Group 8: Temperature Profiles in Home Ovens and Refrigerators

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- Data Acquisition
- Experiments
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- Conclusion

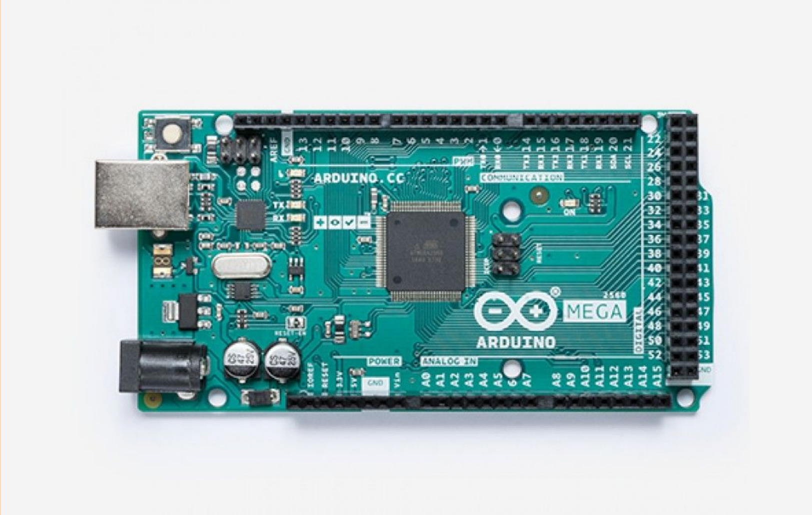
Introduction

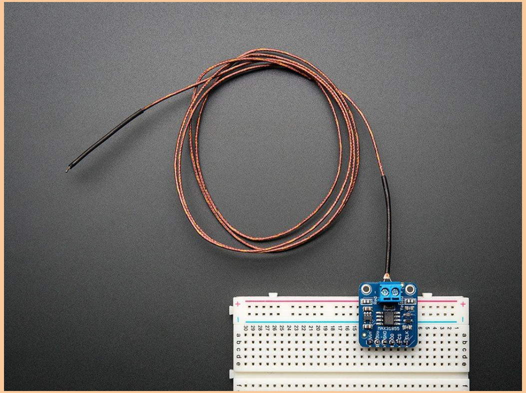
How is our project useful?

- We can compare how different types of ovens heat up.
- We can study how refrigerators control their temperature
- Also study properties of our instruments: how long it takes for them to reach equilibrium with the environment etc…
- This is cool, because we can see how temperature changes in ovens through things like different cooking processes!

Instruments

Instruments

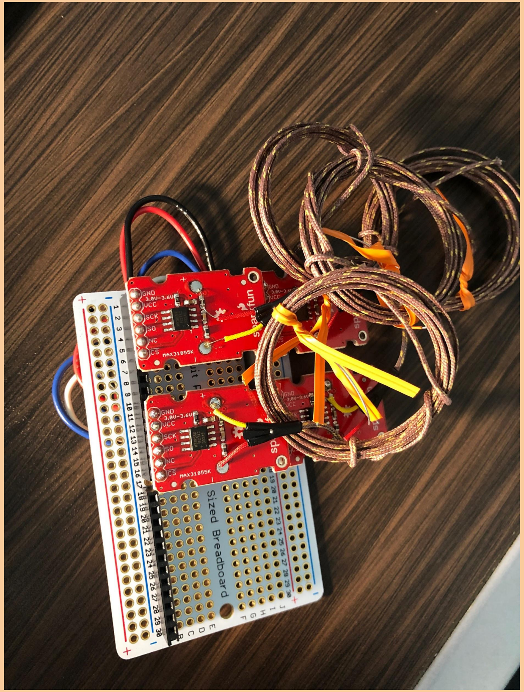


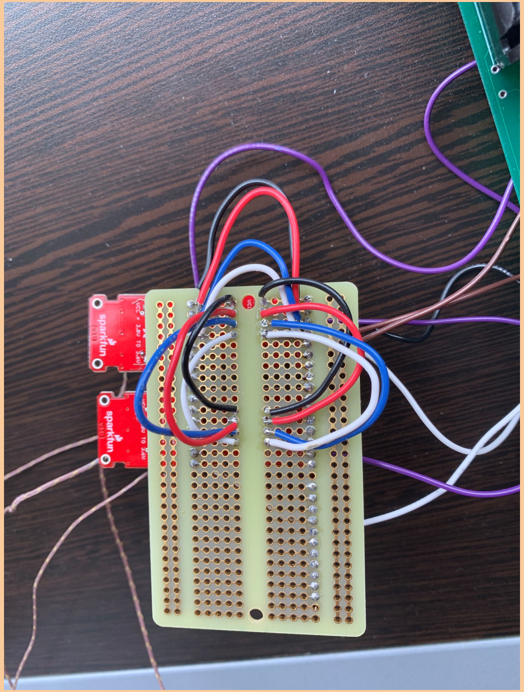


Arduino Mega 2560

Adafruit Thermocouple and Amplifier Breakout Board

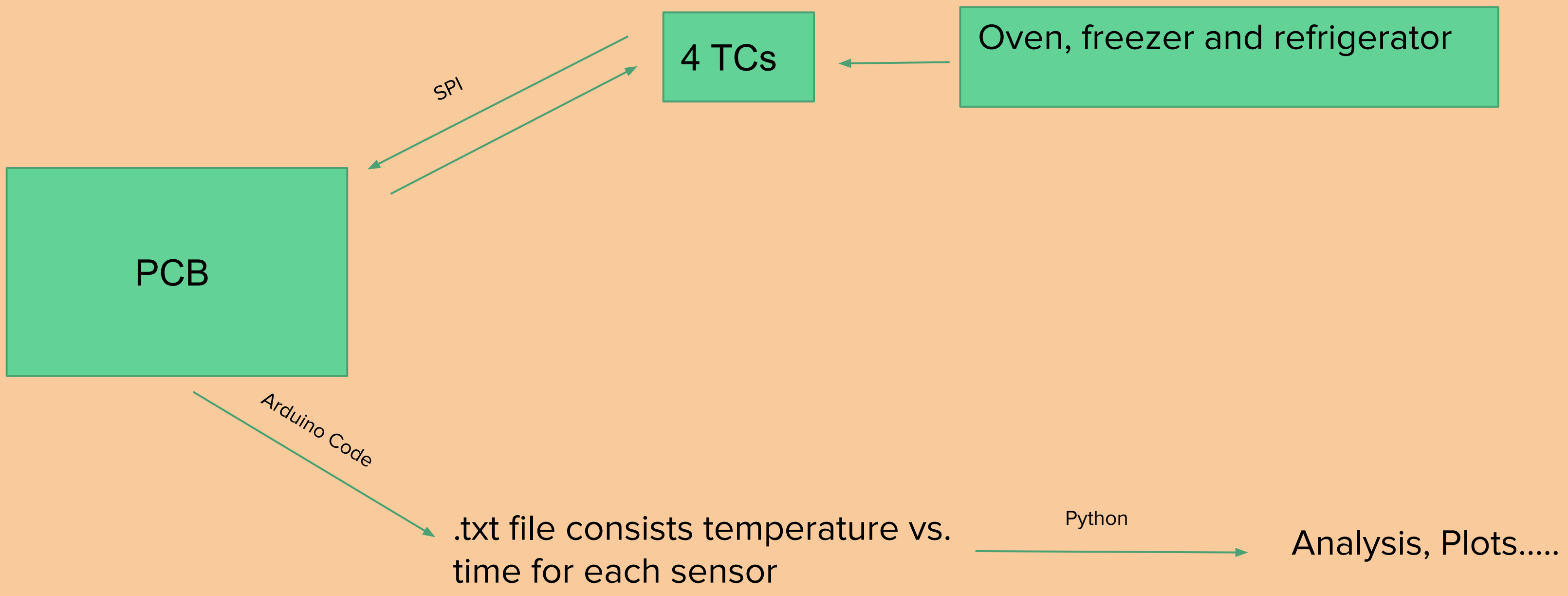
Thermocouples





- We have two sets of thermocouples. that is 8 thermocouples in total
- Every set includes a PCB which is connected to 4 thermocouples via SPI
- Every thermocouple record the temperature

Data Acquisition



Experiments for oven, fridge and freezer

Experiment in the fridge and freezer

Procedure:

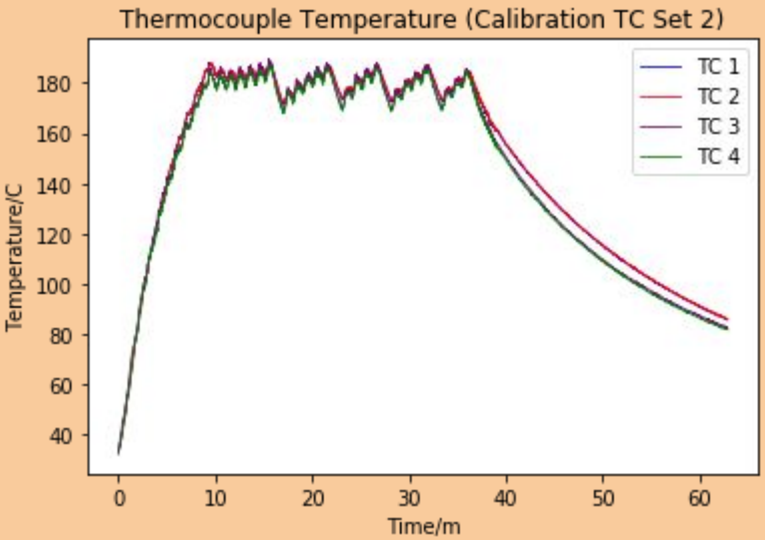
1. Open the door
2. Put a set of thermocouples inside the fridge or Freezer, start recording the data
3. Shut the door and keep recording for > 4 hours

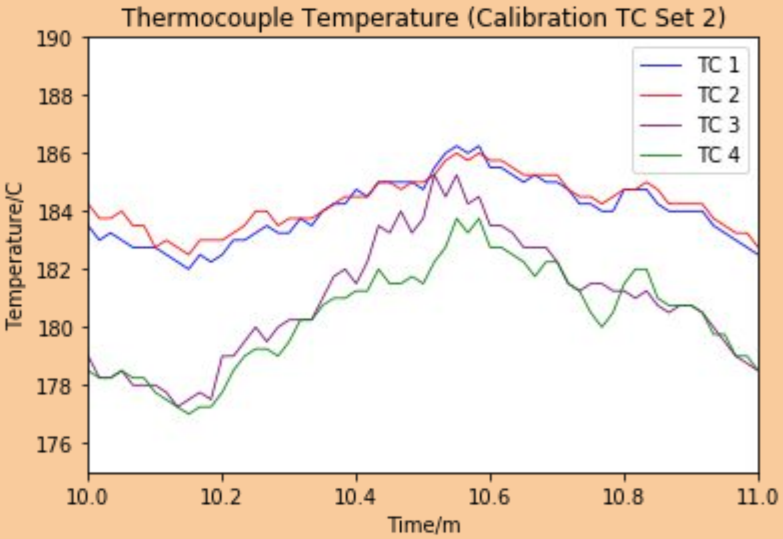
Experiment in the Oven

Procedure:

1. Put a set of thermocouples inside the oven
2. Set for 180 celsius, turn on the oven
3. After heating 30 minutes, turn off the oven
4. Keep recording data for 30 minutes as the oven cools down
5. After the oven is completely cooled down, repeat 1-4 with
   A different position

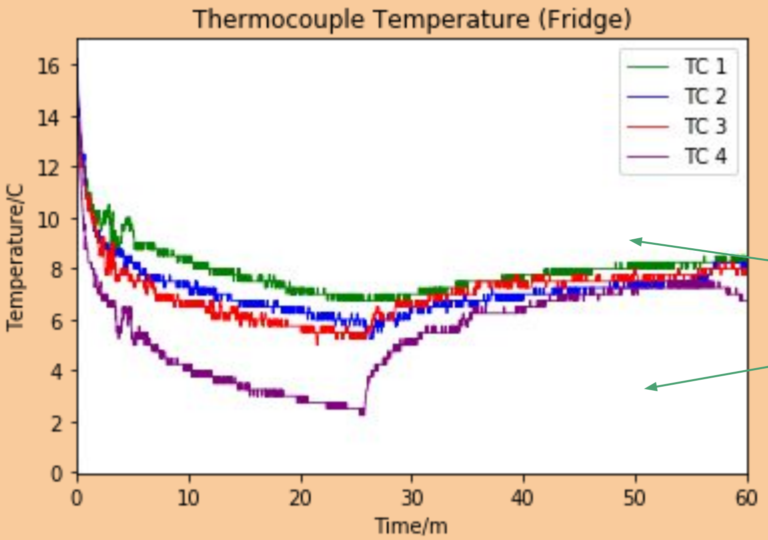
Calibration Data for PCB (in Mike's oven)

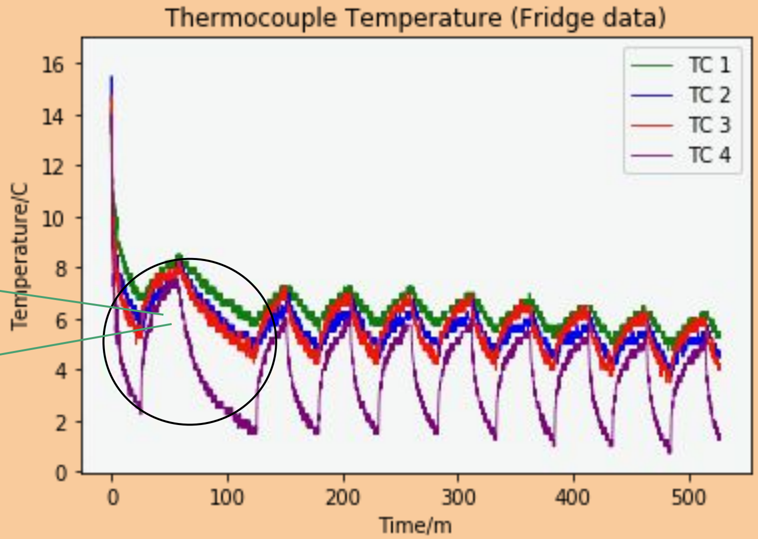




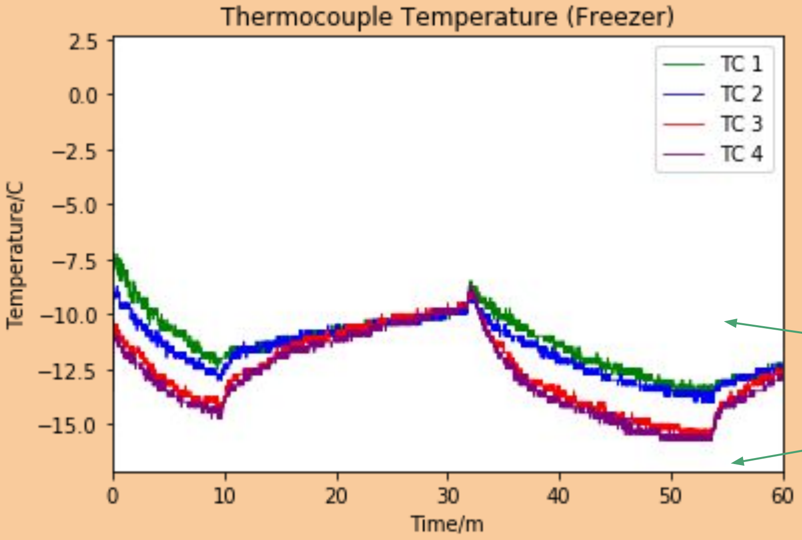
Analysis

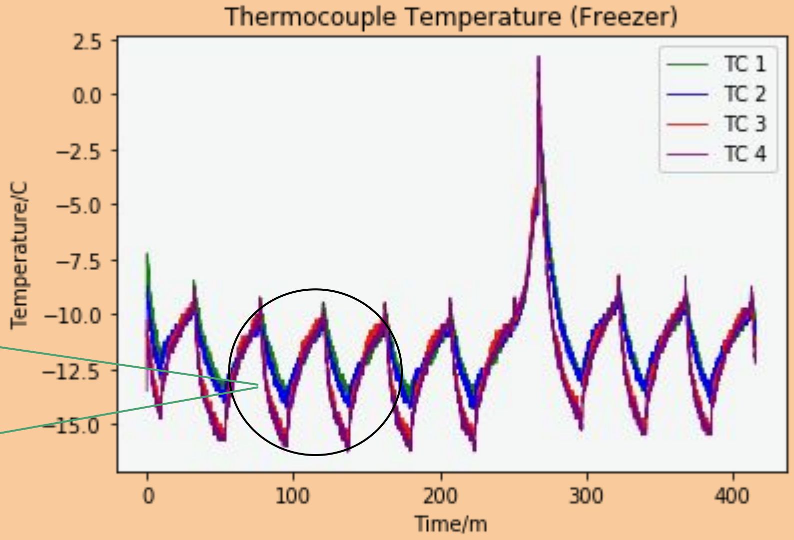
Data for fridge





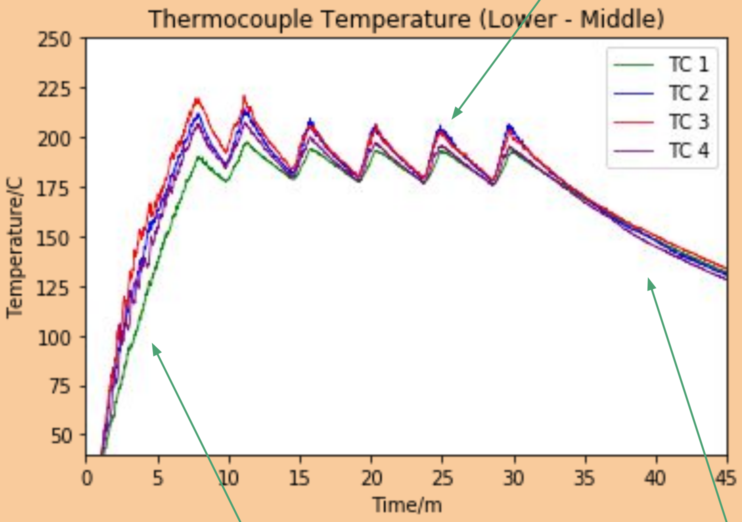
Data for freezer

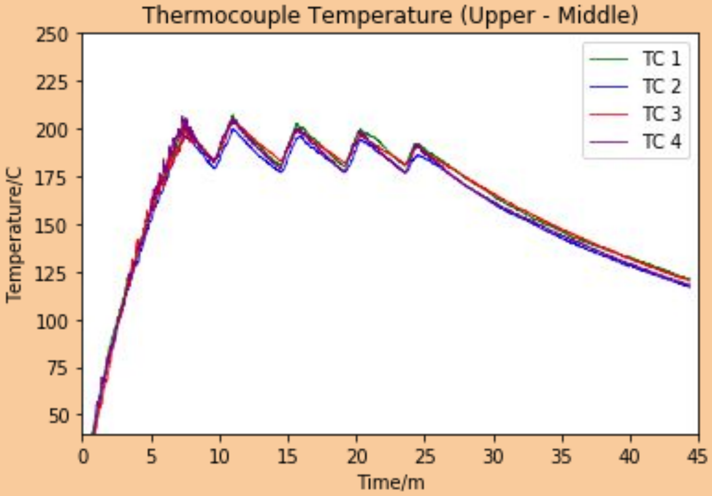




Data for John’s Oven

Oven reaches
targeted temperature

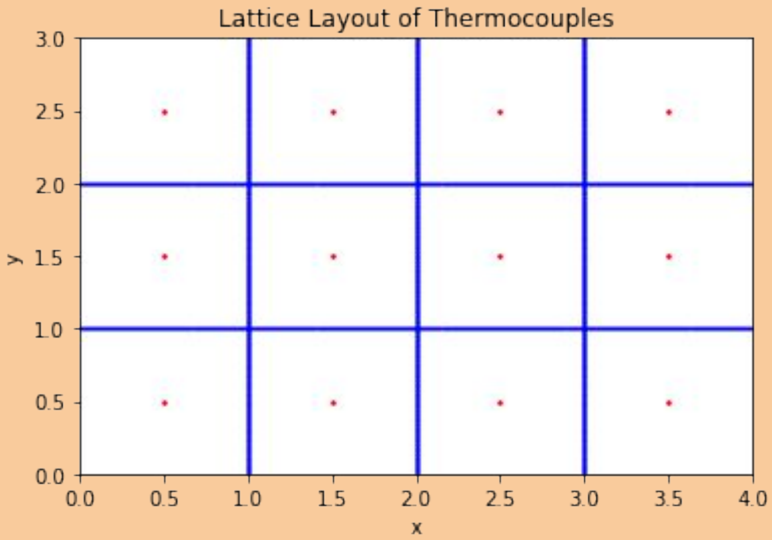




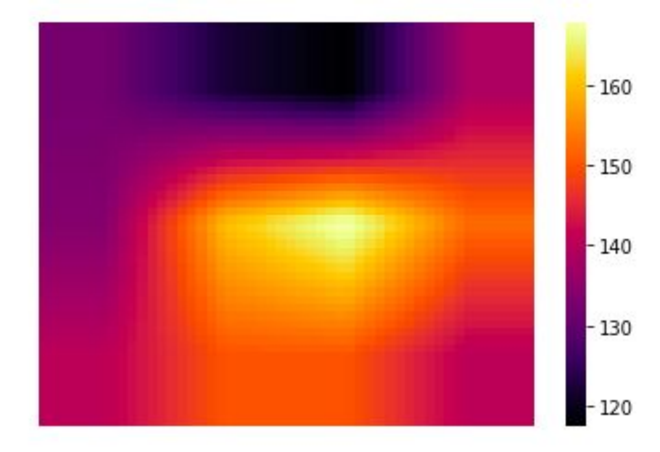
Oven started heating Oven shut down

Coarse-Graining

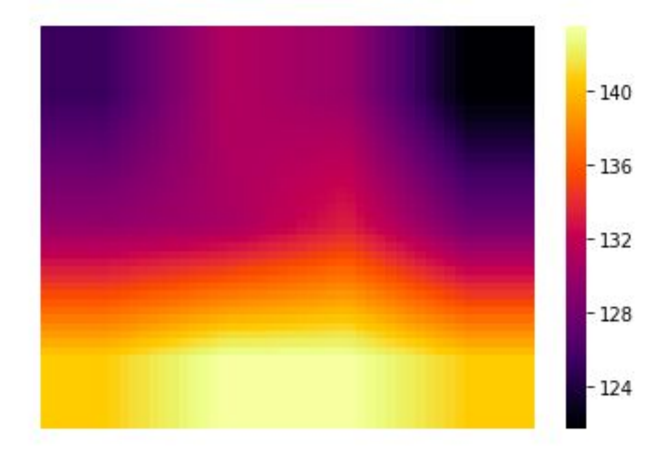
- Data acquisition: not enough thermocouple, take measurements on each constant z-slices in each trial, and carry out multiple trials.
- Coarse-graining method: evenly divide each z-slice into squares each of which contains exactly 1 thermocouple at the center. Do coarse-graining modelling for different scaling parameters. Find the critical scaling parameter for the the approximation is better compare to others.



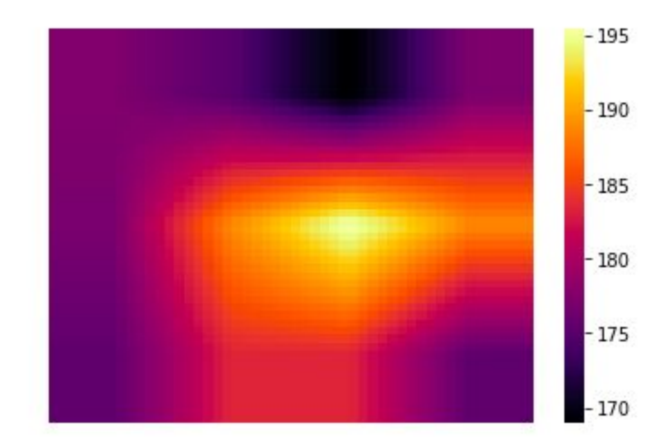
Data for Oven (Lower Rack)



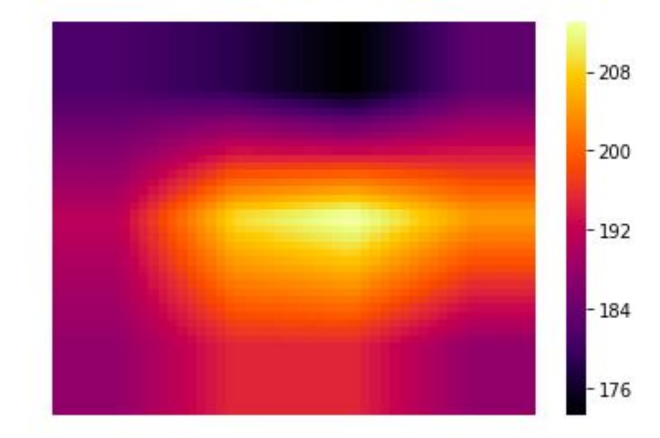
During Heating.



Cooling down.



Local minimum.



Local maximum.

Heat Equation

$$\frac{\partial T}{\partial t} = \kappa \nabla^2 T$$

$$\begin{cases} T(\mathbf{x}, 0) = T_r, \ \forall \mathbf{x} \in \Omega \\ \partial_x T(0, y, z, t) = \partial_x T(L_x, y, z, t) = 0, \ \forall t \geq 0 \\ \partial_y T(x, 0, z, t) = \partial_y T(x, L_y, z, t) = 0, \ \forall t \geq 0 \\ \partial_z T(x, y, L_z, t) = 0, \ \forall t \geq 0 \\ T(x, y, 0, t) = T_o, \ \forall t \geq 0 \end{cases}$$

$$T(\mathbf{x}, t) \approx T_o + \frac{16(T_r - T_o)}{\pi} \sin\left(\frac{\pi z}{2L_z}\right) e^{-\pi\kappa z t/2L_z}.$$

Explanation of the Heat Equation

1. The Heat equation can be derived from random walk model, a continuous limit of lattice random walk. Kappa is air diffusivity.

2. We chose the boundary condition to be the constant oven temperature on the bottom of the rectangle, and normal derivative to be 0 on all other sides. Physically this means the oven is set at a fixed temperature and is perfectly insulated.

3. We separate the function into a steady-state part and a transient part. The steady-state is boring, it's simply the constant oven temperature throughout all space. The transient part is obtained by an eigenfunction expansion of the laplacian operator. In the slide above we only kept the first term in this expansion.

4. The solution fits poorly because of the boundary condition. A more precise model would be to use the so-called Robin boundary condition, which states the heat loss is proportional to the temperature on the walls.

Conclusion

Conclusion

- Temperature distribution inside the oven can be very uneven. We can gain a good understanding of this through our coarse-graining method. Temperature is higher near the source, and heat escapes near the door, which matches our intuition.

- Ovens correct for an overshoot in heating through natural cooling.

- The heat equation solution of our boundary condition is not a good model for an oven. i.e. oven is far from insulated.

- There is also a cooling cycle for the freezer and fridge as well.