

LABORATORY 2: HOME HEATING

Objectives

This lab will introduce you to thermal systems and to data collection using a data acquisition system and MatLab. In this lab, you will model a first order thermal system.

Apparatus

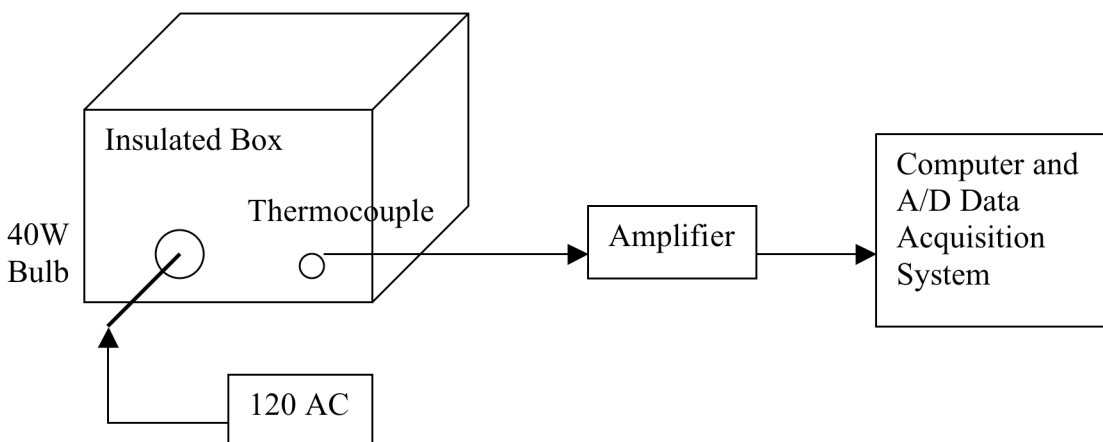
For this lab you will need:

- a simulated house with 40W light bulb
- a thermocouple with amplifier
- a computer with data acquisition equipment

The thermocouple is connected to a thermocouple amplifier (you will learn more about how this works in E14) whose output decreases by 10 mV for every 1°C rise in temperature, with 0V at 0°C.

Background

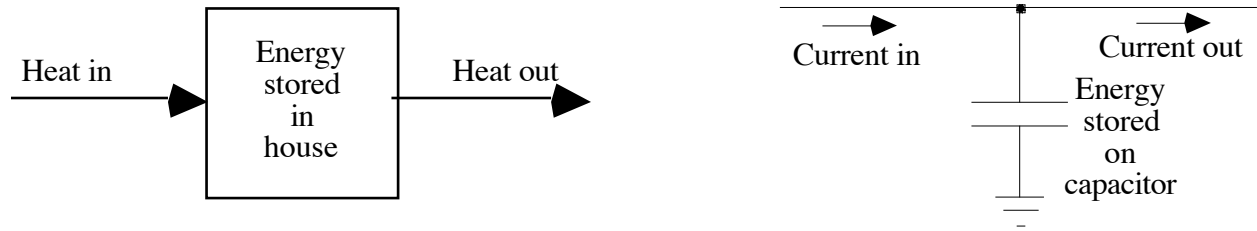
In this experiment, a home-heating system is simulated by a light bulb (the furnace) heating an enclosed box (the home). The temperature of the air in the box is monitored by the computer, using a thermocouple and amplifier connected to a data acquisition system. In a real home-heating system the temperature of the house determines whether or not the furnace is on. You, on the other hand, are simply going to examine the dynamics of this system; that is, how the temperature of the air in the box varies with time. We will look at both heating and cooling in the system.



Heat Transfer and Thermodynamics

We will model the system as a simple first-order system with heat flowing in and out, and energy accumulation evidenced by increased temperature. The rate of energy accumulation in the box is

equal to the rate of energy flowing into the box minus that flowing out. This system is analogous to an electrical system.

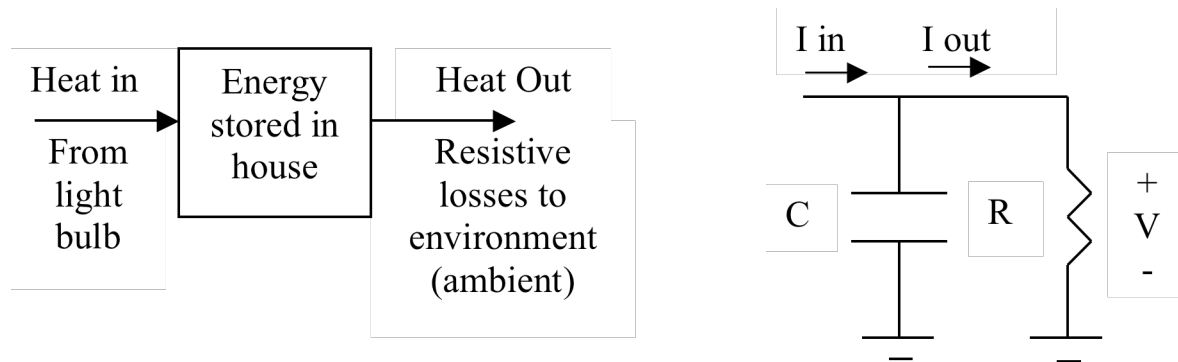


In an electrical system current (Amperes) is analogous to heat flow (Watts) in a thermal system, so charge (Coulombs) is analogous to energy (Joules). Voltage (Volts) is analogous to temperature (Kelvins or °C), electrical resistance (Ohms) to thermal resistance (Kelvin/Watt), and electrical capacitance (Farads) to thermal capacitance (Watt-Seconds/Kelvin, also called thermal mass). There is no thermal analog for inductance.

For the electrical system shown that we can write the equation:

$$C \frac{dV}{dt} = I_{in} - I_{out}$$

If the output of the circuit is connected to a resistor to ground, we have:



and

$$C \frac{dV}{dt} = I_{in} - \frac{V}{R}$$

For the thermal system, our model leads to the equations:

$$\begin{aligned} \text{Rate of Energy Accumulated} &= \text{Rate of Energy in} - \text{Rate of Energy out} \\ \text{Rate of Energy Accumulated} &= \text{Heat in} - \text{Heat out} \end{aligned}$$

$$m \cdot c_p \frac{dT}{dt} = P - \frac{T - T_0}{R}$$

where m , c_p and T are the mass, specific heat and temperature of the air in the box, P is the power supplied by the light bulb, T_0 is ambient temperature, R is the thermal resistance of the box and t is time. This model is based upon the assumption that the only energy leakage is due to a

thermal resistance, and the energy accumulation is due to the heating of the air that is *inside* the box. If we let $\Theta = T - T_o$, and $C = mc_p$ the equation can be rewritten:

$$C \frac{d\Theta}{dt} = P - \frac{\Theta}{R}$$

From this equation the analogy between electrical systems becomes clear. Heat (current) flows into the system. As the temperature (voltage) increases the heat (current) flow to ambient temperature (ground) increases proportionately due to resistive losses. It is the difference between the temperature (voltage) of the house and ambient (ground) that drives the heat (current) flow. Energy is stored in the thermal (electrical) capacitance. The greater the temperature (voltage) differential between the house and the ambient (ground), the greater the amount of energy stored. We assume that an arbitrarily large amount of heat (current) can be absorbed by the ambient (ground) without changing its temperature (voltage).

From this information it should be possible to find Θ as a function of time if P is a step input (i.e., it is initially off, and is turned on at $t=0$).

Computerized Data Acquisition using MatLab

To perform the data acquisition with MatLab, first create an “m-file” that will contain the MatLab commands used to perform the acquisition. Start MatLab, go to *File->New->M-file*. An editor window will open. Copy the SimpleAcqu.m on the course webpage, edit it as appropriate, and save your file with a unique file name. To run the commands in the m-file, go to *Debug->Save and Run*.

Procedure

1. Connect the output of the thermocouple amplifier to one of the analog inputs on the DAQ board.
2. Use the data collection program to collect data from an analog input for as long as it takes for the system to reach equilibrium. You will need to determine a good sampling rate for the following task:
 - a. Close the lid of the box.
 - b. Start your data acquisition program and run it for about 10 minutes. 10 seconds after starting the program, turn on the light bulb. Monitor the box, and don't let the light bulb get too hot.
 - c. When the data collection is finished, open the box to let it cool off.
 - d. Look at your data in a graphing program (Matlab or Excel) and see if the system reached equilibrium.
3. Put a book, or some similar object, on the box lid to keep it closed. Also cover all the holes and cracks as tightly as possible. Repeat step 2.

4. Extra credit: After the second trial, do not open the box. Instead, we will collect data from the box to track the cooling down process. Start up the data acquisition as soon after turning the light off as possible and let it run for at least 20 minutes. Set an appropriate sampling rate so that you don't have too many data points.

Report

Submit a formal lab report that includes the following:

1. Determine the resistance R of the system for parts **2** and **3** of the procedure from the final steady state temperature. Is the resistance higher or lower with the book on, and is this what you expected?
2. Determine C from the time constant of the system from parts **2** and **3**. Find C from the time constant, and find the time constant using a curve-fitting program (like the one in Kaleidograph).
3. Extra credit: Determine R and C from part **4** of the procedure. Please don't include a listing of this data -you need only present the graphical data.
4. Include plots of your data showing incremental temperature (θ) vs. time. Time = 0 should be the time that the light bulb is turned on. For the cooling down data, start from the first data point.
5. In your discussion, consider problems with the model we used. Try to figure out which assumptions are incorrect, and which of these was likely to give you a big error in the calculated value of capacitance. Suggest ways to improve the experiment to make the model better fit the physical situation.