Week 5, Refrigeration examples (continuing the numbering from last week):

5. Plot the following cycle on the R134a refrigerant p-h diagram, observe the saturation temperatures in the condenser and evaporator, and deduce the work in by the compressor, the heat transfer in the condenser and the evaporator, and the coefficient of performance. The brave may also look at finding the increase in entropy in the compressor and the change in specific volume of the refrigerant in the compressor.

    a. evaporator pressure 2 bar gauge

    b. condenser pressure 13 bar gauge

    c. compressor exit temperature 80°C

    d. condenser exit temperature 37°C

    e. evaporator exit temperature 15°C

Given the flow rate of refrigerant is 18 g/s and the atmospheric pressure is 1 bar exactly.

6. Looking at pressure and corresponding saturatation temperature range in the chart for the refrigerant Forane 141b (below), why is this refrigerant more suited to air conditioning in hot countries rather than domestic refrigeration?

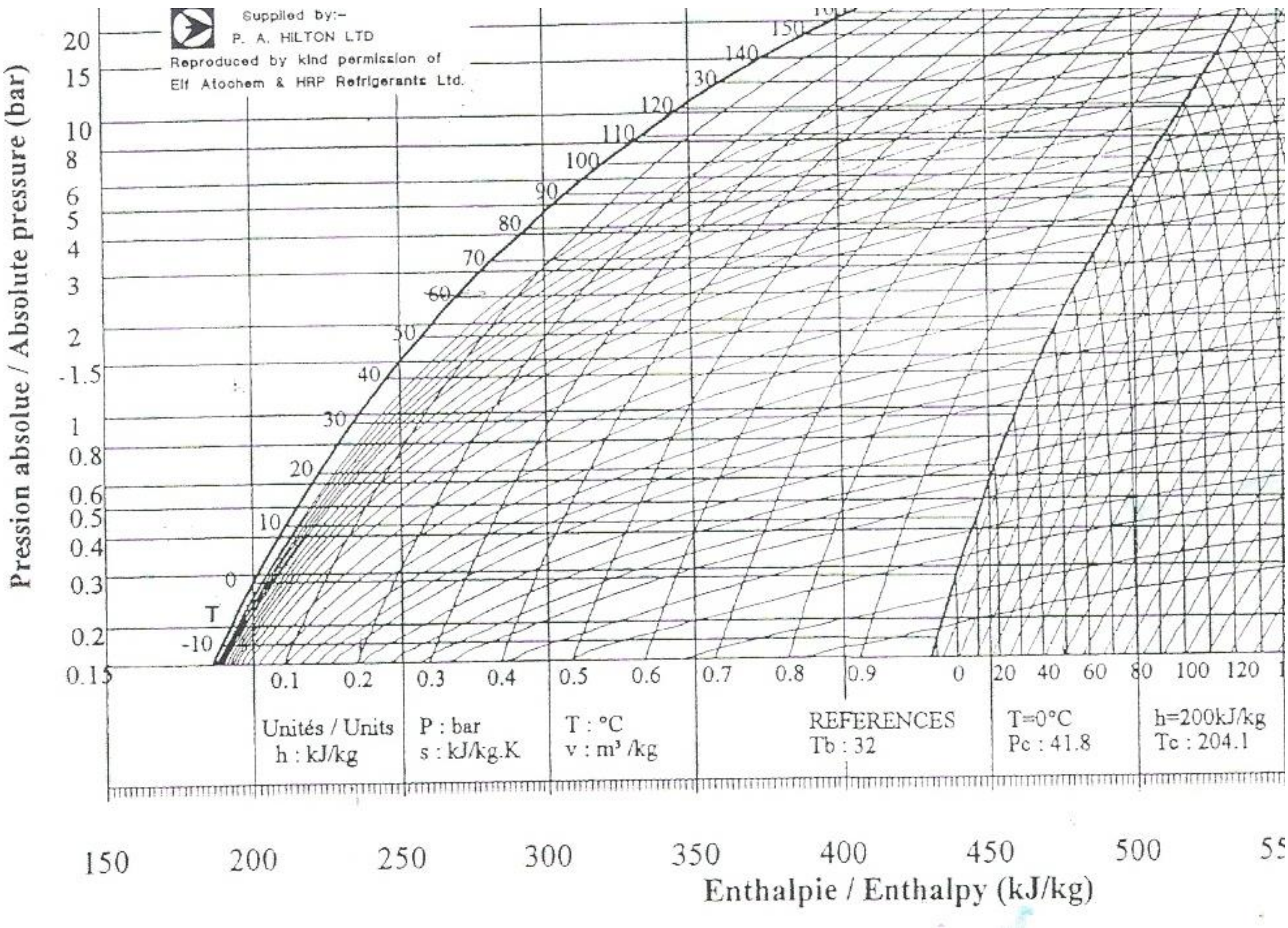

Figure 1 pressure versus specific enthalpy for refrigerant R141b

Air conditioning examples week 5

Refreshing: Boris Johnson on one of the new air-conditioned Tube trains

1. What are the relative and specific humidity today? Both outside and in the room (this requires wet (11°C) and dry bulb (13°C) temperatures).
2. An air conditioning unit draws in 0.5kg/s of atmospheric air at 30°C and specific humidity 0.012. What is the mass flow rate of water vapour in the air?
3. Using the formula relating specific humidity to partial pressure of the water vapour and the atmospheric pressure, and assuming 1 atmosphere atmospheric pressure, what is the partial pressure of the water vapour in question 2?
4. Find the p_g of water in question 2. What is the relative humidity of the incoming air?
5. Find the dew point corresponding to the pressure p_S in question 3. Sketch at T-v diagram showing the process that the water vapour in the atmospheric air from question 2 must go through in order to form dew.

Refrigeration solutions Week 5.

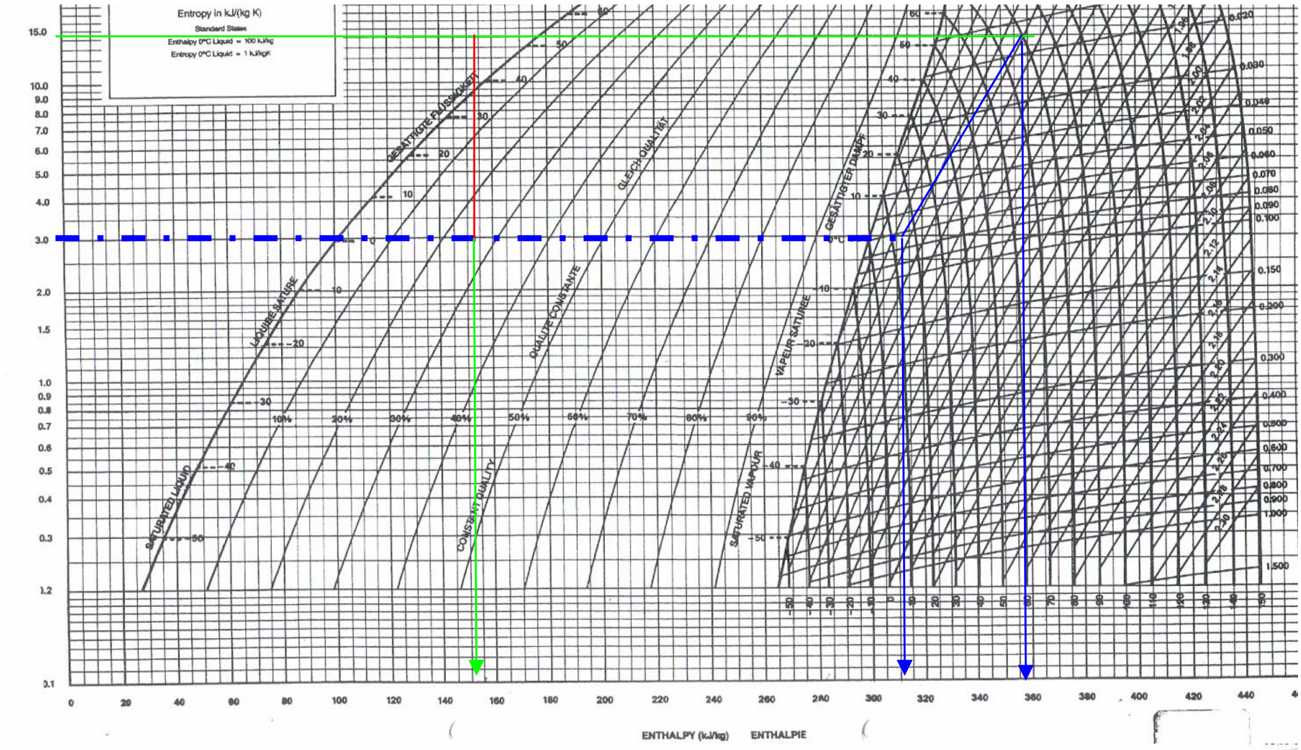

Figure 2 showing chart of pressure versus enthalpy for refrigerant R134a

5. The process is plotted as shown in the figure.

The saturation temperatures are: condenser 53°C; evaporator 0°C (zoom to 200% to see clearly).

Work in the compressor is the enthalpy change in the compressor (blue line process). That is 355 kJ/kg less 310 kJ/kg, which is 45 kJ/kg. The heat out of the cycle in the condenser is the green line, and has enthalpy change is 350 – 150 kJ/kg = 200 kJ/kg. The heat into the cycle in the evaporator, blue chain dashed line, is 310-150=160 kJ/kg. The rate of work and heat transfer given that only 18g/s of refrigerant flows through the cycle is $0.018\times45=0.81$kW, $0.018\times200=3.6$kW, and $0.018\times160=2.88$kW in the respective parts of the cycle. Note there is no enthalpy change in the throttle, red line. The coefficient of performance is the useful output compared to the work done in the compressor; for a refrigerator it is the evaporator that is of interest and COP = 160/45 = 3.55; for a heat pump it is the condenser and COP = 200/45 = 4.44.

For interest the change in entropy in the compressor is 1.77 to 1.8 kJ/kgK, and the change in specific volume is 0.07 to 0.015 m^3/kg.

6. Looking at the chart, a similar pressure range (1-15 bar) has saturation temperatures between 30°C and 140°C. Therefore the condenser temperature can be made to be significantly higher than any atmospheric temperature and is therefore able to cool down even in a desert environment.

Air conditioning solutions Week 5

1. The wet and dry bulb outside on that day (12th October 2009) in Nottingham at about 8.30 a.m. were 6.4° C and 8.4°C. Inside the lecture theatre at the same time, they were 13.2° C and 19.5°C. We can use the psychrometric chart to plot these two points and produce the

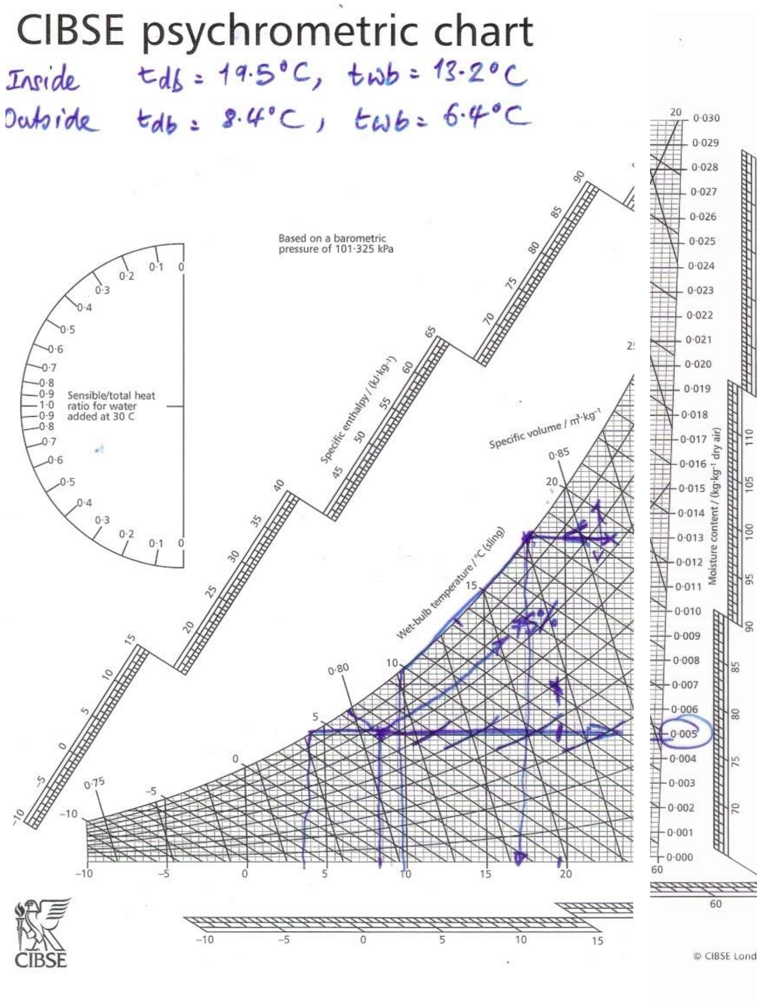

Figure 3 section of the psychrometric chart at 1.01325 bar, showing plot of the data for Question 1

relative and specific humidities.
From this the outside conditions are ω = 0.005 and ϕ = 75%, and inside ω = 0.007 and ϕ = 50%. Note that although the external relative humidity is high, when this air approaches the skin, the temperature of the air rises as it receives heat from the skin, and since the air cannot increase in humidity unless some moisture is added, the state point of the atmospheric air will move horizontally right on the chart and the relative humidity drops as it crosses the lines of RH.

2. 0.5 kg of atmospheric air with a dry bulb temperature t_{DB} of 30° C and a specific humidity, ω, or 0.012. Use the formula for ω in terms of mass fractions of water and air,

$$\omega = \frac{\dot{m}_s}{\dot{m}_{dry-air}}$$

and that the sum of the mass flow rates of dry air and moisture is known,

$$\dot{m}_{dry-air} + \dot{m}_s = 0.5\ kg \cdot s^{-1}$$

These are simultaneous equations and solve to produce,

$$\dot{m}_s = 0.0059\ kg \cdot s^{-1}$$

3. Use

$$\omega = 0.622\frac{p_s}{(p - p_s)}$$

as instructed in the question. *Note carefully that here, p_S is NOT saturation pressure, but just the peculiar case of air conditioning in which the subscript represents partial vapour pressure.*

We need p_S. 1 atmosphere is known to be 1.01325 bar (see back page in tables for properties of air). We can use any pressure units because the equation is in terms of pressure only and is dimensionless overall.

General Information

Standard acceleration: g_n = **9.806 65** m/s² = 32.1740 ft/s²

Standard atmospheric pressure: 1 atm = **1.013 25** bar

= 760 mmHg = 10.33 mH_2O = 1.0332 kgf/cm²

= 29.92 inHg = 33.90 ftH_2O = 14.696 lbf/in²

$$\omega = 0.622\frac{p_s}{(p - p_s)} = 0.622\frac{p_s}{(1.01325 - p_s)} = 0.012$$

$$0.622p_s = 0.012(1.01325 - p_s)$$

$$0.622p_s + 0.012p_s = 0.01216$$

$$p_s = \frac{0.01216}{0.634} = 0.0192\ bar$$

Saturated Water and Steam

T [°C]	p_s [bar]	v_g [m³/kg]
0.01	[illegible]	[illegible]
25	0.03166	43.40
26	0.03360	41.03
27	0.03564	38.81
28	0.03778	36.73
29	0.04004	34.77
30	0.04242	32.93
[illegible]	[illegible]	[illegible]

Figure 4 showing small section of data tables with temperature at 30 degree C, saturation pressure of water vapour is 0.04242 bar

Note carefully that here, p_g IS saturation pressure of water vapour, i.e. the pressure at which it will spontaneously boil, because this is the peculiar case of air conditioning in which saturation pressure is represented by subscript g, short for 'gas' perhaps. In this case, for 30° C dry bulb temperature, the corresponding saturation pressure for that saturation temperature is from the tables

At 30°C, p_{SAT} = 0.04242 bar. The relative humidity, $\phi = p_S/p_g$ = 0.0192/0.04242 = 0.453. That is 45.3%.

15	0.01704	77.97
16	0.01817	73.38
17	0.01936	69.09
18	0.02063	65.08
19	0.02196	61.34
20	0.02337	57.84
21	0.02486	54.56

Figure 5 section of the data tables showing saturation pressure is 0.01817 bar and 0.01936 bar for 16 and 17 degree C respectively

Find dew point temperature for p_S = 0.0192 bar. Look to the table, from which we see it occurs at approximately T = 16.5° C.