UNIVERSITY OF CALIFORNIA, MERCED

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ME 021: Engineering Computing
MATLAB® Project

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Preliminary Notes

- **You need to choose one project out of four problem statements** Choose a project that is closest to your interests in "engineering computing" out of the four engineering projects posted as PDF on CatCourses (also available in course Box/MATLAB® Project folder). You must denote your choice in the 2nd MATLAB® project milestone, that is, the 7th project milestone on CatCourses.
- Your solution must be exclusively submitted via CatCourses. Email submission will not be accepted. Pay attention to the posted deadline because **the system automatically stops accepting submissions when the deadline passes.** You can upload one or more `.m` or `.mlx` files for your code.
- **To receive credit, you must also demo your project to your TA, either in your lab or during office hours.** You must show your working program, be prepared to explain your code, and answer other questions that the TA asks about MATLAB® programming. You must demo before the end of your last lab of the semester (that is, before Dec. 8, 2023). **You will get a 0 if you do not demo, even if you made a submission.**
- Four milestones will be released to help you make progress towards the project. However, milestones are simply to push you in the right direction. You need to put in extra effort beyond the milestones to complete the project satisfactorily.
- A short (1-2 page) report in PDF format that consists of main parts of the code, the visualizations, and any mathematical equations must be submitted for the final project submission along with the MATLAB® script files.
- The grading rubric for all milestones, demo, and the report submission will be posted on CatCourses and it will be available for the students to read through to prepare their submissions.

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ME 021: Engineering Computing
MATLAB® Project – Thermodynamics of refrigeration

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1 Overview

Who doesn't like a nice iced cold drink in the summer!? In this project, you will have a chance to explore how refrigeration works to create ice and as a result, your favorite iced drinks. The refrigeration cycle is a thermodynamic process that is used in all kinds of refrigeration applications and air conditioning systems. The goal of the project is to evaluate the refrigeration performance in different conditions.

2 Preliminaries

2.1 Properties of refrigeration

To simulate a vapor compression refrigeration system, we need to discuss the following key properties:

1. **Coefficient of Performance (COP):** The efficiency of the refrigeration cycle is computed at various operational stages throughout the year. The Coefficient of Performance (COP) is a measure used in thermodynamics to assess the efficiency of a cooling systems. It's defined as the ratio of the amount of cooling provided to the amount of energy consumed by the system. The higher the COP, the more efficient the system is, meaning it provides more heating or cooling for the same amount of energy input. It's a useful metric for comparing the performance of different heating and cooling systems.
2. **Thermal energy:** The heat extracted from the refrigerated space (Q_L) and the heat discharged to the environment (Q_H) during the cycle.
3. **Work Input:** The work input (W_{in}) required by the compressor.
4. **Energy Costs:** Energy costs associated with operating the system throughout the year.

In a simulation, we can model realistic environmental conditions that the system would experience over a year, including temperature fluctuations and varying load conditions due to weather changes.

2.2 Mathematical description

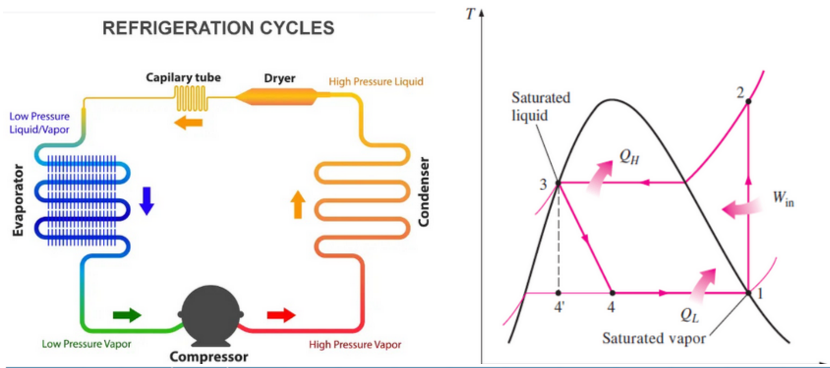
1. The coefficient of performance can be computed as:

$$COP = \frac{|QL|}{W_{net,in}},$$

where QL is the cooling effect or the desired cool output, and $W_{net,in}$ is the work done in one refrigeration cycle.

QL and $W_{net,in}$ can be expressed as power (kw) or energy (kwh). Both quantities need to be in the same units (either kW or kWh) for the COP calculation to be meaningful.

- If expressed in kW (power), the COP gives a snapshot of the system's efficiency at a given moment.
- If expressed in kWh (energy), the COP reflects the efficiency over a longer period, such as a day or a billing period, which can be more practical for understanding overall energy usage and cost.



Model			Cond. temp. °C	Evap. temp. °C -40	-35	-30	-25	-20	-15	-10	-5	0	5	7
ZF06KQE	TFC TFD	Q	30	1.28	1.61	1.99	2.46	3.00	3.63	4.36	5.21	6.17	7.26	7.74
			40	1.12	1.42	1.77	2.17	2.64	3.19	3.83	4.56	5.40	6.36	6.78
			50	0.95	1.21	1.50	1.84	2.24	2.70	3.23	3.85	4.56	5.38	5.73
		W_in	30	1.17	1.23	1.30	1.37	1.45	1.54	1.64	1.75	1.87	2.00	2.05
			40	1.40	1.46	1.52	1.59	1.67	1.76	1.85	1.96	2.08	2.20	2.26

Figure 1: Refrigeration cycles and the corresponding thermodynamics diagram is shown alongside data for compressor performance (CSV available on Box). The first three rows correspond Q_L and bottom two rows correspond to W_{in}.

In a refrigeration cycle, the condenser, evaporator, and compressor are key components that work together to facilitate the cooling process. Here are their definitions:

1. Condenser: The condenser is a heat exchanger in a refrigeration system that releases heat absorbed by the refrigerant from the evaporator. In the condenser, the refrigerant, which enters as a hot vapor, is cooled and condensed into a liquid form. This process involves the transfer of heat from the refrigerant to the surrounding environment, which could be air or water, depending on the type of condenser. The primary function of the condenser is to expel the heat absorbed from the cooled space and carried by the refrigerant from the evaporator.
2. Evaporator: The evaporator is another crucial heat exchanger in a refrigeration system, but it operates opposite to the condenser. In the evaporator, the refrigerant absorbs heat from the environment or space that needs to be cooled (like a refrigerator interior or air in a room). The refrigerant enters the evaporator as a low-pressure liquid and, as it absorbs heat, it boils and changes into a vapor. This phase change and the heat absorption process lower the temperature of the surrounding area, achieving the desired cooling effect.
3. Compressor: The compressor is the component that drives the refrigeration cycle, pumping the refrigerant through the system. It compresses the refrigerant gas, which enters the compressor as a low-pressure vapor, increasing its pressure and temperature. This high-pressure, high-temperature vapor is then fed into the condenser to start the cycle anew. The compressor is crucial for maintaining the pressure difference in the system, which allows the refrigerant to circulate and undergo the necessary phase changes for cooling.

3 Computational Tasks

For this project, you will work with real data and apply computations on that data. These tasks are defined in detail below.

3.1 The temperature data

Get the temperature data using the data image available on the Box folder. Extract data from the provided graph that plot the experimental data for temperature every hour for a month. You must use the MATLAB® module GRABIT for this purpose.

3.2 Computation of parameters in a thermodynamic cycle

Compressor performance is determined by two temperatures: the condenser temperature, and the evaporator temperature. In this project, you should consider a performance curve for the compressor as described in the data for a compressor (CSV file available on Box Compressor performance table). To load the CSV file in MATLAB, you can use the `importdata` function.

Set the condenser temperature to be 5°C above the hourly ambient temperature. The hourly ambient temperature is the data you extracted earlier from GRABIT. Round the hour values to the nearest hour integer value. Adjust the evaporator temperature to two specific settings: first set it to $4°C$, and then adjust it to $7°C$ (this means that you should show the results for both evaporators temperatures). However, if you choose to work with different evaporator temperatures, you should give a brief explanation of your choice.

Once all these parameters are set, you can use the reference table provided in the Box folder (comperessor performance table.csv) to find out the Q_L and W_{in} parameters directly from the file by interpolating between the values that are provided. You might find the MATLAB `interpolation` module helpful for this purpose (Hint: `interp1` can interpolate data in 1-D).

Note that the system is activated only when we need to cool the room! So, let us assume that we activate the cooling system when the ambient room temperature is above 18°C. That means you should consider that the refrigeration is on when the ambient temperature is above 18°C (think of this as an LED signal that is ON).

Once you have computed the heat extracted (Q_L) and the work input (W_{in}), you can compute the heat discharged to the environment, $Q_H = Q_L + W_{in}$ and the coefficient of performance (COP) as the ratio of Q_L and W_{in}. Figure 1 illustrates the metrics in a thermodynamic cycle.

3.3 Cost Computation

Find out the cost of refrigeration by applying different energy tariffs for normal and peak hours to calculate the overall energy cost. You may choose normal and peak hours in the hourly data that you have extracted (usually, evenings are hottest, and hence, peak hours). By adding the power values (use the W_{in} in kW units) over a period of time, you can compute the energy use in kWhr units (these are the units that are reported on your home energy bill!).

3.4 Visualization

For visualization in this project, you have the following tasks,

1. Generate hourly graphs to illustrate the variation in COP, Q_H, Q_L, W_{in}. This will be represented as power in kW units.
2. Show the temperature and signal (whether the refrigeration LED is ON or not) graph for the month of June. You can assume that the refrigeration is ON only above 18°C.

Can you propose a design for a vapor compression refrigeration system that can operate under varying climatic conditions while maintaining optimal efficiency? Try out your ideas computationally in MATLAB® and report your findings.

4 Open-ended tasks

1. You may use the yearly data (available on Box as a CSV) to find out any patterns in the data for the metrics (power, cost, efficiency, etc.)
2. Do you have an energy bill for your home? What information can you extract from that bill? Can you regenerate the energy usage and costs graphs from the bill using MATLAB®?
3. Can you graph the energy price expenses with time by considering different prices for normal and peak hours.
4. What are some trade-offs in refrigeration that you found using your computational simulations.

For the open-ended problems, include justifications for each of your choices, that is, explain your reasoning and thought process. Discuss the potential trade-offs (advantages and disadvantages) and how you address them. Take the open-ended questions as an opportunity to explore data/system design/visualization that interests you the most!