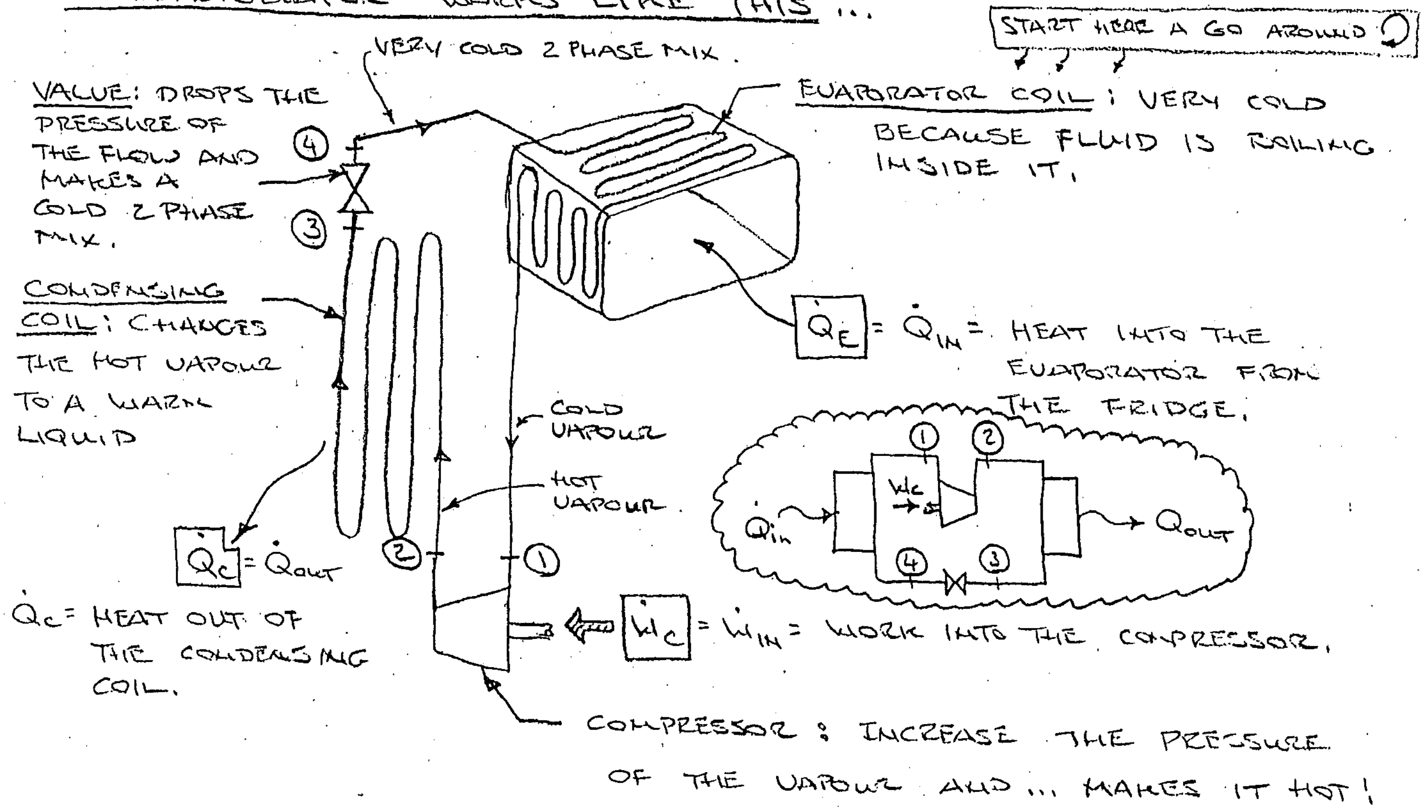
REFRIGERATION

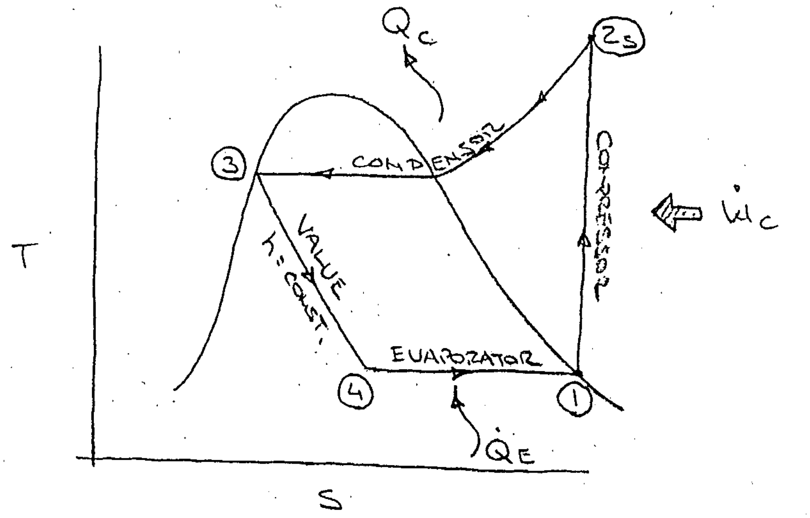
AN IDEAL VAPOUR-COMPRESSION REFRIGERATION CYCLE OPERATES AT STEADY STATE WITH REFRIGERANT R134A AS THE WORKING FLUID. SATURATED VAPOUR ENTERS THE COMPRESSOR AT -12°C, AND SATURATED LIQUID LEAVES THE CONDENSER AT 28°C, THE MASS FLOW RATE OF REFRIGERANT IS 5kg/min.

DETERMINE:
- a) THE COMPRESSOR POWER, kW
- b) THE REFRIGERATING CAPACITY, TONS.
- c) THE COEFFICIENT OF PERFORMANCE (COP).

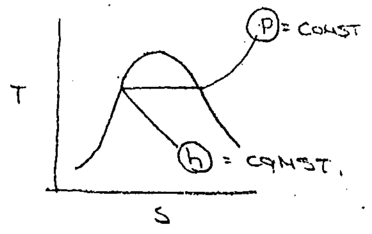
A REFRIGERATOR WORKS LIKE THIS ...



ON A T-S DIAGRAM THE PROCESS LOOKS LIKE THIS!



RECALL



REFRIGERATION EXAMPLE

(SEE SIDE ① FOR THE QUESTION.)

0.7 MPa	s	h
30°C	0.9197	265.37
31.33	0.9242	266.77
40°C	0.9539	275.93

0.727 MPa	s	h
31.33	0.9194	266.06
34.04	0.9267	268.95
40	0.9494	275.32

0.8 MPa	s	h
31.33	0.9066	264.15
40	0.9374	273.66

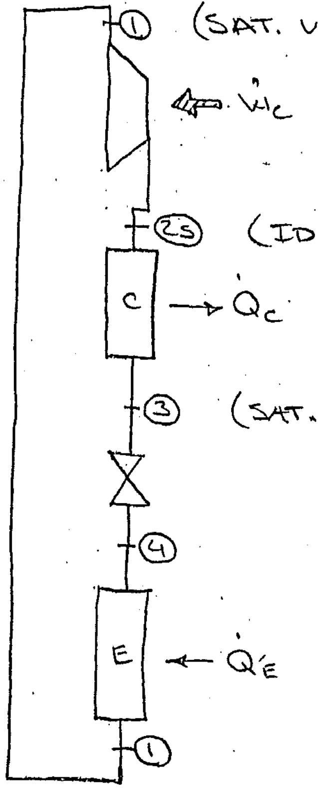
FIND : a) $\dot{W}_c$ = COMPRESSOR POWER , kW

b) $\dot{Q}_E$ = REFRIGERATING CAPACITY, TONS

c) COP.

① DRAW CYCLE AND SUMMARIZE PROBLEM.

FLUID : R134A , $\dot{m} = 5$ kg/min.



① (SAT. VAPOUR AT −12°C)

$$\boxed{\dot{W}_c = \dot{m}\left(h_{2s} - h_1\right)} = \frac{5}{60}\left(268.95 - 240.15\right) = 2.4\ \frac{kJ}{s}, kW$$

2s (IDEAL CYCLE ∴ $s_1 = s_{2s}$)

$$\boxed{\dot{Q}_c = \dot{m}\left(h_{2s} - h_3\right)} = \frac{5}{60}\left(268.95 - 88.61\right) = 15.03\ \frac{kJ}{s}, kW$$

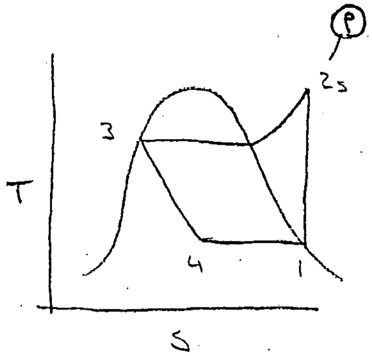
③ (SAT. LIQUID AT 28°C)

$$\boxed{h_3 = h_4}$$

$$\boxed{\dot{Q}_E = \dot{m}\left(h_1 - h_4\right)} = \frac{5}{60}\left(240.15 - 88.61\right) = 12.63\ \frac{kJ}{s}, kW$$

② FIND PROPERTIES (TABLE A-7)

STATE	T	P	v	h	s	CONDITION
1	−12°C*			240.15	0.9267	SAT. VAPOUR*
2s	34.04	0.727		268.95	0.9267	
3	28°C*	0.727		88.61		SAT. LIQUID*
4	−12°C			88.61		



③ FIND ANSWERS.

a) $\dot{W}_c = 2.4$ kW (WHAT YOU PAY FOR)

b) $\dot{Q}_E = 12.63$ kW $= 3.6$ AC TONS (WHAT YOU WANT).

c) $COP = \frac{\text{WHAT YOU WANT}}{\text{WHAT YOU PAY FOR}} = \frac{12.63}{2.4} = \quad \simeq 5.3$ (GOOD UNIT).

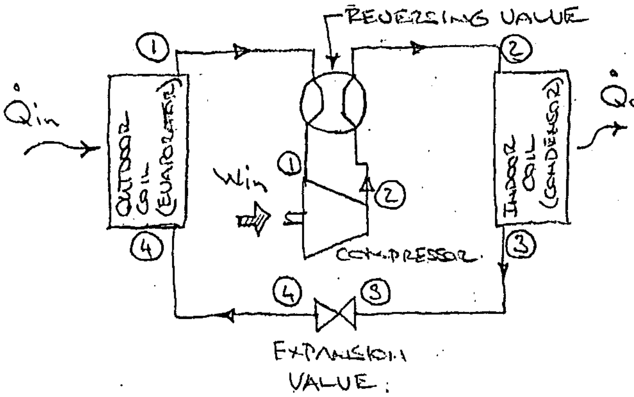
NOTE: 1 AIR CONDITIONING TON = 12000 BTU/HR = 3516 WATTS.

HEAT PUMPS

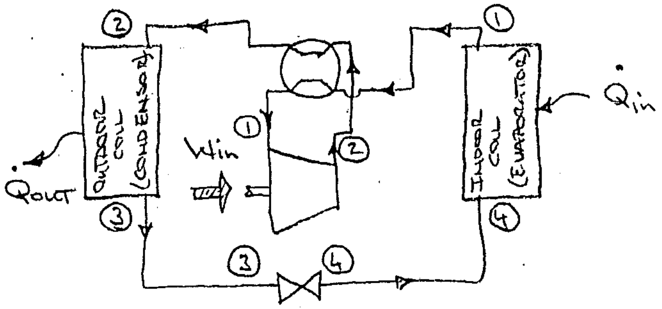
A HEAT PUMP OPERATES IN EXACTLY THE SAME WAY AS A REFRIGERATOR. ENERGY IS EXTRACTED FROM A COLD PLACE AND DELIVERED TO A HOT PLACE. THE ONLY THE THING THAT CHANGES, FROM A THERMODYNAMIC POINT OF VIEW, IS WHAT THE USER WANTS : A REFRIGERATOR → COLD IS DESIRED
A HEAT PUMP → HEAT IS DESIRED.

HOUSEHOLD HEAT PUMPS CAN OFTEN SUPPLY BOTH COOLING AND HEATING THANKS TO A VALVE INSIDE THE SYSTEM THAT SWITCHES THE FUNCTION OF THE HEAT EXCHANGER COILS.

HEAT PUMP - HEATING MODE.

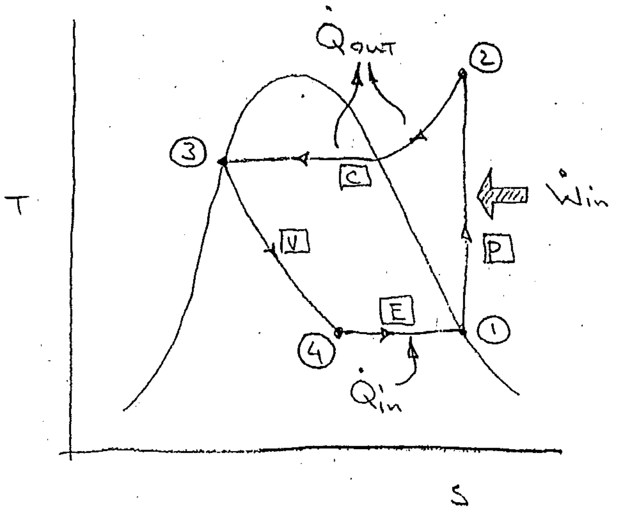


HEAT PUMP - COOLING MODE (REFRIG).



<u>NOTE</u> THAT'S ALL IT TAKES TO REVERSE THE FUNCTION OF THE DEVICE — TURN THE REVERSING VALVE 90° AND REVERSE THE FLOW THROUGH EACH COIL AND THE EXPANSION VALVE.

T - S DIAGRAM



COEFFICIENTS OF PERFORMANCE (COP).

$$COP = \frac{\text{DESIRED OUTPUT}}{\text{REQUIRED INPUT}}$$

REFRIGERATOR

$$COP_R = \frac{\text{COOLING EFFECT}}{\text{WORK INPUT}} = \frac{\dot{Q}_{in}}{W_{in}}$$

HEAT PUMP

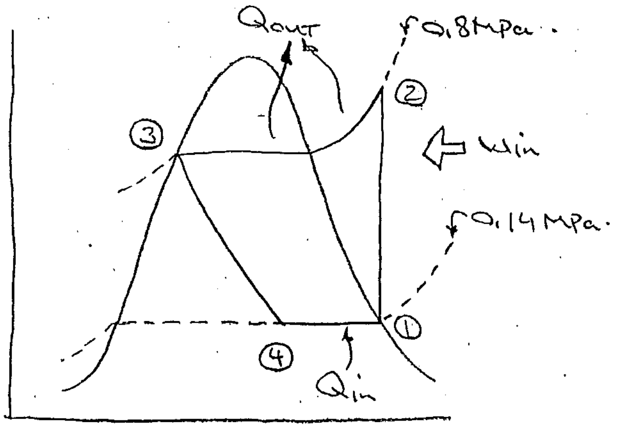
$$COP_{HP} = \frac{\text{HEATING EFFECT}}{\text{WORK INPUT}} = \frac{\dot{Q}_{out}}{W_{in}}$$

① EXAMPLE - HEAT PUMPS

A SMALL SCALE HEAT PUMP SET-UP USES R-134a AND OPERATES AS AN IDEAL VAPOUR - COMPRESSION REFRIGERATION CYCLE BETWEEN 0.14 MPa AND 0.8 MPa. THE MASS FLOWRATE OF THE REFRIGERANT IS 0.05 kg/s.

DETERMINE
- a) THE RATE OF HEAT REMOVAL FROM THE OUTDOOR AIR
- b) THE RATE OF HEAT DELIVERY TO THE INDOOR SPACE
- c) COP_{HP}

① T-S DIAGRAM.



② TABLE OF PROPERTIES.

STATE	T	P	v	h	s	COND.
1	-18.8	0.14*		236.04	0.9322	SAT. VAP.*
2	38.54	0.8*		272.05	0.9322*	
3	31.33	0.8*		93.42		SAT. LIQ.*
4	[illegible]3	0.14*		93.42*		

-18.8

I WANT THESE BUT TEMPERATURE IS INTERESTING TOO.

③ FIGURE OUT POWER AND WORK.

a) $Q_{in} = \dot{m}(h_1 - h_4) = 0.05(236.04 - 93.42)$
$= 7.13 \text{ kJ/s}$
$= 7.13 \text{ kW}$

b) $Q_{out} = \dot{m}(h_2 - h_3) = 0.05(272.05 - 93.42)$.
$= 8.93 \text{ kJ/s}$
$= 8.93 \text{ kW}$.

c) $COP_{HP} = \frac{Q_{out}}{W_{in}}$ $\qquad W_{in} = \dot{m}(h_2 - h_1) = 0.05(272.05 - 236.04)$
$= 1.8 \text{ kJ/s}$
$= 1.8 \text{ kW}$

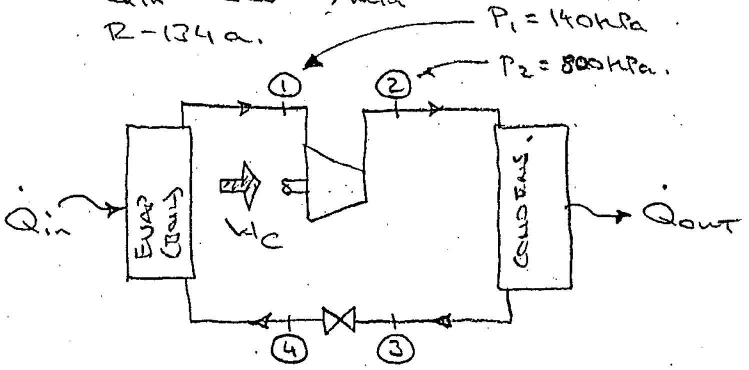
$= \frac{8.93}{1.8}$

$= 4.96$ PRETTY GOOD AND QUITE NORMAL FOR HEAT PUMPS.

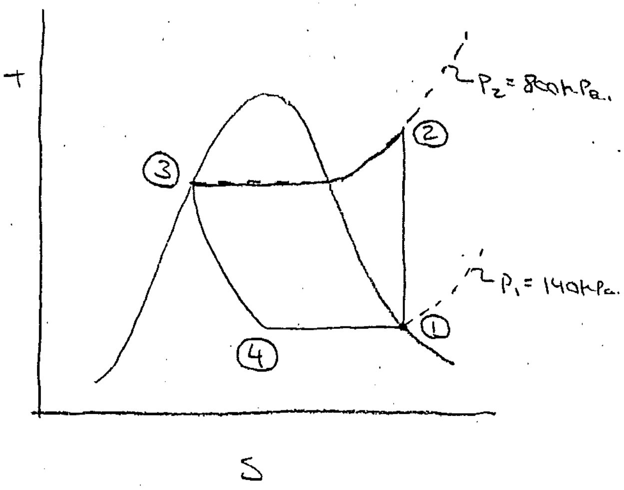
② REFRIGERATION SYSTEM - IDEAL

$\dot{Q}_{in} = 300$ kJ/min

R-134a.



T-S DIAGRAM



a) $x_4 = ?$

$$x_4 = \frac{h_4 - h_f}{h_g - h_f}$$

$$= \frac{93.42 - 25.77}{236.04 - 25.77}$$

$$= 0.322$$

STATE	T	P	v	h	s	COND.
1		140*		236.04	0.9322	SAT VAP.*
2		800*		272.05	0.9322	SUPER
3		800*		93.42	0.3459	SAT LIQ.*
4		140*		93.42		$x = ?$

NOTE: h_2 WAS OBTAINED BY LINEAR INTERPOLATION. ON THE SUPER HEAT TABLES USING THE KNOWN S.

b) $$COP_R = \frac{Q_{in}}{W_c}$$

$$Q_{in} = 300 \text{ kJ/min} = 5 \text{ kJ/s}$$

$$= m(h_1 - h_4)$$

$$\text{So } m = \frac{Q_{in}}{(h_1 - h_4)} = \frac{5}{(236.04 - 93.42)}$$

$$= 0.035 \text{ kg/s}$$

$$W_c = m(h_2 - h_1)$$

$$= 0.035(272.05 - 236.04)$$

$$= 1.26 \text{ kJ/s}$$

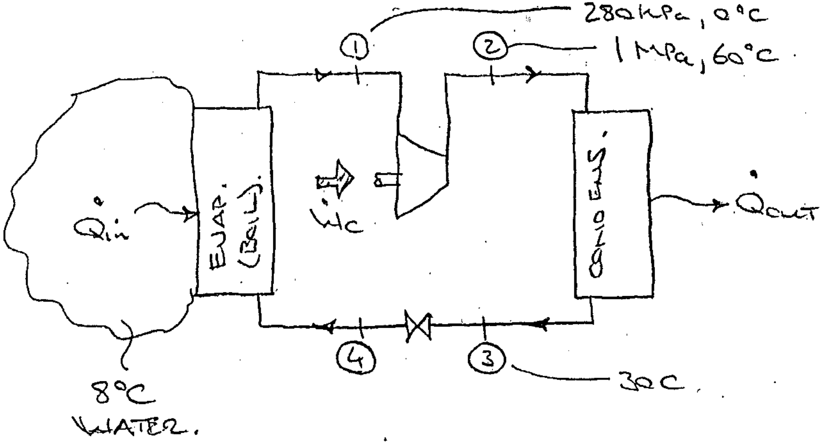
$$\text{So } \underline{COP_R} = \frac{5}{1.26}$$

$$= \underline{3.97}$$

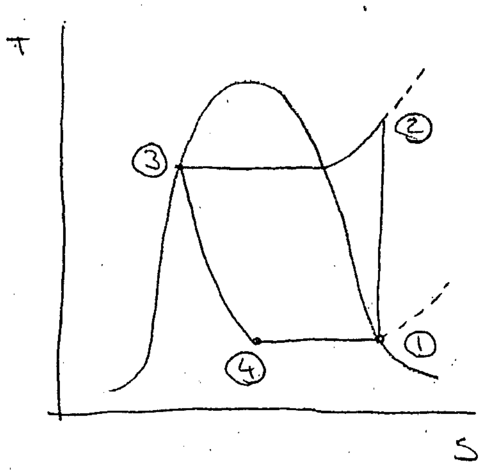
c) $W_c = 1.26$ kJ/s $= 1.26$ kW.

③ HEAT PUMP

$\dot{Q}_{out} = 60{,}000\ kJ/h = 16.67\ kJ/s$



T-S DIAGRAM



STATE	T	P	v	h	s	COND.
1	0*	280*		247.64	0.9238	SUPER.
2	60*	1M*		291.36	0.9768	SUPER
3	30*			91.49		SAT. LIQ.*
4				91.49		

a) POWER INPUT = W_c

$\dot{W}_c = \dot{m}(h_2 - h_1)$.

$m = ?$

$\dot{Q}_{out} = 16.67\ kJ/s =$

$= m(h_2 - h_3)$

$\therefore \dot{m} = \dfrac{Q_{out}}{(h_2 - h_3)}$

$= 16.67/(291.36 - 91.49)$

$= 0.083\ kg/s$

so $\underline{\dot{W}_c} = (0.083)(291.36 - 247.64)$

$= \underline{3.63\ kJ/s}$

NOTE: THAT THE COMPRESSER IS A REAL COMPRESSOR.

$S_2 > S_1$

$\therefore$ ITS NOT 100% EFFICIENT.

BY THE WAY...

$COP_{HP} = \dfrac{Q_{out}}{W_c}$

$= \dfrac{16.67}{3.63}$

$= 4.59$ (3-5 IS TYPICAL)

b) $\underline{\dot{Q}_{in}} = \dot{m}(h_1 - h_4)$

$= (0.083)(247.64 - 91.49)$

$= \underline{12.96\ kJ/s}$

c) CURRENTLY ONLY 3.63 KW OF ELECTRIC POWER ARE USED. IF THE HOUSE'S HEAT CAME FROM ELECTRIC RESISTANCE HEATERS THEN ALL 16.67 KW WOULD HAVE TO BE PROVIDED BY ELECTRICITY.

THAT'S $\underline{13.04\ kW}$ MORE ELECTRIC POWER.