Design of Thermal Systems
Professor Weisensee
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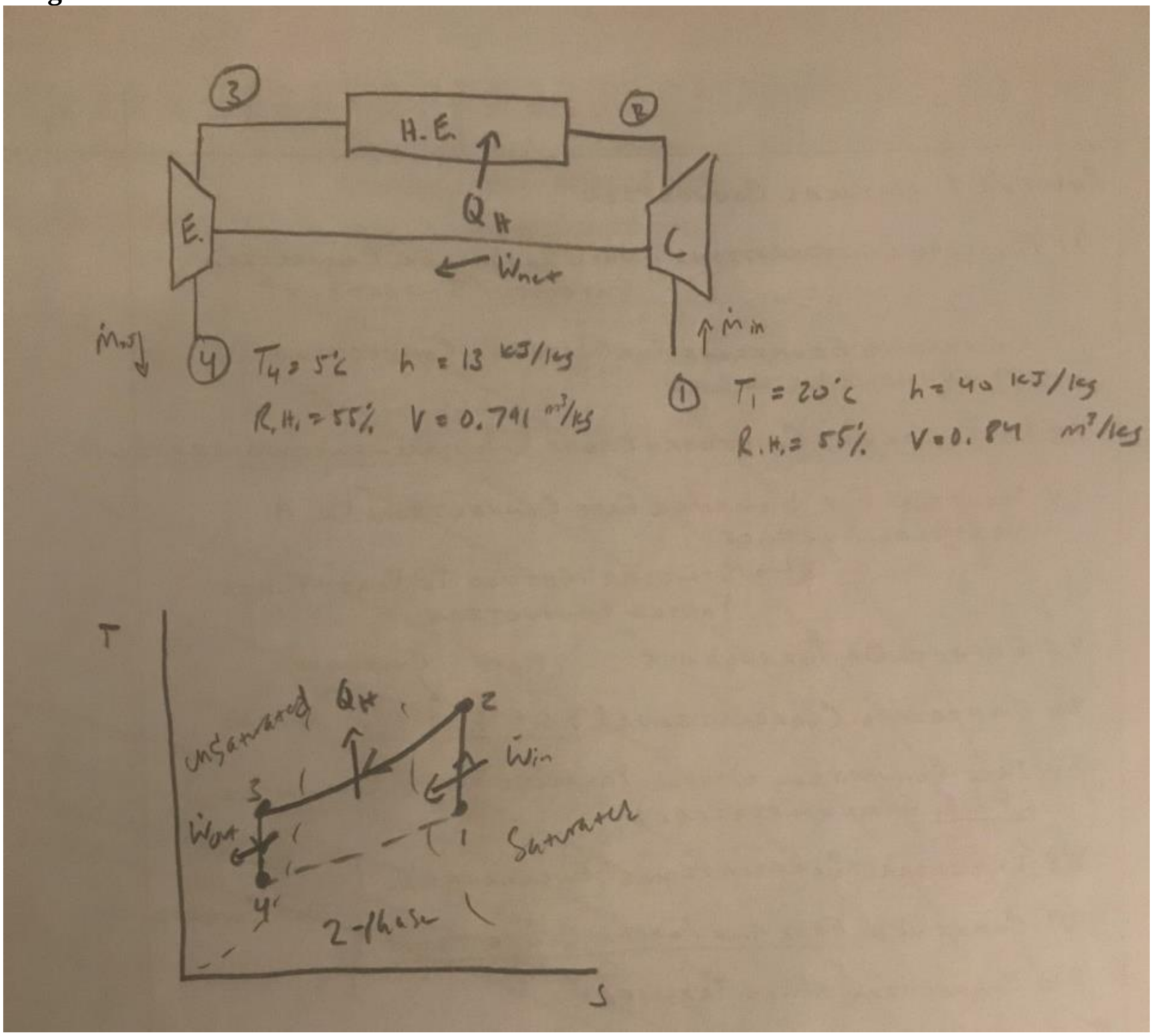
DHW 3 – Dehumidification

The objective for this design homework is to analyze the cost and amount of energy three different technologies would need to keep the air from condensing in the refrigeration display. For the design homework I chose to analyze the volume of only the refrigeration display cases. My three technologies that I will be looking at are the refrigeration cycle, a solid desiccant system and a compression system.

Assumptions:

- Volume of the display cases is 61.1645 m^3. This is assuming that for every 3 display cases that the volume is 2.03381 m^3,[1] with 15 display cases in one isle and that there are 5 isles of refrigerated display cases in the grocery store [2]. I thought this was reasonable because I think that is about how many display cases there could be in a grocery store. I also did not choose to do the whole grocery store because there is plenty of space that does not need to be kept at 5 ˚C and 55% relative humidity.
- I will also assume that the average relative humidity in the display cases is around 55% [3]. I think this is a reasonable level, and from the psychrometric chart you can see that the dew point is lower than the desired temperature so you know the moisture would not condense. Also, that is what is said online.
- The cost for electricity is 7.94 cents per kWh in the state of Missouri [4]. I think this is reasonable because we are in Missouri and to get a cost analysis, I needed to have a cost for kWh.
- I will also assume that the technology is running 24 hours a day throughout the whole year. This is reasonable because you need to keep the product cold to stay fresh.
- Starting temperature and relative humidity are 20 ˚C and 55% humidity respectively and the temperature inside the refrigerated display case is 5˚C [5].
- The Desiccant system is based off of the Ebac DD1200 240 V Industrial Desiccant Dehumidifier, where it has a maximum power output of 7,200 Wh [13].
- The compressor system is based off of the Sullair ShopTek 10-HP Base Mount rotary Screw Air Compressor, where its maximum power output is 121 kWh [9].
- Assume that all the air is circulating through the system ever second with no obstruction. This means that the mass flow rate is constant and that the all the air is being cycled out every second. This probably isn't the best but makes the math easy for when calculating cost.
- Also assume no heat loss due to friction in the system. This simplifies the problem when doing an energy balance of the system.

Diagram/ Schematic:



Calculation for amount of water removed:

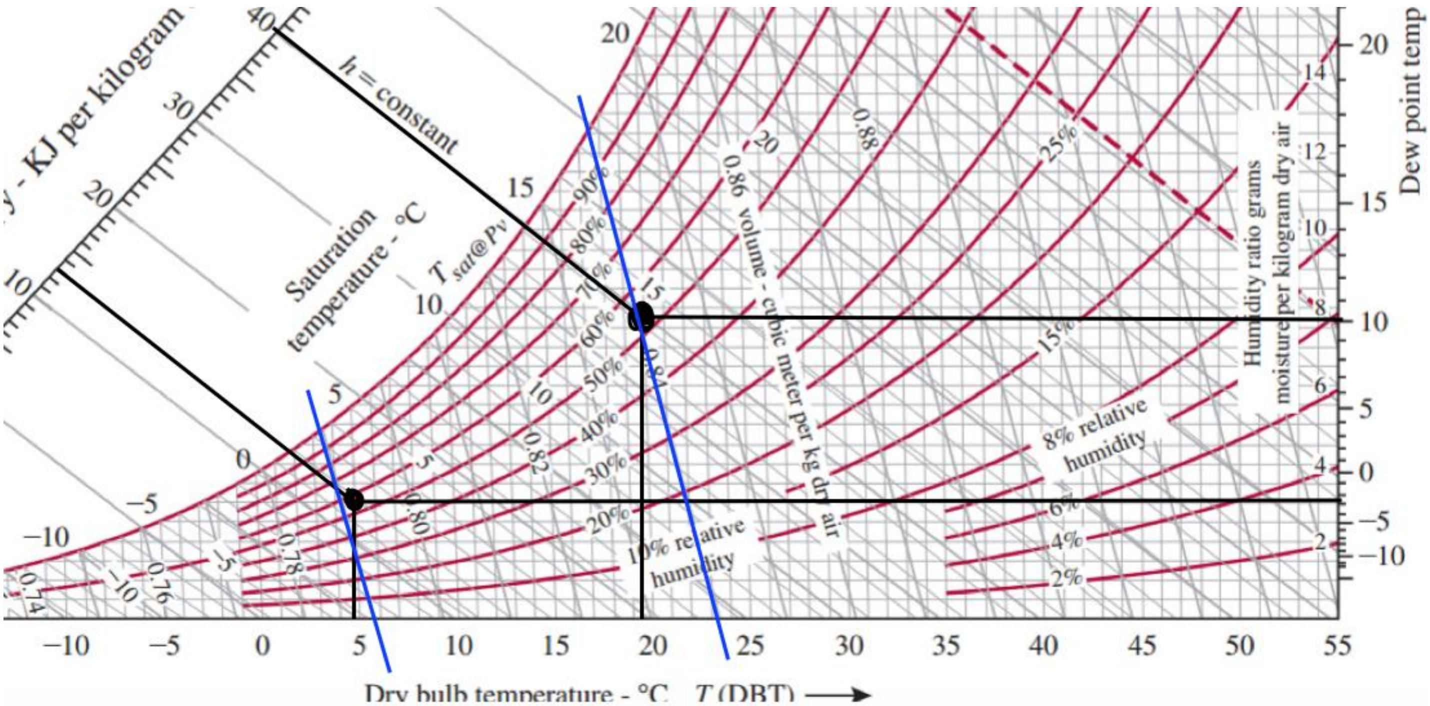


Fig. 1 In this figure the dot on the right represents state 1(outside the refrigerated display case) and the dot on the left represents state 2(inside the refrigerated display case). The black lines are to help with seeing the temperature, humidity and the dew point for each state. The blue lines help show the closest volume each state is at. It is also important to note that the dew point for state 2 is below 5 ˚C so there would be no condensation on the display case.

Table 1 In this table shows the necessary values for each state for the calculations. These values were from the assumptions and from psychrometric chart in fig. 1. The volume for state 2 was near 0.79 (m^3/kg) so I chose a number just above the value of the line.

State	Temperature (˚C)	Relative Humidity (%)	Enthalpy (kJ/kg)	Volume (m^3/kg)
1	20	55	40	0.84
2	5	55	13	0.791

In order to find the amount of energy used in the system, the difference in mass first needs to be calculated. First solving for the amount of water that needs to be removed, take the difference in the reciprocals of the volumes and get:

$$Amount\ of\ water\ removed = \frac{1}{v_2} - \frac{1}{v_1} = \frac{1}{0.791} - \frac{1}{0.84} = 0.0737\frac{kg}{m^3} = 73.7\frac{g}{m^3}$$

Answer:

Amount of water need to be removed (g/m^3)	73.7

Discussion of working principles:

The refrigeration cycle can be either open or closed. In a closed system, such as a refrigerator, moisture is taken out of the air by coming into contact with a refrigerant that is used to extract the heat from the air. In this process the refrigerant goes through, first a compressor, then a heat exchanger and finally an expander before exiting the system. In this way the refrigerant takes the heat away from the air as the air passes through the heat exchanger with the refrigerant in there. This is where moisture would form due to the airs inability to hold the moisture. Then the refrigerant is taken through a compressor causing it to turn into a liquid. Once in liquid form the refrigerant goes to a condenser where the refrigerant losses the heat absorbed from the air. After the refrigerant leave the condenser it moves into an expanded to lower the pressure and then into another heat exchanger where it turns back into a gas and ready to be recycled through the system to extract more heat from the air [8]. Some refrigerants currently used as coolants are freon and R410A. Freon is less environmentally safe than R410A so is being phased out of production.

In the compression system, such as the one assumed for the calculations, it takes air and compresses it. This will not only increase the pressure but the temperature of the air and decrease the amount of moisture the air can hold. So, when the air condenses it can hold less moisture cause some of the moisture that was in the air to form droplets in the chamber [9]. From my source [10], the air is pressurized up to 85 bars from a high-pressure pump. Filters and separators are then used to collect the droplets that have formed. But this does not extract any of the vapor that is still in the air. With the air now saturated with the rest of the moisture that it was holding further heating needs to be done in order to remove more. The downside to this process is that it needs to be followed up by another one, such as desiccant or coils. But the most common way to further reduce the moisture in the air after it goes through compression is to use a dryer [12]. If the moisture is not removed it can cause corrosion on a part of the machine and then the machine can become inefficient or fail.

In the desiccant system, such as the one assumed for the calculations, a solid or liquid is used to take out the moisture. These solids and liquids naturally attract toward absorbing moisture. As the desiccant removes the moisture it releases heat into the air. Then the air can be cooled to the desired temperature using a heat exchanger, cooling coils or other cooling techniques such as evaporation. For the desiccant to be reused over and over again the moisture needs to be extracted. The moisture in the desiccant can be taken out by a heating source such as solar energy, waste heat, natural gas or electricity. If the desiccant is a liquid it is cycled through two chambers, one where it collects the moisture and the other a heat exchanger to remove the moisture. What is good about this type of system is that it is more efficient in the amount of energy needed to remove the moisture from the air than a refrigeration cycle. This allows for a more consistent use of electricity which saves on cost in the long run. Today Desiccant systems are used in a wide variety of places such as supermarkets, hotels, office buildings and ice rinks and may be continued to be used more as so refrigerants are phased out of use in refrigeration systems [7, 11].

Calculations of electricity input:

Refrigeration cycle

So, since a volume of 61.1645 m^3 is assume we can find the mass in each state from dimensional analysis:

$$m_1 = \frac{V}{v} = \frac{61.1645\ m^3}{0.84\ (m^3/kg)} = 72.814\ kg$$

$$m_2 = \frac{V}{v} = \frac{61.1645\ m^3}{0.791\ (m^3/kg)} = 77.33\ kg$$

And the difference between the masses is:

$$\Delta m = m_2 - m_1 = 77.33 - 72.814 = 4.516\ kg$$

Now doing an energy balance around the whole system we have:

$$m * h_1 = m * h_2 + w$$

So then we can say:

$$w = (\Delta m) * (h_1 - h_2) = (4.516\ kJ) * \left(27\frac{kJ}{kg}\right) = 121.932\ kJ$$

Now I am assuming that all the air passes through the system ever second ever hour, so I get 19.783 kWh of power. From this I can calculate the cost for my system to remove the moisture from the air.

$$Cost\ (\$) = 121.932(kWh) * 24\left(\frac{hrs}{day}\right) * 365\left(\frac{days}{year}\right) * 0.0928\left(\frac{\$}{kwh}\right) = \$99{,}121/\text{year}$$

Desiccant system

$$Cost\ (\$) = 7.2(kWh) * 24\left(\frac{hrs}{day}\right) * 365\left(\frac{days}{year}\right) * 0.0928\left(\frac{\$}{kwh}\right) = \$5{,}853/\text{year}$$

Compression system

$$Cost\ (\$) = 171.511(kWh) * 24\left(\frac{hrs}{day}\right) * 365\left(\frac{days}{year}\right) * 0.0928\left(\frac{\$}{kwh}\right) = \$139{,}426/\text{year}$$

Table 2 Answer of cost for each system

System	Cost ($/year)
Refrigeration	99,121
Desiccant	5,853
Compression	139,426

Cost Comparison:

From my cost analysis I have to go with the desiccant system. However, $5,853/ year should not be right, that is way too low for cost and I think I probably messed up with how much space it can operate at when searching for something similar to the volume I assumed. But from the other two systems I think those are more reasonable because they seem to be closer to the cost you see online for how much grocery stores pay for electricity each year, $160,000[14]. But some things that could influence the cost are the maximum capacity at which these systems can take in the air and cool it down as well as how many of each system you need. One may be cheaper per unit, but you could end up buy triple the amount to cool the same space as another system would. One way to maybe improve the cost of energy for these systems is to maintain the system so none of the parts start to deteriorate or corrode. Another way would be to make sure that the systems are placed so that the air in the display cases can circulate. Also, if the relative humidity is lower than what you want, you could stop the system until the relative humidity goes about the desired level again [15].

References:

[1] https://www.centralrestaurant.com/Kratos-Refrigeration-69K-825-Swing-Glass-Door-Merchandiser---3-Doors-81-inW-72-Cu-Ft-White-Exterior-c182p619347.html

[2] https://i.pinimg.com/originals/00/03/6c/00036c33dc4c4681f92741216849d06d.jpg

[3]https://www.researchgate.net/publication/279572201_Humidity_effects_on_supermarket_refrigerated_case_energy_performance_A_database_review

[4] https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a

[5]] P. Weissensee, *3rd Design Homework –Dehumidification,* MEMS 412 – Design of thermal systems, Washington University in Saint Louis.

[6] https://www.sylvane.com/ebac-dd1200-industrial-desiccant-dehumidifier.html?product_id=94388&s_cid=cse_gpl&gclid=CjwKCAjwguzzBRBiEiwAgU0FT7C7IEZELUJWhM0Ao5tMKTA1tLAAtXZXlqxVGd2KjIhXRzdg2VBzDRoCwQ0QAvD_BwE

[7] https://www.nrel.gov/docs/legosti/old/7010.pdf

[8] https://www.swtc.edu/Ag_Power/air_conditioning/lecture/basic_cycle.htm

Air compressor

[9] https://www.compressorworld.com/shoptektm-10-hp-base-mount-rotary-screw-air-compressor-230v-single-phase-125psi.html?matchtype=&network=g&device=c&adposition=&keyword=&gclid=CjwKCAjwguzzBRBiEiwAgU0FTzjcm480vHV-l5X634otOz0SFEAYCyAd9uOKVNZwJ_FuC1BdCsHYXBoCxv8QAvD_BwE

[10] https://www.condair-systems.eu/knowledge/system-comparison/technologies

[11] https://smarterhouse.org/cooling-systems/types-cooling-systems

[12] https://www.thecompressedairblog.com/how-to-remove-moisture-from-compressed-air

[13]https://www.sylvane.com/ebac-dd700-industrial-desiccant-dehumidifier.html?product_id=94394&s_cid=cse_gpl&gclid=CjwKCAjwguzzBRBiEiwAgU0FT8_zlrsxcHuLbOJVcurXleIYLj4Vw0lavcNwJ31rwyVoZQqhUfT6FxoCnsEQAvD_BwE

[14] https://3fficient.com/managing-energy-costs-in-grocery-stores/

[15] https://thesoothingair.com/how-to-improve-dehumidifier-efficiency/