

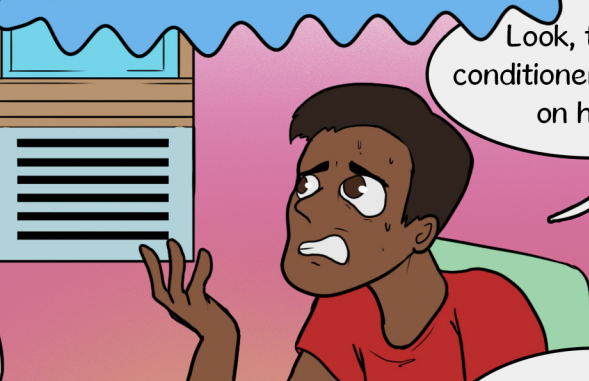
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REFRIGERATION CYCLES



I am literally melting into this chair...



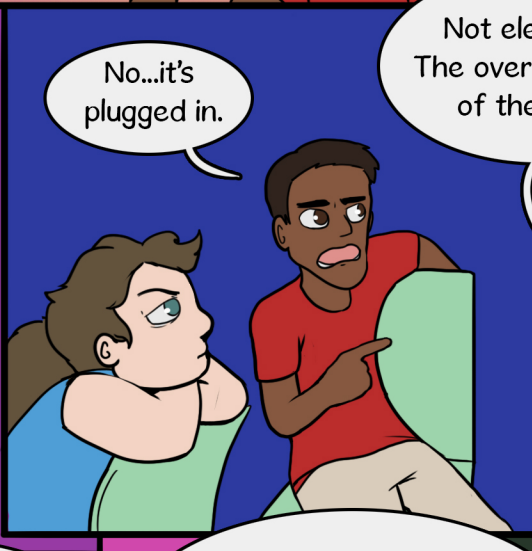
Look, the air conditioner is already on high...



What more do you want me to do?



Hm, seems to me you've got an energy problem!



No...it's plugged in.

Not electricity! The overall energy of the room!

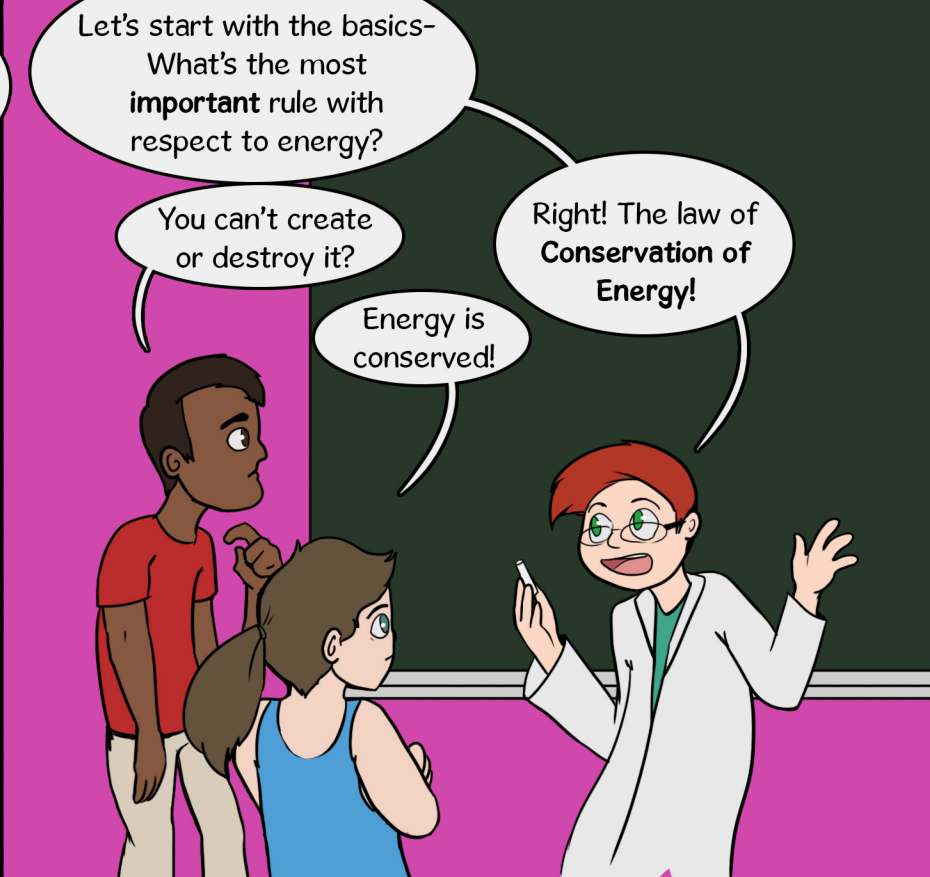
You're not pulling enough out from the room and rejecting it outside!



It actually might, a little bit-

Would it help if we increased the electricity input?

but you're missing the big picture



Let's start with the basics- What's the most important rule with respect to energy?

You can't create or destroy it?

Energy is conserved!

Right! The law of Conservation of Energy!

We refer to this as the **First Law of Thermodynamics**-

whatever changes occur in the energy that exists to make a system...

$$\Delta E_K + \Delta E_P + \Delta U = Q + W$$

INTERNAL ENERGY

...must be equal to the energy that enters or leaves the system!

$$\Delta E_K + \Delta E_P + \Delta H = Q + W_s$$

KINETIC ENERGY POTENTIAL ENERGY ENTHALPY HEAT SHAFT WORK

In the application of thermodynamics to a system,



Let's use an example:

there is a limited amount of work that can come from a heat energy input.

I can plug in a hot plate to provide energy to a cup of coffee, right?



Electrical work converted to heat!

But I can't draw in heat from a cold room to heat up a warm cup of coffee!

There are limitations on the direction of energy!

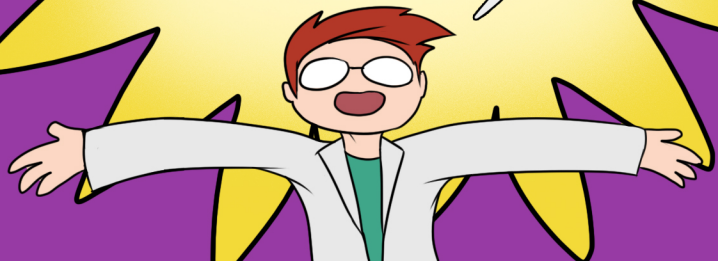


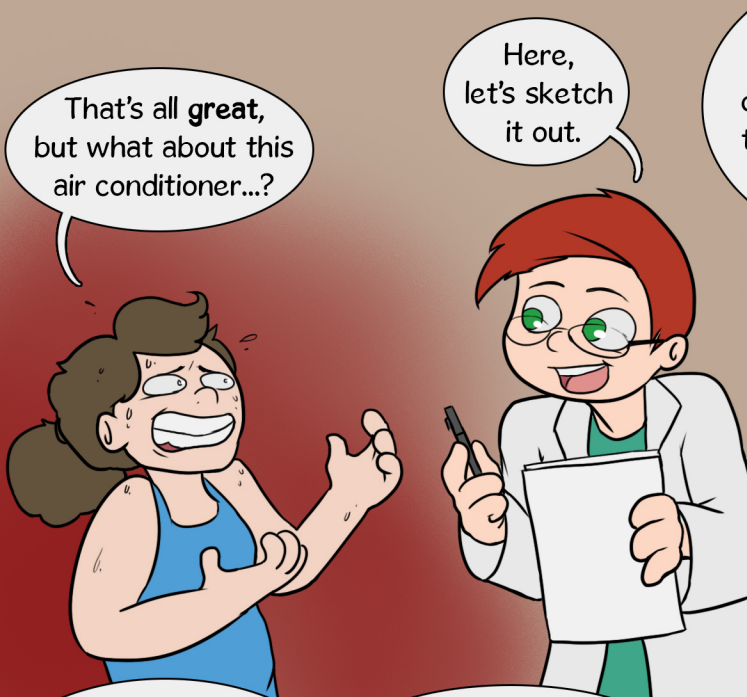
This brings us to the **SECOND LAW OF THERMODYNAMICS**- considering the quality of the energy as opposed to the quantity of energy

Entropy has to be greater than or equal to zero...

S

...for a real-world process to be possible!

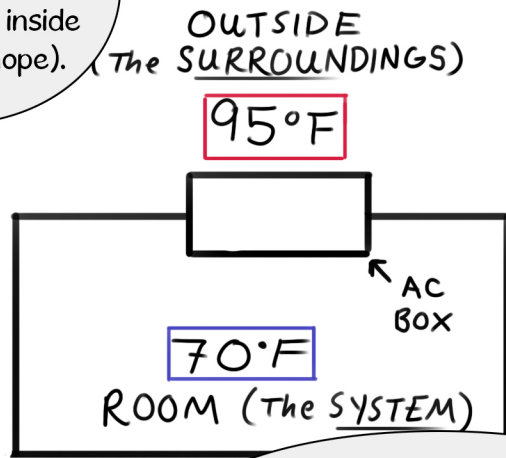




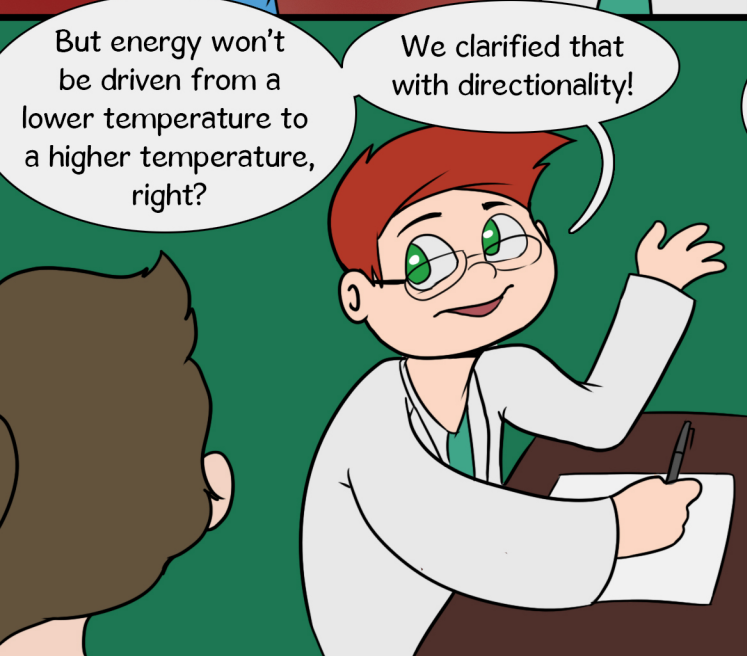
That's all great, but what about this air conditioner...?

Here, let's sketch it out.

You have a hot temperature outside, and a cold temperature inside (or so you hope).



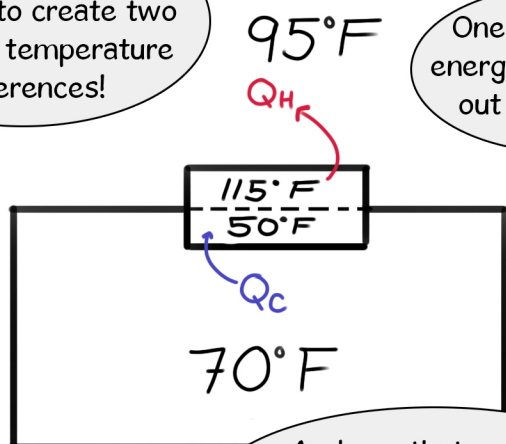
Meanwhile, all that is inducing this temperature difference is your AC box in the window.



But energy won't be driven from a lower temperature to a higher temperature, right?

We clarified that with directionality!

So within the AC box, we need to create two different temperature differences!



One that ensures energy will be drawn out of the room,

And one that ensures energy will be rejected into the surrounding environment.



So how do we ensure that temperature difference?

That's the main question!

And you have to keep in mind - you're not doing it for two separate materials

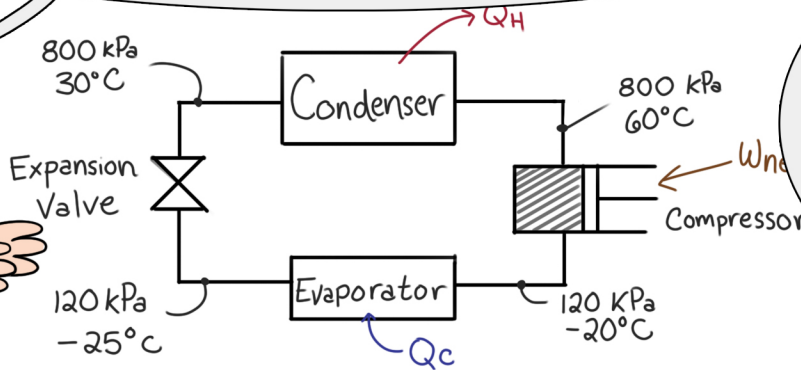
There's only one operating fluid circulating through the AC box, and you need it to achieve very different states, temperatures, and pressures at different points in the circulation.

What we're trying to create is a CYCLE!

And there are a number of different types!

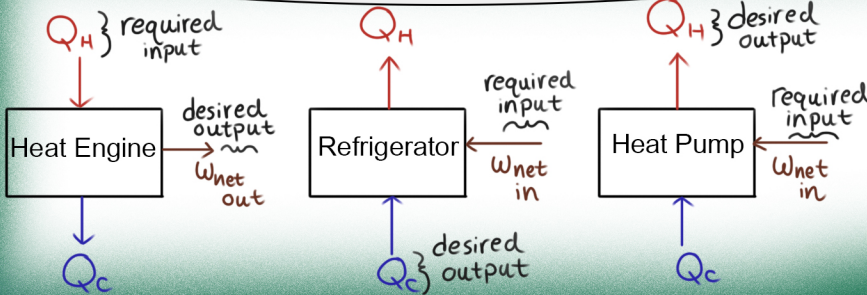
An operating fluid or coolant passes through a series of states, allowing for energy in the form of heat to enter the system, and then outputs work or heat to ensure the conservation of energy across the system!

Because the operating fluid cycles, it needs to return to the same energy conditions at its final state as its initial state - and the work and/or heat done on or by the system helps to ensure this overall balance!



Depending on the type of system you're trying to develop, you can end up with different objectives and necessary energy inputs -

such as the heat energy from/to the hot environment (Q_H), the heat energy from/to the cold environment (Q_C), and the net work input or output (W_{net})



From these main types, we're clearly talking about a refrigeration cycle.

So let's investigate it more closely!

The goal in this case is to pull energy out of the colder room and reject it into the hot outer environment.

Q_c

Q_H

W_{net}

In order to do this, we'll need to input some work!

We'll need four main components to construct our cycle, and we can use our understanding of the 1st and 2nd Laws to quantify and characterize each step!

Condenser

Expansion Valve

Evaporator

Compressor

So let's start with the system's objective: absorbing energy from the colder environment! This step will be conducted in an evaporator.

Evaporator

We want to make sure that the coolant is generally held at a constant temperature, so we ensure a temperature difference between the coolant and the colder environment.

EVAPORATOR

But pressure is just as important - in many ways, it's a characteristic that can be more readily controlled within the operation equipment.

In order to absorb energy while still maintaining the same temperature and pressure, we want the coolant to be saturated!

Thus, all the incoming energy is used to convert liquid-phase coolant to vapor-phase coolant!

As long as the coolant is saturated, the temperature can't change unless the pressure changes. So to maximize energy absorbed, all liquid must be vaporized!

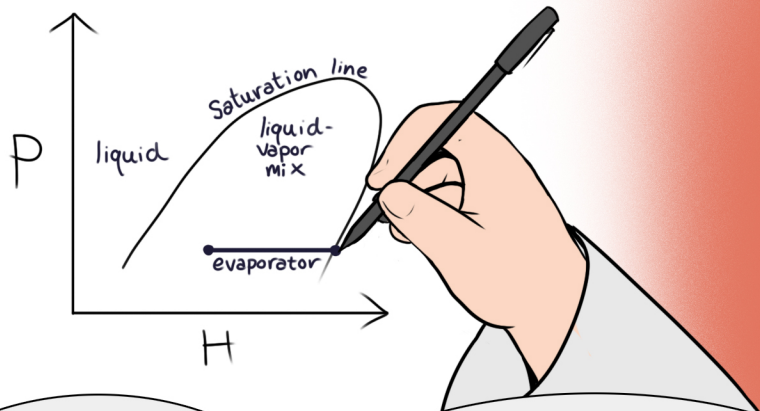
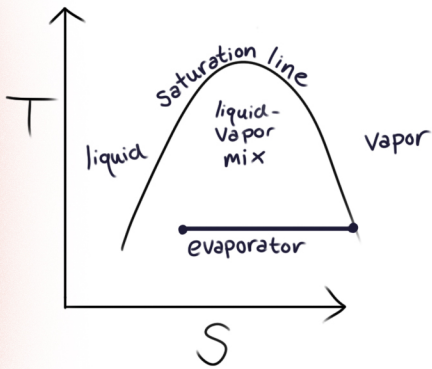
GAS

LIQUID

EVAPORATOR

GAS

We can depict this step on a saturation curve as well, using either a temperature-entropy plot or pressure-enthalpy plot



And we can determine how much heat will be absorbed from the simplified 1st law!

$$\cancel{\Delta E_K} + \cancel{\Delta E_P} + \Delta H = \cancel{Q_c} + \cancel{W_s}$$

↓

$$\Delta H = Q_c$$

Pressure is constant, so no work is input, so the change in enthalpy is equal to the heat absorbed!

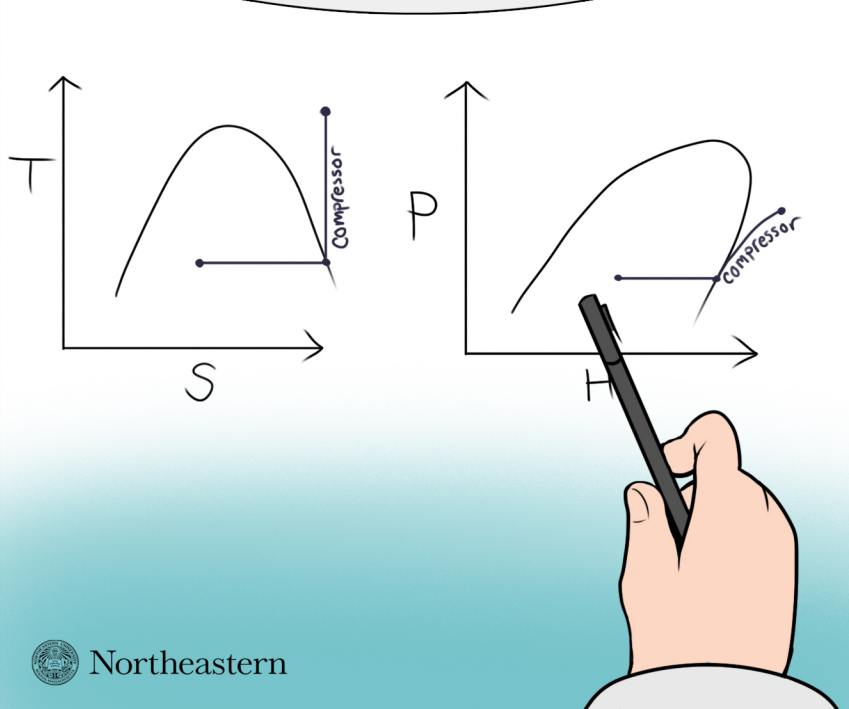
On to the next step - right after the coolant has pulled off as much energy as it can from the colder environment

At this point, we need to take the coolant and get it up to a much higher temperature for it to be able to release the absorbed energy into the hotter environment



To do that, we need to crank up the pressure - and doing so increases the temperature! This means using a **compressor**, inputting work to do so. Our pressure-volume work is likely adiabatic, so we can use the 1st law to calculate the work done!

So the vapor will become **superheated**. And we specifically increase the pressure to the level needed to create the right temperature difference for heat rejection - which, yes, means overheated vapor. But the **pressure** is the more critical operating characteristic!



While there are different types of compressors, it's much easier to use one designed to only handle one phase. Which is good, because we've already fully vaporized the coolant in the evaporator step!

There is one main problem with this step we've glossed over a bit-

It's not really that perfect in actual operation.



The compressor is usually insulated, making it an adiabatic step - thus no heat. So the change in enthalpy is equal to the work input, and we can quantify these values.

A perfect compressor would be isentropic - no change in entropy - but that would require operation at 100% efficiency!

$$\cancel{\Delta E_k} + \cancel{\Delta E_p} + \Delta H = \cancel{Q} + W_s$$

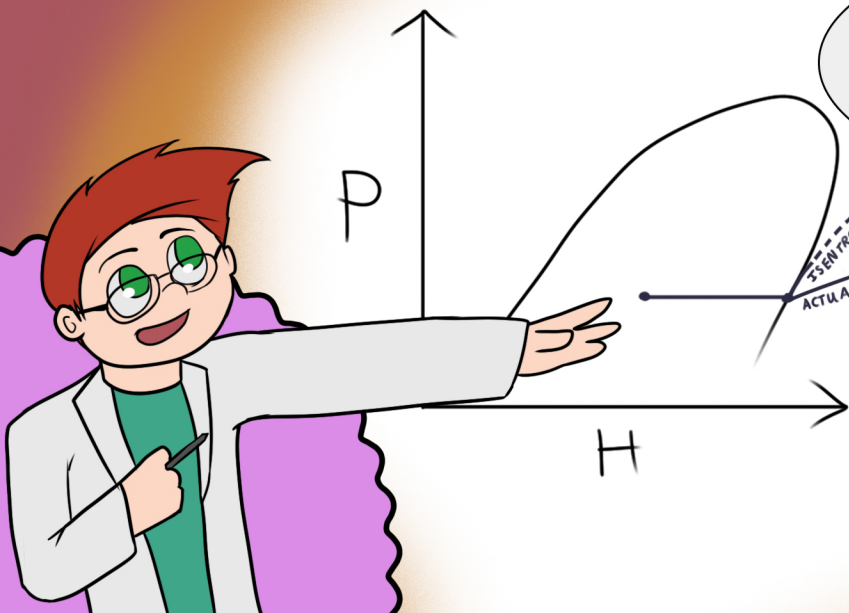
$$\Delta H = W_s$$

$$\eta_{\text{Compressor}} = \frac{\Delta H_{\text{isentropic}}}{\Delta H_{\text{actual}}}$$

Compressors never operate that efficiently - it's more than likely they'd be 90, 80, 70% efficient. Which means the change in enthalpy is much larger - meaning a lot more work is necessary to achieve the change in pressure and temperature of the coolant!

So we actually need more work input to get our system to work, and our diagram would look a little different, realistically.

For the rest of our analysis here, let's assume a really high efficiency and neglect this issue, just to reduce the number of concerns we're dealing with at once.

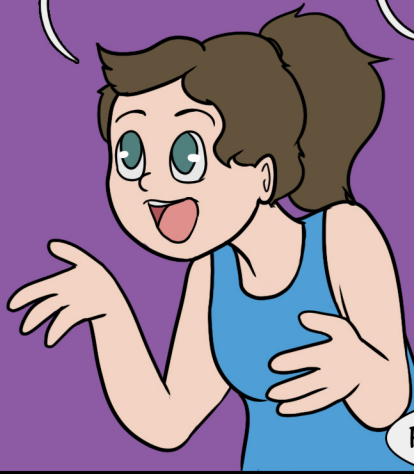


On to the third step - **heat rejection**. We again want a constant pressure and as close to a constant temperature as we can get. So how do we reject heat while maintaining constant pressure and temperature?



Oh! Keep it saturated again!

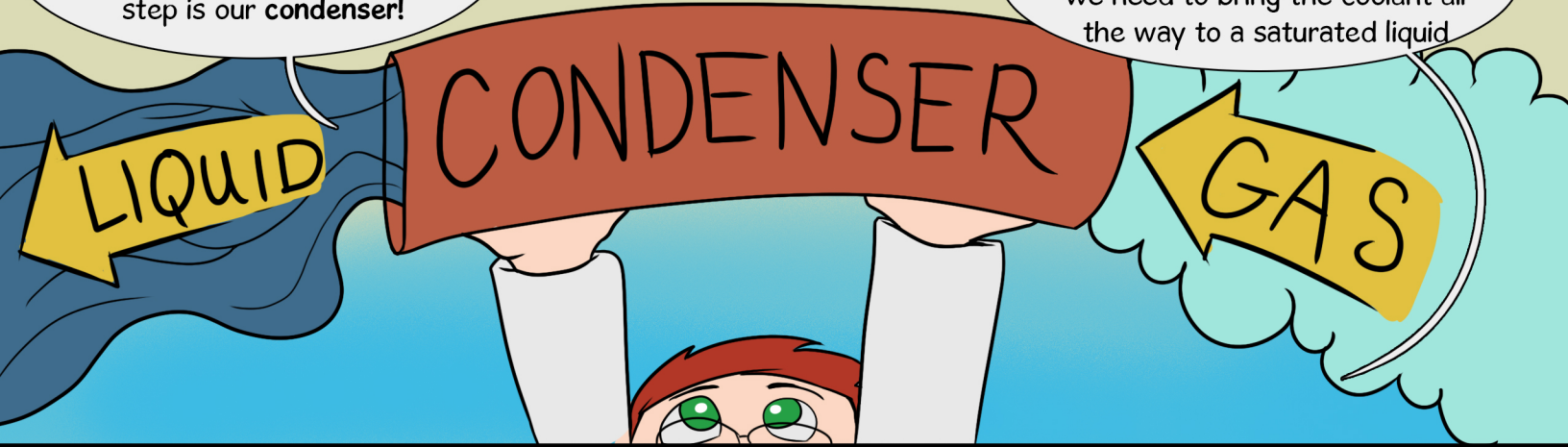
Yeah, hold the equipment at a constant pressure, which fixes the constant temperature!



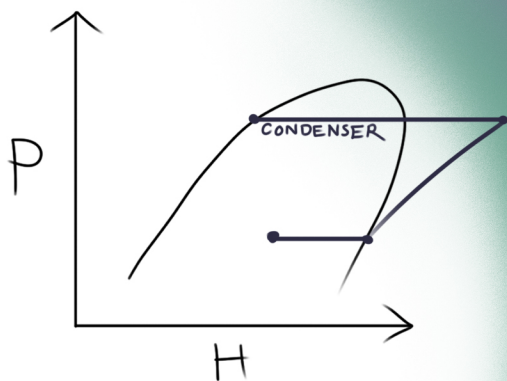
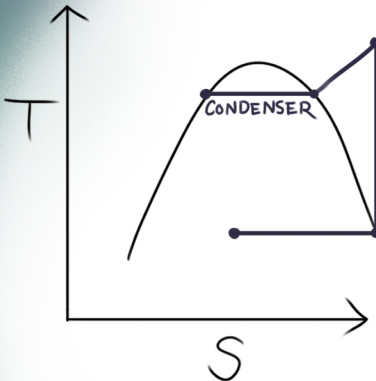
Right! Saturated coolant!

Now we want our coolant to release heat and transfer from vapor to liquid, so this equipment step is our **condenser**!

And to maximize the energy transfer out into the hot environment, we need to bring the coolant all the way to a saturated liquid



Let's add this condenser step to our cycle diagrams.



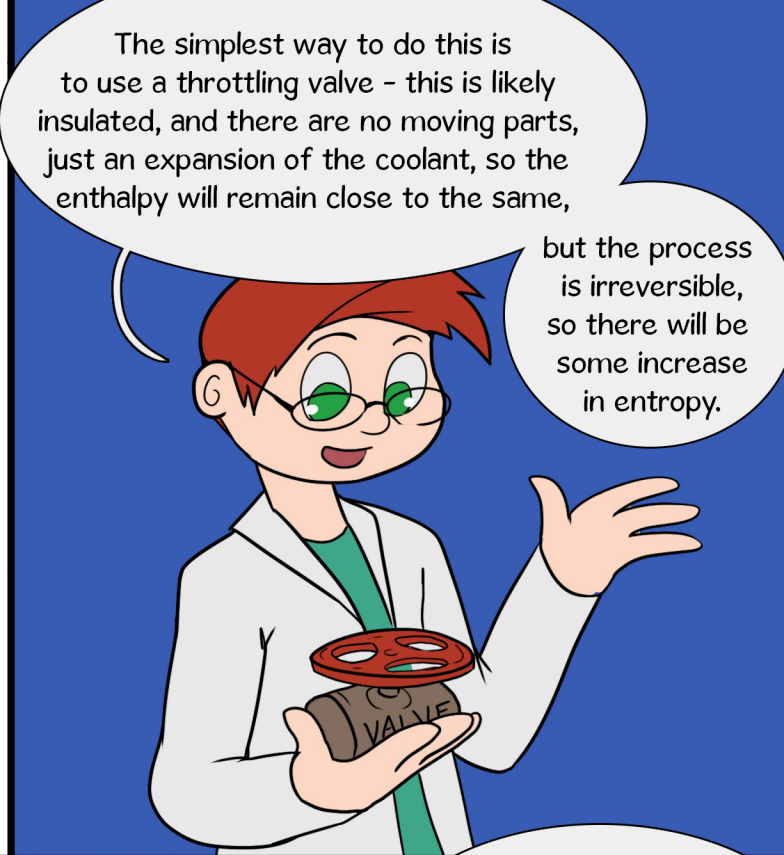
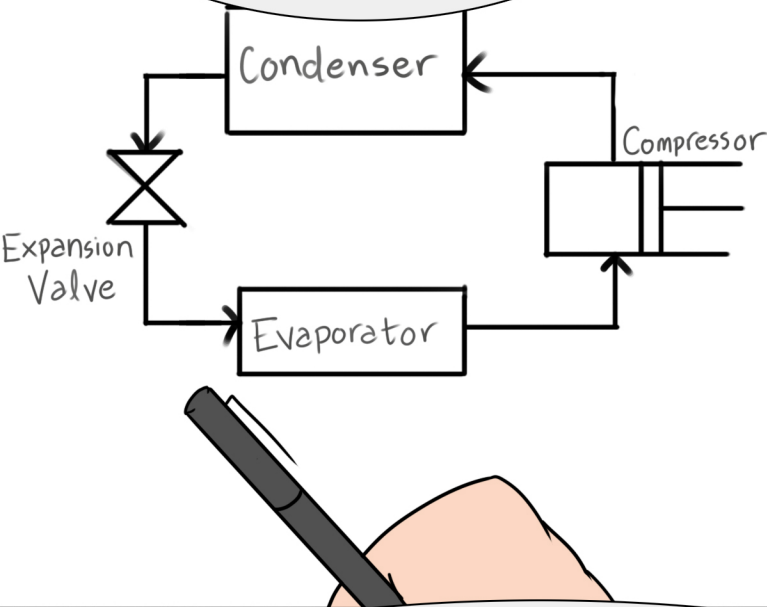
$$\Delta H = Q_H$$

And don't forget the simplification of the 1st law for this step! Once again, change in enthalpy will be the heat rejected.

Finally, the coolant needs to be brought back to its original starting point so that it can absorb energy from the cold environment again - which means reducing the operating pressure and temperature.

The simplest way to do this is to use a throttling valve - this is likely insulated, and there are no moving parts, just an expansion of the coolant, so the enthalpy will remain close to the same,

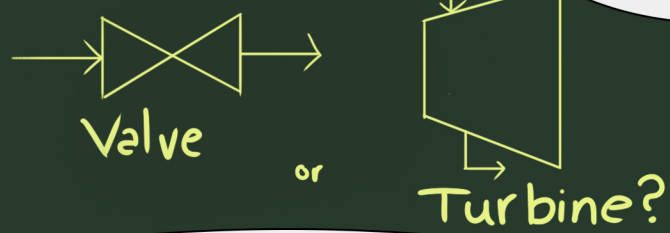
but the process is irreversible, so there will be some increase in entropy.



You could suggest using a turbine in this step to regain some of the work, and reduce the overall energy cost...

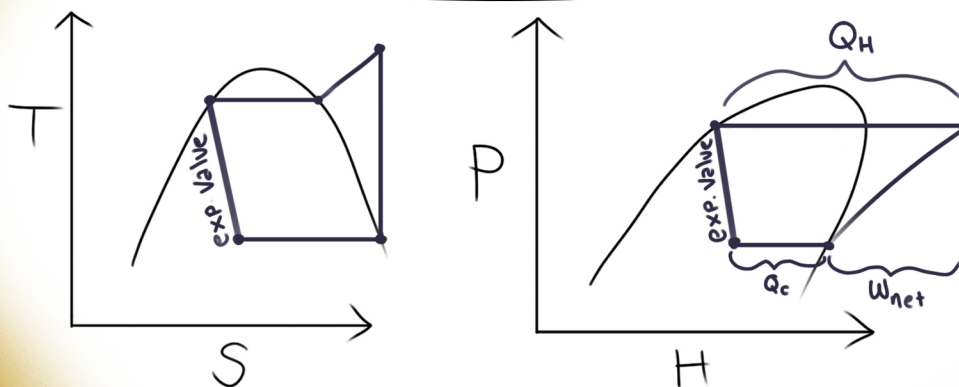
...and potentially reduce the gain in entropy,

AND potentially reduce the energy state of the coolant, increasing the amount of energy that can be absorbed from the cold room!



...But that's a little unrealistic to implement, leaving us with the throttling valve instead.

And now we can finish our overall diagrams - and also get some sense of how the cycles work, now that we can visualize the amount of both the energy absorbed and rejected, and the amount of work input!



To quantify how well the refrigeration cycle functions, we rely on the **coefficient of performance**, or COP. The higher COP value, the better!

$$\text{COP}_R = \frac{\text{desired output}}{\text{required input}} = \frac{q_c}{W_{\text{net,in}}}$$

But that still doesn't explain why the AC box isn't working!

Well, assuming that all the components inside are functioning correctly...

Remember the driving force at work?

Temperature difference!

Between the coolant and the surrounding air, on both sides!

Right!

The thing to be careful of is that a **refrigeration cycle** works similarly to a **heat pump** - but the refrigeration cycle is designed to pull heat energy out of a colder environment, and a heat pump is designed to pump heat energy into a warmer environment. A correctly installed AC is essentially a heat pump for the outdoors.

Incorrectly installed, however...

You're telling us we put it in the window as an *indoor* heat pump?!

We put it in backwards??

This is what we call a learning experience - in more ways than one! Stay cool!