LAB EXERCISE 2: REFRIGERATOR

Introduction

Break down refrigerator efficiency, and see what is improved in an Energy Star rated fridge versus a standard one from the same manufacturer.

Equipment

Data logging thermometer(s) with thin-wire probe(s). At least 7 total probes, 4 with thin wires. Thermocouples have thin wires.
Misc. little stuff: clamps, insulating foam for clamping temperature probes on, duct tape, putty to seal door shut.
2 data logging kWh meters
DC power supply, power resistors (2), and reasonably thin wires, for 10~ 15 W in each fridge.
Refrigerators:

Haier HSA04WNCWW, not Energy Star rated, 340 kWh/year, 3.9 cu. ft.
Haier ESR042PBB, Energy Star rated, 270 kWh/year, 4.1 cu. ft.

General Procedure

We will collect one set of data as a class. The steps are listed below; on the next page is a schedule of which will be done when. Different people will participate in doing different steps. It is your collective responsibility to make sure that everybody gets the data and information they need. If you are missing information you need when you go to analyze the data, you will need to contact your classmates, not the instructors. When you leave the lab after performing some steps, you will need to leave clear notes for the group that comes in to do the next step. In order to figure out what information they will need, you will need to understand their steps as well as your own. There are various ways you can transfer the information. You can leave paper notes in the lab, you can use the class "kite" google drive, or you can choose something else.

Note that you are only collecting data as a class; you are not analyzing it together. You should not post files that include any calculations or plots. Doing so would violate the honor principle.

Specific Procedure

1) Note: The fridge thermostats are probably set right from last year. Don't move them unless you have to.
2) Set up to stabilize refrigeration temperatures:
   a. Connect all the temperature probes and let them sit in the air near each other. Calibrate the thermocouples if necessary.
   b. Set up with temperature probes on the evaporator and condenser, in the middle of the interior, and one for ambient temperature.
   c. Close the door, and seal any gaps with putty (e.g. modeling clay).
   d. Start logging temperatures once per minute.
   e. Turn it on to run as a fridge.
   f. Connect both power meters to the same fridge. This is to check that their calibrations match.
   g. Take a photo of the inside so future groups can understand what your setup was.
3) Run for at least 5 hours.
4) Check temperature stabilization. Look at a plot of temperature as a function of time on the data logger and eyeball the centerline of the plot to get the average stabilized temperature. If the two interior temperatures don't match to within 1.5 degrees C, adjust one or more thermostats and repeat from step 3. If they match reasonably well, go on to step 5.
5) Record the kilowatt hour readings from the two meters. If they don't match, he sure you can trace which meter goes with which reading. The absolute readings from this step will not be used in the analysis. However you can use their ratio to correct the readings from one of them in future measurements so that you have an equal calibration on both. You have no way to know which one to correct, so you simply have to arbitrarily choose one and assume that is correct and adjust the reading from the other one for future measurements.

6) Set up the two kWh meters to each measure power consumption of one fridge over the following 24 hour period, and configure temperature logging equipment to log temperatures about once per minute over the same 24 hour period.
7) Run 24 hours.
8) Collect and save data from the 24 hour run.
9) Set up a power resistor in each fridge and connect to a power supply with about 10 to 15 W power dissipation in each fridge.
10) Allow to reach a steady-state temperature (5-10 hours or more).
11) Record inside and outside temperatures and power dissipated in the resistors.

Schedule:
Monday afternoon, 4 PM: steps 1, 2, and start 3.
Tuesday morning, 9:30 AM: step 4
Tuesday afternoon 2 PM: Step 4, again
Tuesday evening, 7 PM: Step 4,5,6 and start 7
Wednesday evening, 7 PM: Steps 8, 9, and start 10.
Thursday morning 9:30 AM AM: step 11.

Analysis

For each of the two refrigerators:

1) As a practice problem, calculate the steady-state power consumption of a fridge with the following specifications:
    a. Interior (compartment) temperature: 5 °C.
    b. Exterior (room) temperature: 20 °C.
    c. Thermal resistance of the box, interior to exterior: 0.5 C/W.
    d. $COP_{cooling}$: 2.
2) For the hypothetical system in problem 1, suppose assume that the refrigeration system runs constantly at a low rate, rather than cycling as in a real fridge.
    a. Calculate the heat flow rate from the interior into the inside heat exchanger on the evaporator.
    b. Suppose the thermal resistance of that evaporator is 0.2 C/W. Find its operating temperature.
    c. Calculate the heat flow rate from the outside heat exchanger (on the condenser) to the ambient. Remember that this is different from the heat flow into the evaporator, consulting the diagrams of heat pump energy flows from class if you forget why this is true.
    d. Suppose that the thermal resistance of the condenser heat exchanger is 0.1 C/W, find its operating temperature.
    e. From the condenser and evaporator operating temperatures, find the ideal COP (what could be achieved with an ideal heat pump), and the ratio of the actual COP to the ideal COP.
    f. Assume that the ratio in e. remained constant, but the thermal resistances of the heat exchangers were each cut in half. Find the new steady-state power consumption of the fridge, in W.

Make sure you have a solid grasp of problem 1 and 2. They assume we know all the data perfectly. That is easy compared to figuring out what is going on with the real data.

3) From the resistor tests, calculate the thermal resistance, inside to outside for each fridge.
4) Calculate the required cooling power (heat flow into the cold side of the heat pump) from the thermal resistance and the interior and exterior temperatures used in the cooling test.
5) Calculate the actual cooling COP from the required cooling power and the actual electricity consumption.
6) Calculate the theoretical maximum cooling COP based on the heat exchanger temperatures.
   (Use the typical peak temperatures—hottest outside and coldest inside—because those are when the heat-pump is running. I say typical because you aren't looking for a random noise spike in the data, but rather you are looking for the top or bottom of the typical cycle)
7) Calculate the theoretical maximum cooling COP if the heat exchanger temperatures matched the inside and outside temperatures.

8) Quantitatively assess the effect (if any) that each of the following differences between the two fridges have on the energy consumption of the two fridges. For each part, report your best estimate of the effect on average power consumption in W. The sum of these differences should be equal to the observed difference in power consumption.
    a. Insulation
    b. Inherent heat pump performance, which you could describe as the ratio between measured COP and theoretical COP.
    c. Heat exchanger performance: a better heat exchanger would keep the evaporator or condenser temperature closer to the interior or exterior temperature (respectively).

Note that in recent tests, we have found that the energy star fridge performance has degraded to the point where it is similar to the non-energy-star fridge. It is most likely that it now is better in at least one category (a, b, or c), and worse in another.

9) Calculate energy consumption reduction that would be possible in the energy-star fridge from:
    a. Improving insulation by a factor of 2, keeping cooling COP the same.
    b. Improving the heat exchangers to cut the temperature drop from the heat exchanger to the air in half. For example, if the outside temp is 20 C and the condenser 30 C, you are considering what could happen if it were 25 C. Similarly, if the inside temp is 10 C and the heat exchanger 0 C, you are considering what could happened with it at 5 C. You don't need to analyze each individually—just the overall improvement if both are upgraded. Assume that the ratio of actual cooling COP to ideal cooling COP stays the same.
    c. Bringing the actual cooling COP closer to the ideal cooling COP, for the same heat exchanger temperatures. Assume the improved fridge has a cooling COP halfway between the ideal (for the actual heat exchanger temperatures) and the actual measured cooling COP.
    d. Doing a, b, and c. Note that the answer to a question like this might be the product of the improvement factors, or the sum of the improvement amounts, or something else, so to know for sure you'll need to do the analysis for the new scenario, not just add or multiply results from the previous parts.