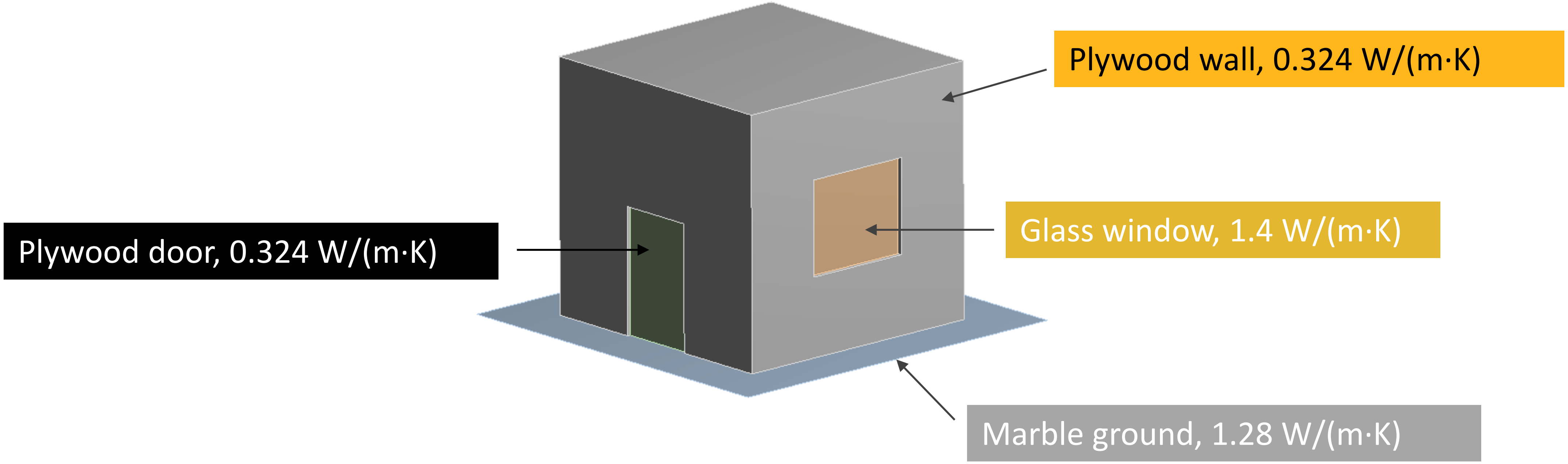


Constant heat flux to the inside surfaces



An Insulated House: Thermal Conductivity of Materials

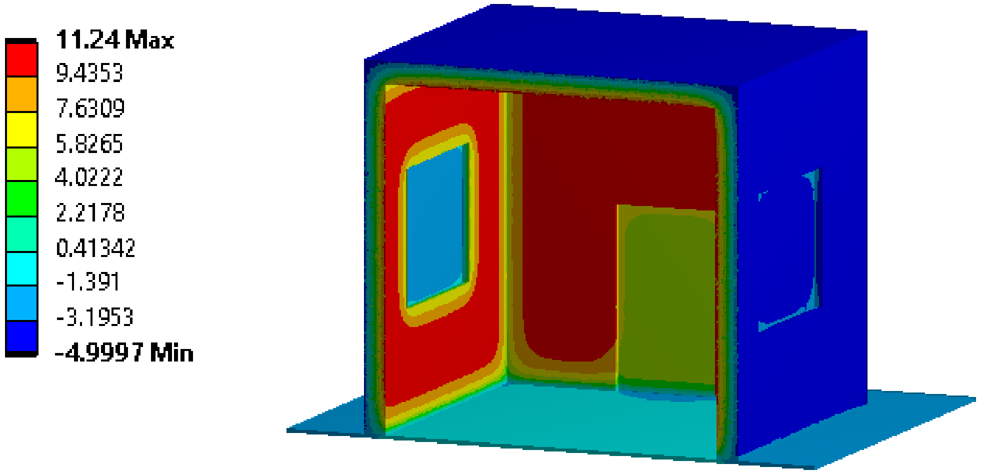
In this simulation, materials are all isotropic and with constant thermal conductivities.



An Insulated House: Results Without an Insulation Layer

Let's have a look of the results from this simulation.

- Note the inside temperature variation over the windows and doors. Under the same heat flux, the higher the thermal conductivity is, the lower the temperature change will be.
- The wall and the door are made of the same material. However, because of different thicknesses, the temperature change is different.
- The outside surface is exposed to a -5°C environment. Therefore, it's expected to have close to a -5°C temperature.



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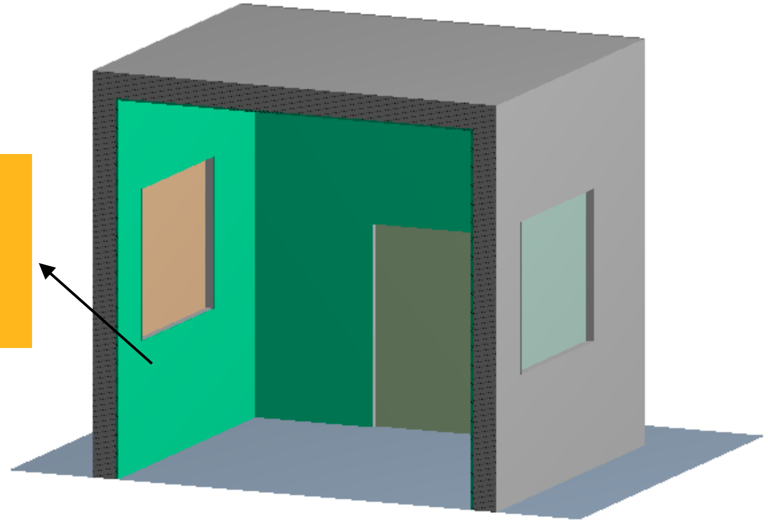
An Insulated House: Adding an Insulation Layer

Now, let's add a layer of insulation to the inside surface of the house.

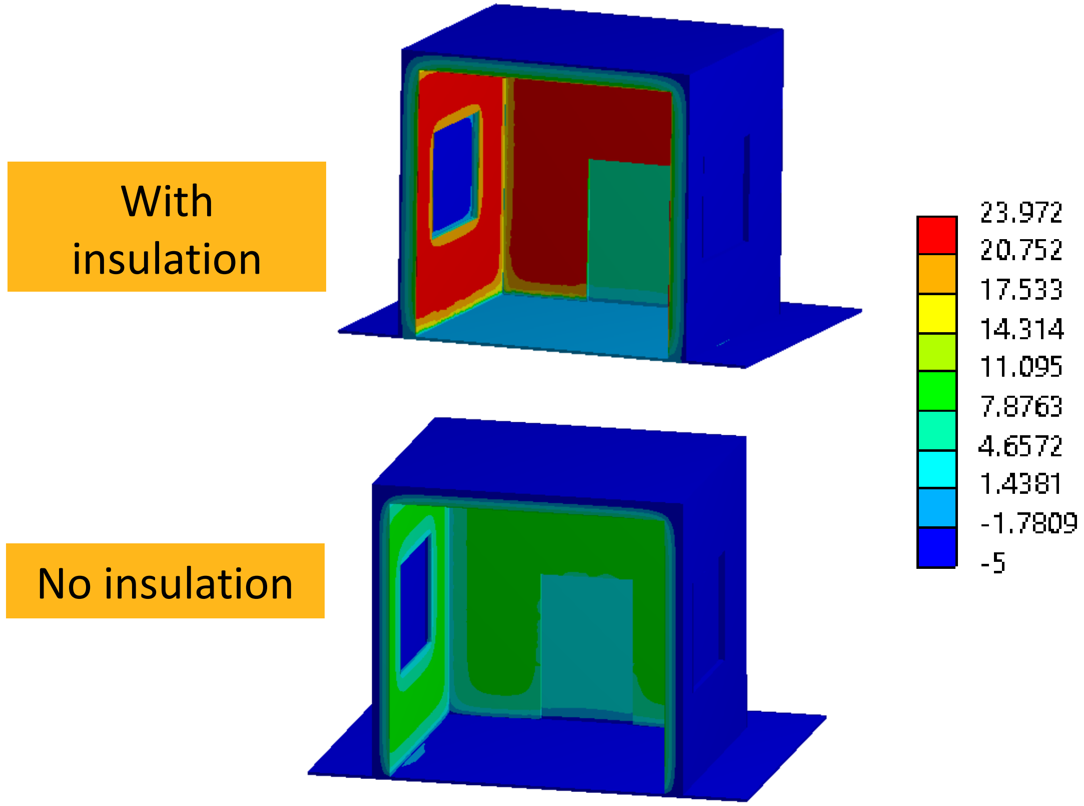
- The insulation layer is made of Styrofoam, a material with low weight and low thermal conductivity.
- In this simplified model, we assume that the insulation layer perfectly covers all exposed surfaces (no gaps, perfect conductance), excluding the window and door area.

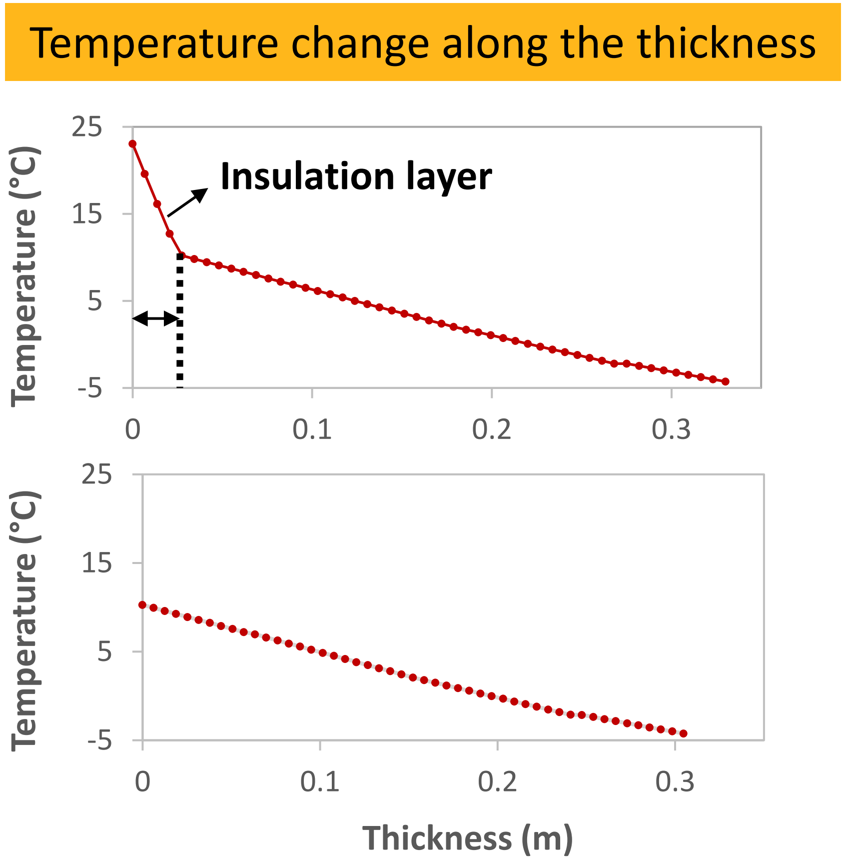
Styrofoam layer
Thermal conductivity 0.02 W/(m·K)
Thickness 25.4mm



An Insulated House: Adding an Insulation Layer

Compare the temperature results of the insulated house and the uninsulated house:

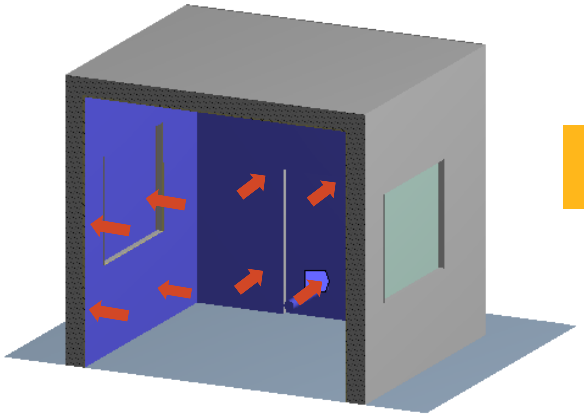




An Insulated House: Discussion of Boundary Conditions

In this simulation, what if we remove the convection boundary condition?

- In the absence of the boundary condition, this problem cannot form a steady-state system, because the inputs and outputs of heat are not balanced.
- Solving this as a steady-state problem will lead to unreasonable results (infinitely large temperature) or error.



What if no convection?

Heat flux

Consider a structural problem, can we solve a static analysis with loads, but without the boundary condition?

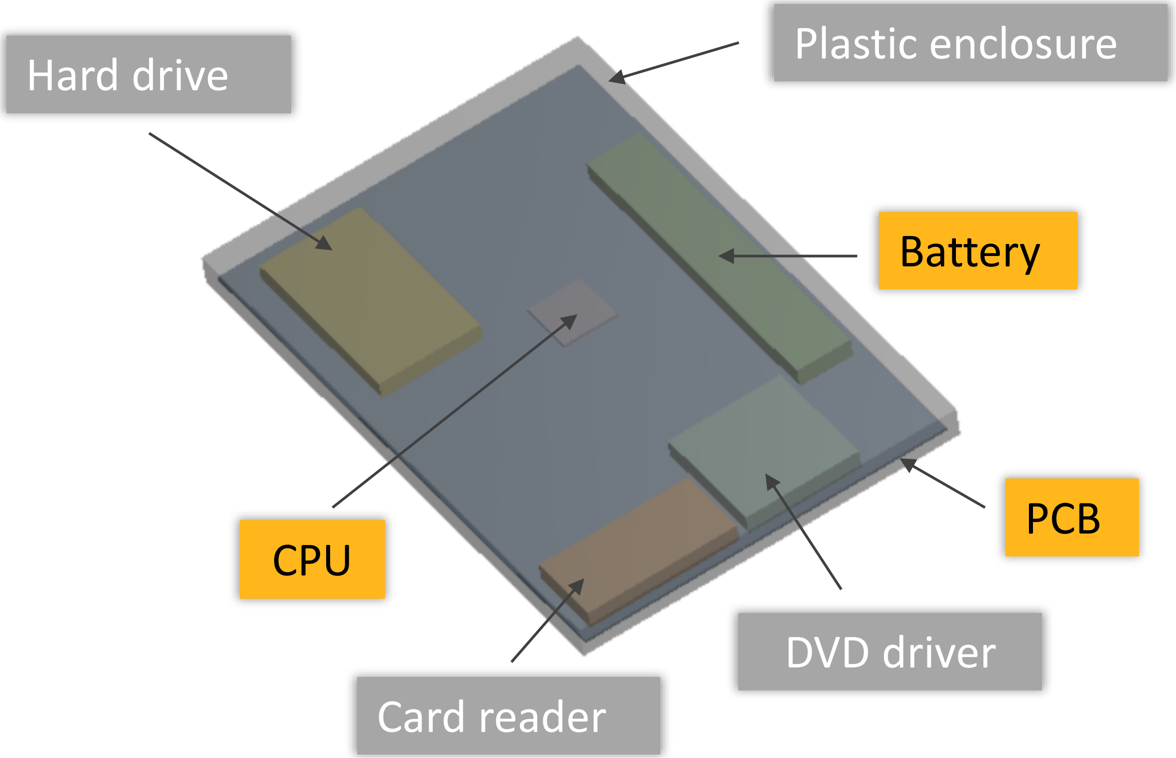
Laptop Heating

Laptop heating is a problem that engineers must consider in the design of the product. Overheating can damage the electronics components inside it. Moreover, it can even lead to burns or other safety issues.

- A laptop is a complex system and has many components. The main heating source inside a laptop is the CPU and the battery.
- The components are in contact with each other. Heat transfer is mainly done by conduction.
- Many laptops are installed with a cooling fan to output the heat to the ambient air by convection.

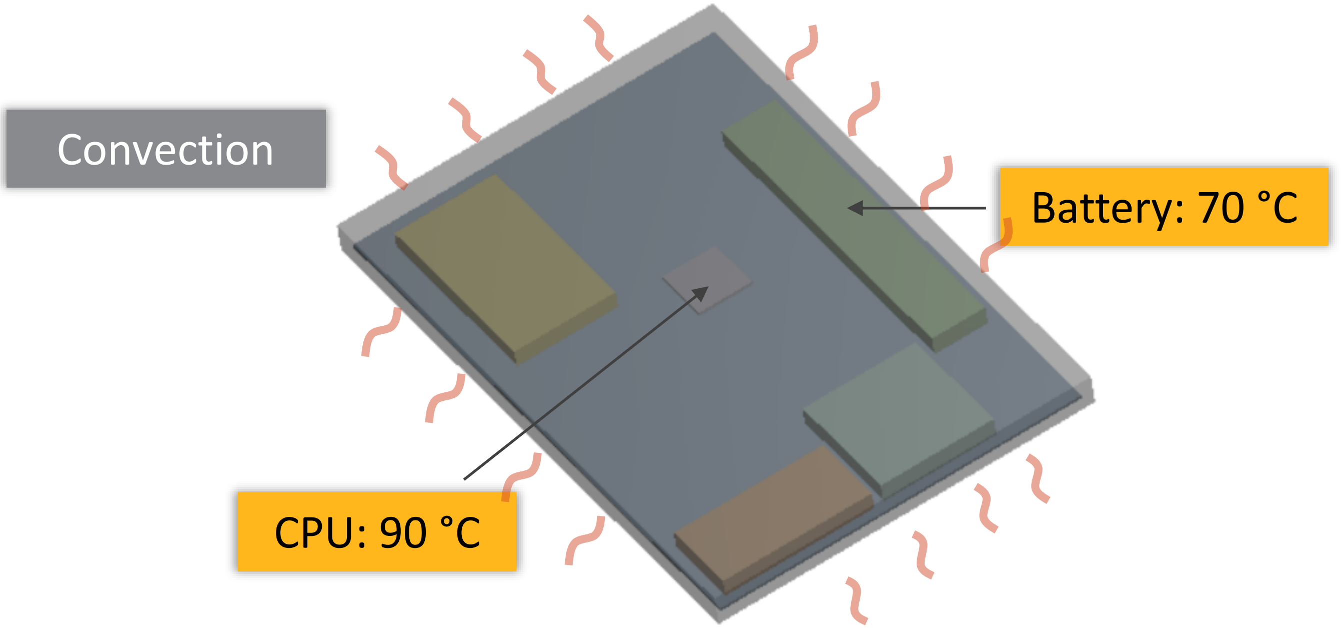
Laptop Heating: Parts

Let’s conduct a steady-state thermal analysis of a simplified laptop system.



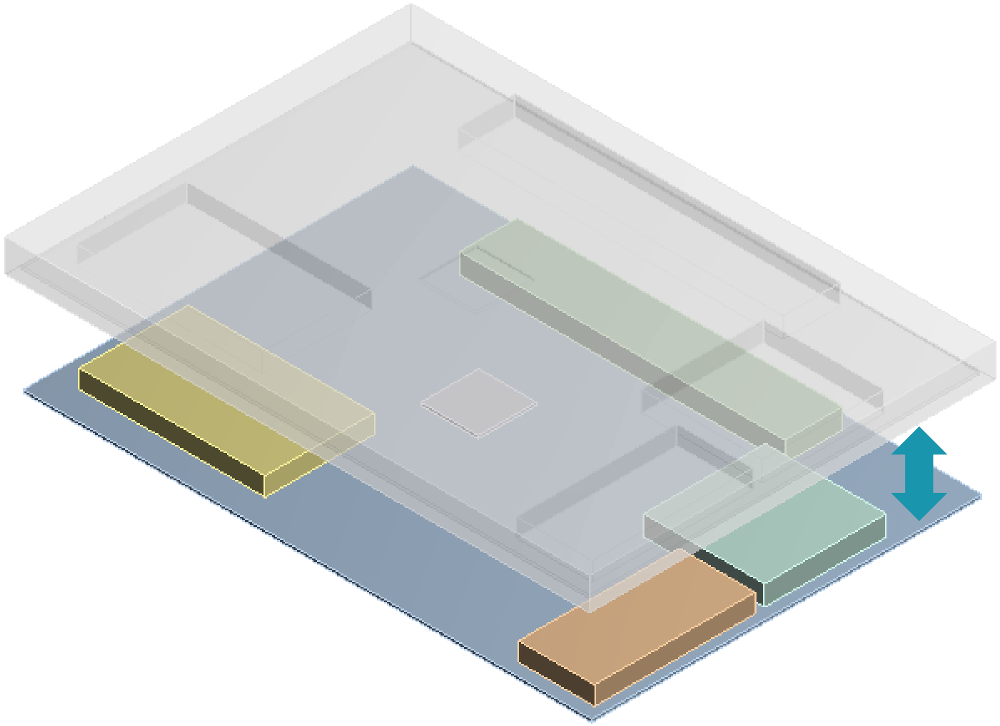
Heating Inside a Laptop: Boundary Conditions

- The two main heat sources in a laptop are the CPU and battery. In this simulation, we defined ixed temperatures on the CPU and battery parts.
- In this simplified model, the cooling fan is not considered. Convection is modeled on the outside surface of the enclosure for outputting of heat to the ambient air.



Heating Inside a Laptop: Contacts

Thermal contacts are defined between all the electronic parts and the enclosure. Between the electronic parts, the contacts are all perfect. For the contact between the electronic parts and the plastic enclosure, perfect and imperfect contacts are tested.



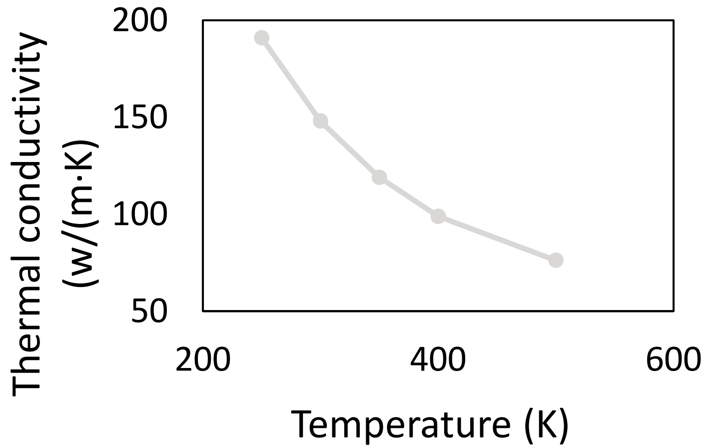
Between parts and enclosure

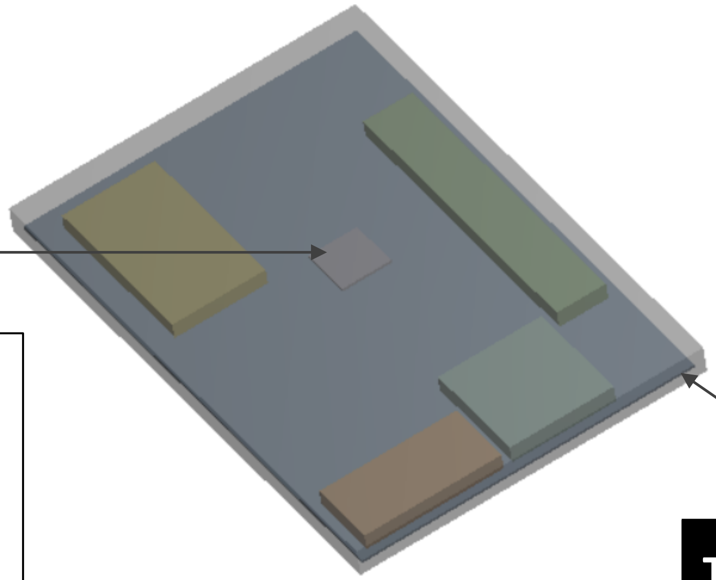
- Perfect contact
- Imperfect contact

Laptop Heating: Materials

Temperature-dependent thermal conductivity is modeled for the CPU part, and orthotropic thermal conductivity is used for the PCB. The rest of the materials are modeled with isotropic and constant thermal conductivity.

CPU: temperature-dependent



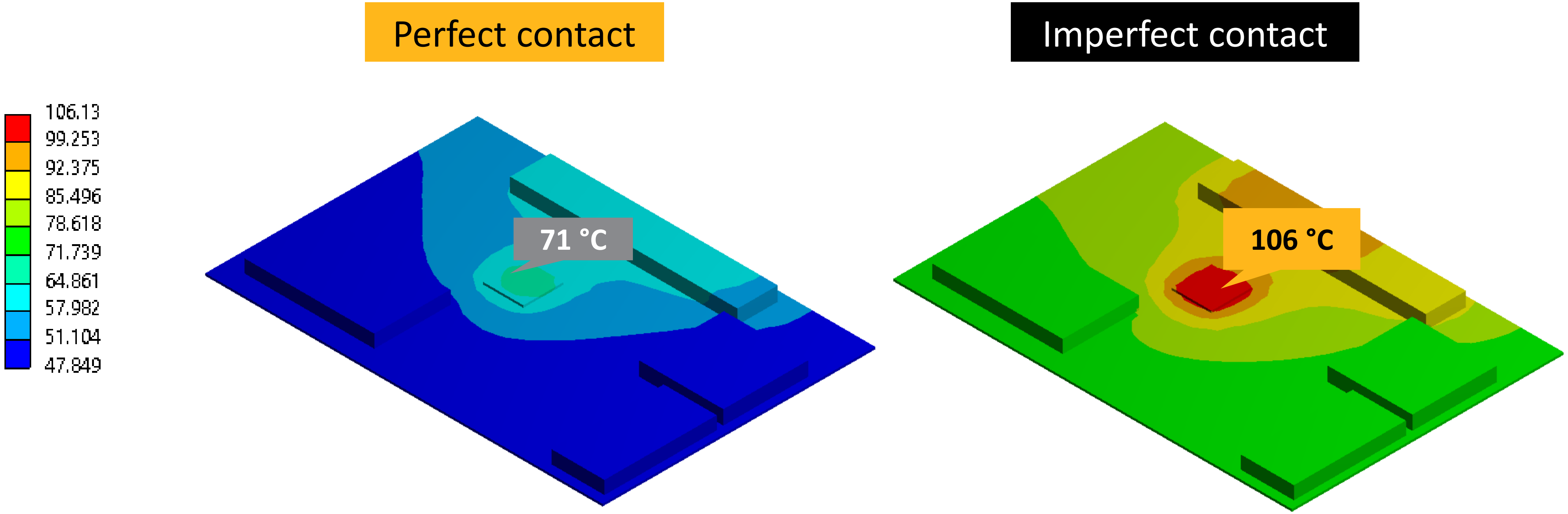


PCB: orthotropic

Thermal Conductivity (W/m·K)	
Out-of-plane	0.25
In-plane	390

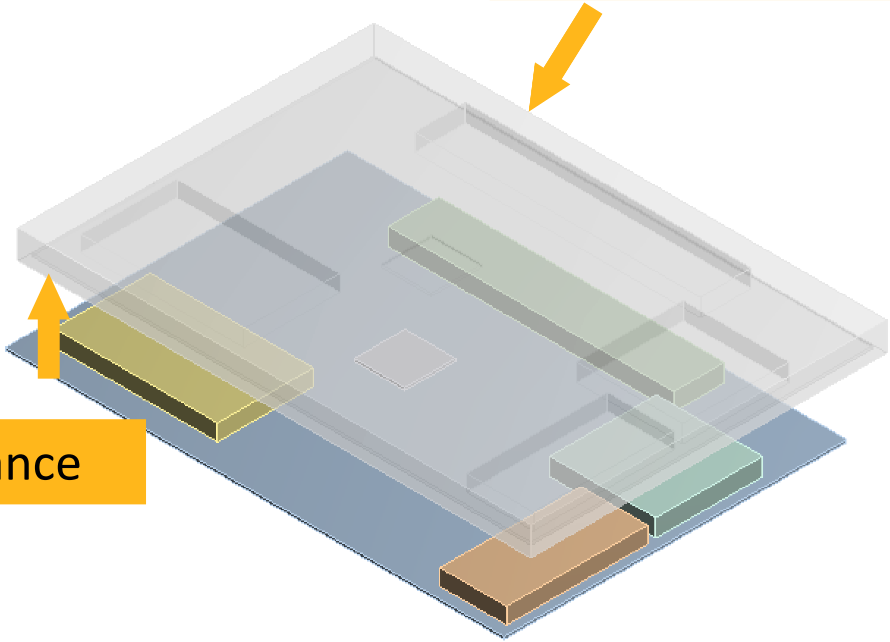
Laptop Heating: Results on the Electronic Components

Perfect contact results in a lower temperature on the electronic components.



Laptop Heating: Results on the Electronic Components

Perfect contact exerts no thermal resistance between the electronic component and the plastic closure. This way, more heat can be transferred to the enclosure and further transferred to the ambient by convection.



Calculate Input and Output Heat

We can validate the results to show that the input heat is equal to the output heat.

Internal heat generation magnitude × Volume

Input heat

$$(9e6\ W/m^3 \times 2.738e-6\ m^3) + (3e5\ W/m^3 \times 1.01e-4\ m^3) = 54.95\ W$$

Output heat

Reaction on convection boundary

$$54.95\ W$$

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