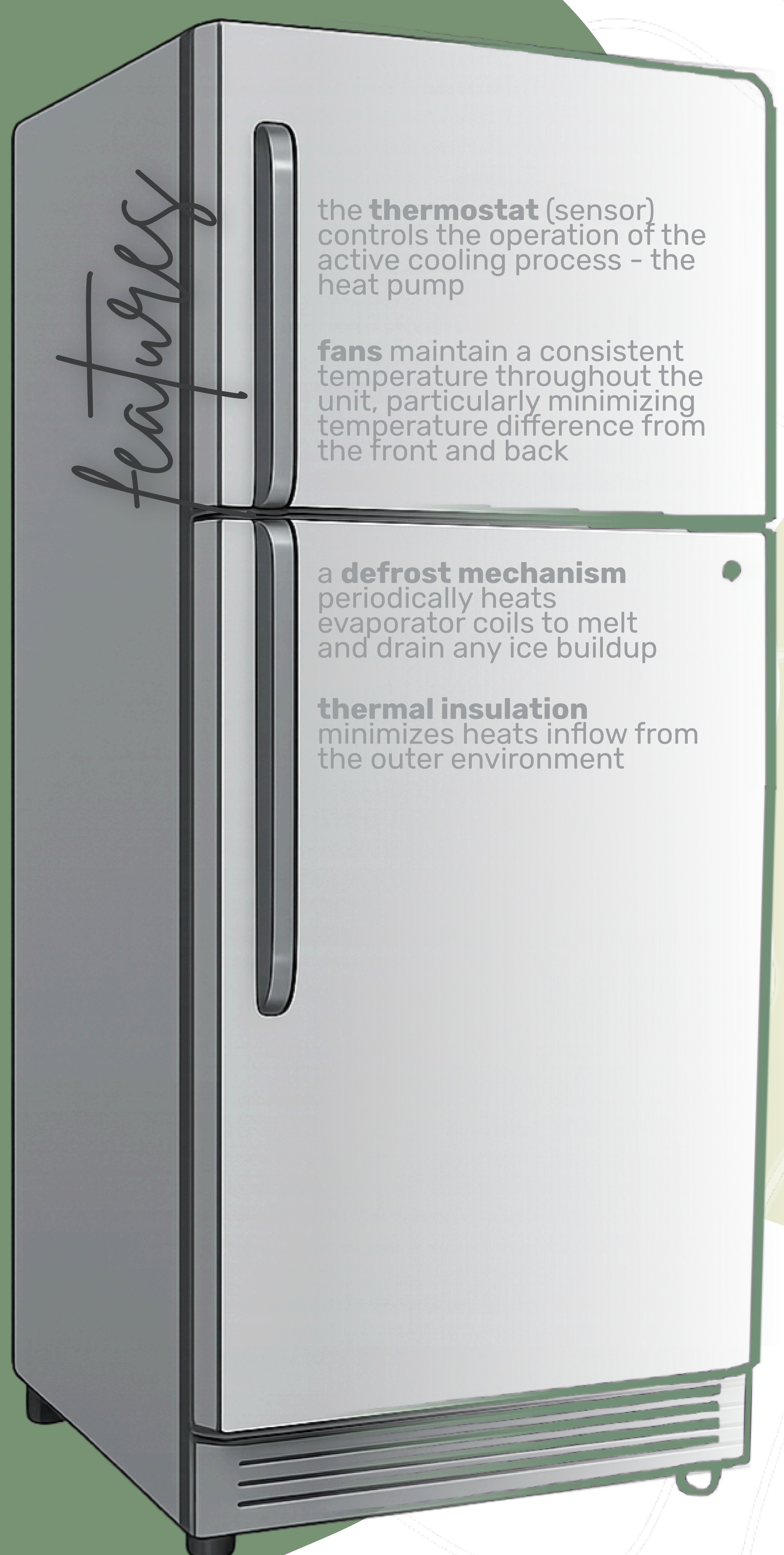
BY: ADARSH SHETH

RE•FRIG•ER•A•TOR

noun, *an appliance or compartment which is artificially kept cool and used to store food and drink*

makes use of a heat pump to remove heat, instead of the common perception of adding 'coldness' to the environment; as such, it is important to note **heat ONLY moves from hot to cold**

engineering breakdown
COMMON ITEM SERIES



DEFINITIONS, CONTEXT

- **RE•FRIG•ER•ANT:** chemically stable, non-reactive fluid used for cooling in heat pumps; with extremely low boiling point (circa -26C) and high heat of vaporization, allowing high heat absorbtion during evaporation
- **WORKING FLUID:** any fluid (liquid, gas) that participates in the thermodynamic cycle to transfer heat to/from system and surroundings
- **FIRST LAW OF THERMODYNAMICS:** energy can change form but can never be created or destroyed; **ΔU=Q−W** where ΔU is change in internal energy, Q is heat added to system, and W is work done by the system
- **ENTHALPY:** the total heat of a system calculated using **H=U+PV**, not to be confused with **entropy**, the system's measure of disorder
- **LATENT HEAT:** energy absorbed during a phase change (solid ↔ liquid ↔ gas), without temperature change
  - **HEAT OF VAPORIZATION:** AKA the enthalpy of vaporization; an example of latent heat; the amount of energy required to convert a substance from its liquid phase to gaseous phase at a constant temperature; represented by the equation: $\Delta H_{vap} = \Delta U = P\Delta V$
- **SENSIBLE HEAT:** the rise in temperature contributing to an increase in the heat of a system; paired with latent heat, they make up the two ways for the heat of a system to change
- **SATURATED VAPOR:** the pressure and temperature at which a vapor is in equilibrium with liquid phase; compression leads to condensation and heating leads to *superheated vapor*
- **SUPERHEATED/SUPERCOOLED GAS/LIQUID:** the temperature above/below saturated temperature for a given pressure; no liquid in superheated gas and supercooled liquid cannot boil until at saturated temperature
- **ADIABATIC:** any process in which no heat is absorbed by nor emitted from the system; any temperature change is solely due to work done on or by the system

ACTIVE COOLING PROCESS

COMMON REFRIGERANTS

	NAME	FORMULA	BOILING POINT	SAFETY	GWP (global warming potential)
R-600a	isobutane	C_4H_{10}	-11.7	mildly flammable	3.3
R-290	propane	C_3H_8	-42.2	flammable	3.3
R-134a	tetrafluoroethane	CH_2FCF_3	-26.3	non-flammable	1550
R-12	freon	CCl_2F_2	-29.8	ozone-depleting	10,200
R-22	HCFC	$CHClF_2$	-40	mildly toxic	1810
R-17	ammonia	NH_3	-33.3	toxic	0

01. COMPRESSOR: increases pressure by adiabatic compression, thus raising temperature
- goal: raise the temperature of the refrigerant well above ambient temperature to allow for heat transfer from superheated vapor to environment, remembering heat moves from hot to cold
  - a refrigerant temperature below (or at) room temperature would transfer no heat, and instead absorb heat from the environment
- starts the refrigeration cycle, by pressure-driving the system
- input: ↓ pressure (1-2 atm), ↓ temperature ***saturated*** vapor (~0°C)
  - brought from the evaporator through the suction line
- output: ↑ pressure (8-15 atm), ↑ temperature ***superheated*** vapor (60-90°C)
  - higher pressure is vital as raises the boiling point and in turn, the condensation point, which means it can condense at room temperature instead of its usual sub-zero
- methodology:
  - (1) ***adiabatic*** compression (no heat in/out of the system; Q=0) of the refrigerant: decreasing the volume of the vapor, forcing it into a smaller space
    - to allow near perfect adiabatic conditions, the compressor is **heavily insulated** to prevent heat from escaping to or being absorbed from the environment
    - vapor is mechanically compressed, often using a piston[1]
  - (2) frequent molecule collisions raises the temperature
    - PV=nRT ⇒ decreasing volume at constant conditions, increases pressure
    - the piston pushes against the internal pressure of the refrigerant, doing work (W) on it
    - at Q≈0, ΔU=W, thus the work directly increases the internal energy (U) of the gas
    - +ΔU increases the frequency and strength of molecule collisions, and thus, its kinetic energy (KE)
    - KE ∝ T, thus temperature increase
  - (3) simultaneously, the enthalpy (H) increases, raising the "energy state of the gas"
    - change in enthalpy = ΔH = ΔU + ΔPV
    - as established earlier, +ΔT leads to +ΔU which also raises ΔPV according to ΔPV=nRΔT
    - thus enthalpy increases and the gas is ready to release its energy in the next step
- [1] ***reciprocating compressors*** operate in the reverse of an internal combustion engine, powered by an electric motor; process ↻:
  - stoke 1: the piston moves downstroke, creating a suction which opens a valve for refrigerant vapor to enter
  - stroke 2: the suction valve closes and gas is compressed as the piston moves toward the cylinder head
  - once cylinder pressure > discharge line pressure, the discharge valve opens, allowing refrigerant to enter the condenser
- less common, alternate methods: rotary vane compressor, scroll compressor

02. CONDENSER COIL: condenses refrigerant to release heat to surroundings
- goal: maximize ***convection*** (transfer of heat through movement of fluids) and ***radiation*** (heat emission and carried over electromagnetic waves; no medium required for transfer)
  - made of copper or aluminum are shaped in s-curves or ***serpentine fins*** maximize surface area
  - ***radiative emissivity*** is maximized using a black coating, following the ***blackbody principle***
  - ambient air vented or fanned over the coils
- most of the energy is lost during phase change ($Q_{\text{latent heat of vaporization}} = m_{dot} \cdot h_{fg}$) rather than temperature drop ($Q_{sensible} = m_{dot} \cdot C_P \cdot \Delta T$); as such condensation of refrigerant is most important
- input: superheated *vapor* at ↑P and ↑T; output: ΔP=0, ambient temperature saturated *liquid*

03. EXPANSION via CAPILLARY TUBE: a passible system throttle, dropping pressure
- reduce pressure so the refrigerant can boil at the low temperature required in the evaporator
- ***isenthalpic expansion*** (expansion with no heat transfer or work) significantly reduces pressure
  - done by restricting refrigerant flow using a thin, coiled tube capillary tube
  - a complex ***thermostatic expansion valve (TXV)*** is used in industrial applications
- ***Joule-Thomson effect:*** rapid depressurization, combined with some partial vaporization, causes the refrigerant's temperature to drop drastically, turning it into a liquid and vapor *mixture*
- input: subcooled liquid (wants to boil), ↓P; output: ↓P and ↓T

04. EVAPORATOR: refrigerator heat flows to the colder refrigerant, bringing it to a boil
- ***evaporation*** occurs when vapor pressure = ambient pressure, which is to say when the pressure exerted by the gas above a liquid = pressure pushing down on the surface of the liquid
  - weaker intermolecular forces, the higher the vapor pressure
  - thus, lower external pressure = lower boiling point
- heat from refrigerator moves to the much cooler, sub-zero temperature region near the evaporator coils, which absorb heat and boil
- this heated vapor is then sent to the compressor to repeat the cycle again
- around the inside of the fridge; absorbs latent heat, converting it into a vapor

wattage: 300-800W
energy use: ~50% of energy bills, high due to 24/7 operation

PRESSURE 1-2 atm to 8-15 atm

TEMPERATURE –15 °C - to - 60-90 °C

ITEM= common