Temperature and humidity interactions in fruit moisture loss

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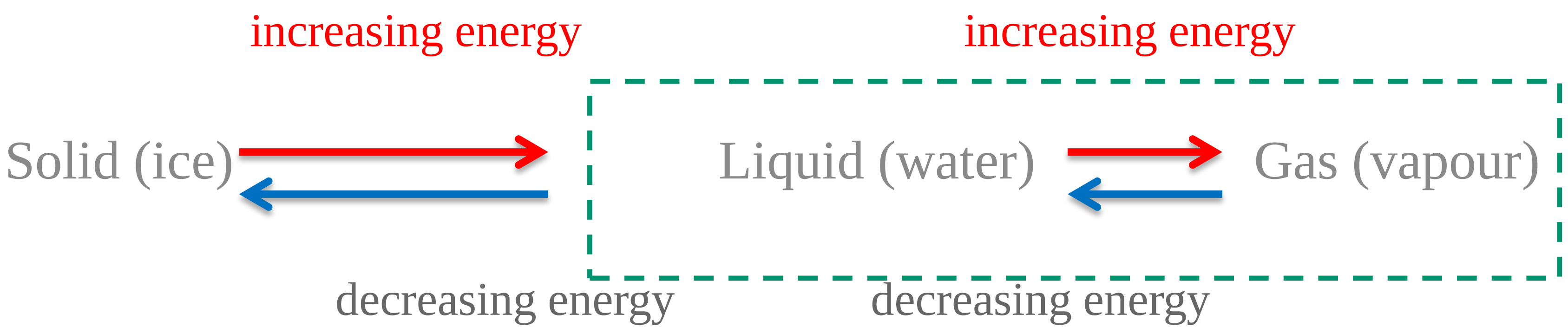
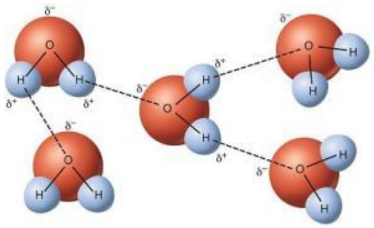
Some physics

1. Water molecules vibrate (kinetic energy). The faster they vibrate, the higher their energy status and the greater their heat content (heat is a form of energy).
2. We measure the energy status by measuring the temperature: the higher the energy (heat) status, the higher the temperature.
3. Water can exist in three forms or phases: solid, liquid and gas. A change from one phase to another requires a change in energy status of the molecules.



basis for mechanical refrigeration
and transpiration (moisture loss)
and condensation

Water's unique characteristic:
van der Waals hydrogen bonds

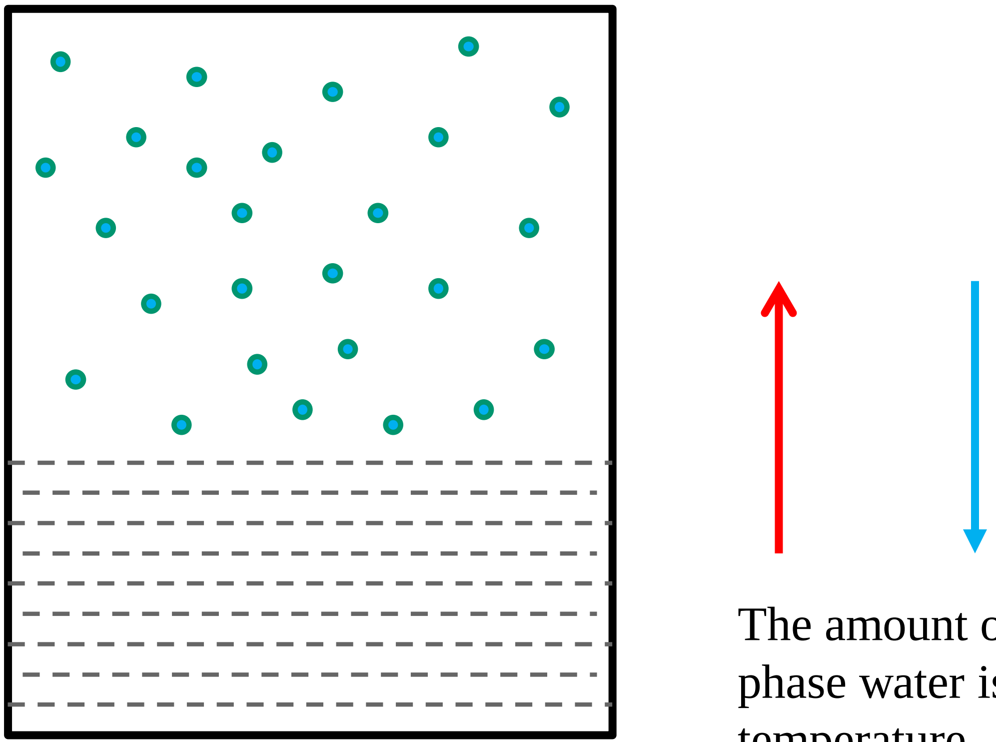


https://manoa.hawaii.edu

As energy levels fluctuate in water molecules, they tend to evaporate or condense

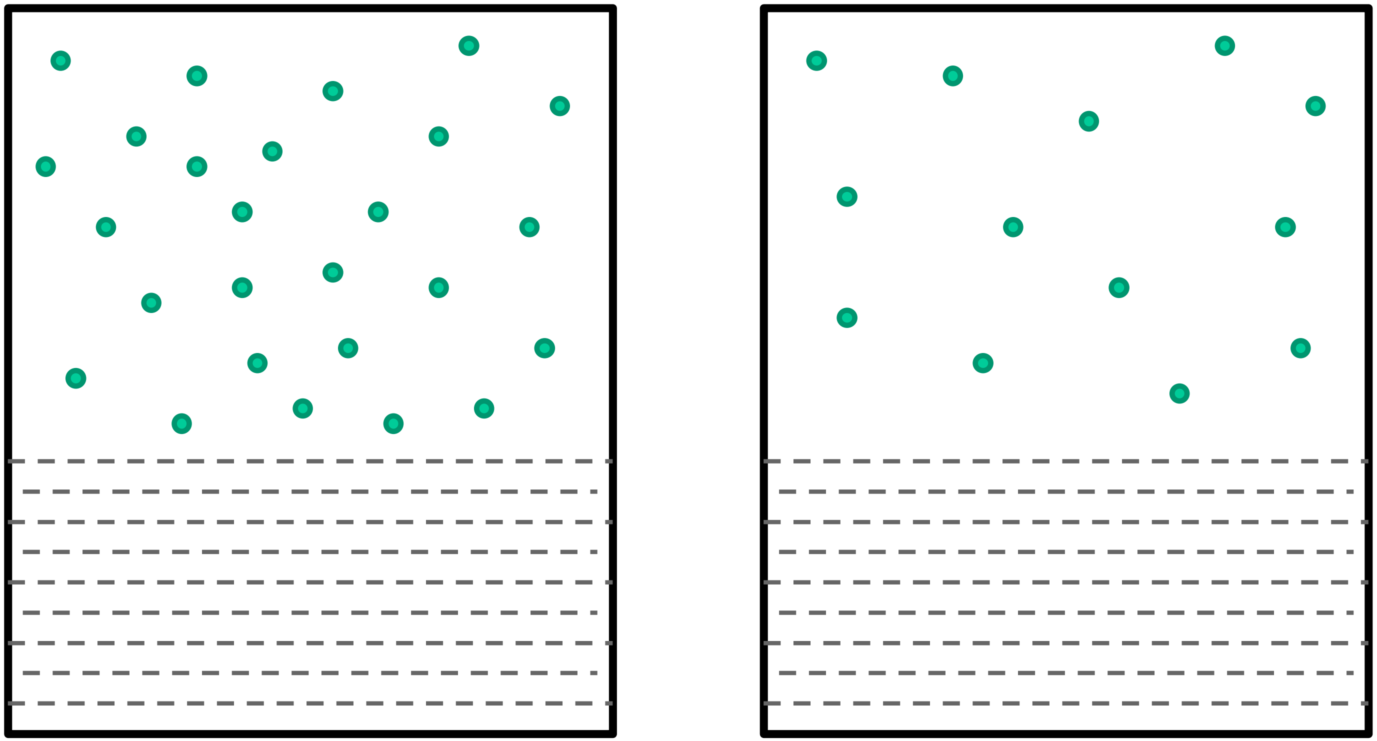
Water vapour

Liquid water



The amount of vapour phase water is a function of temperature

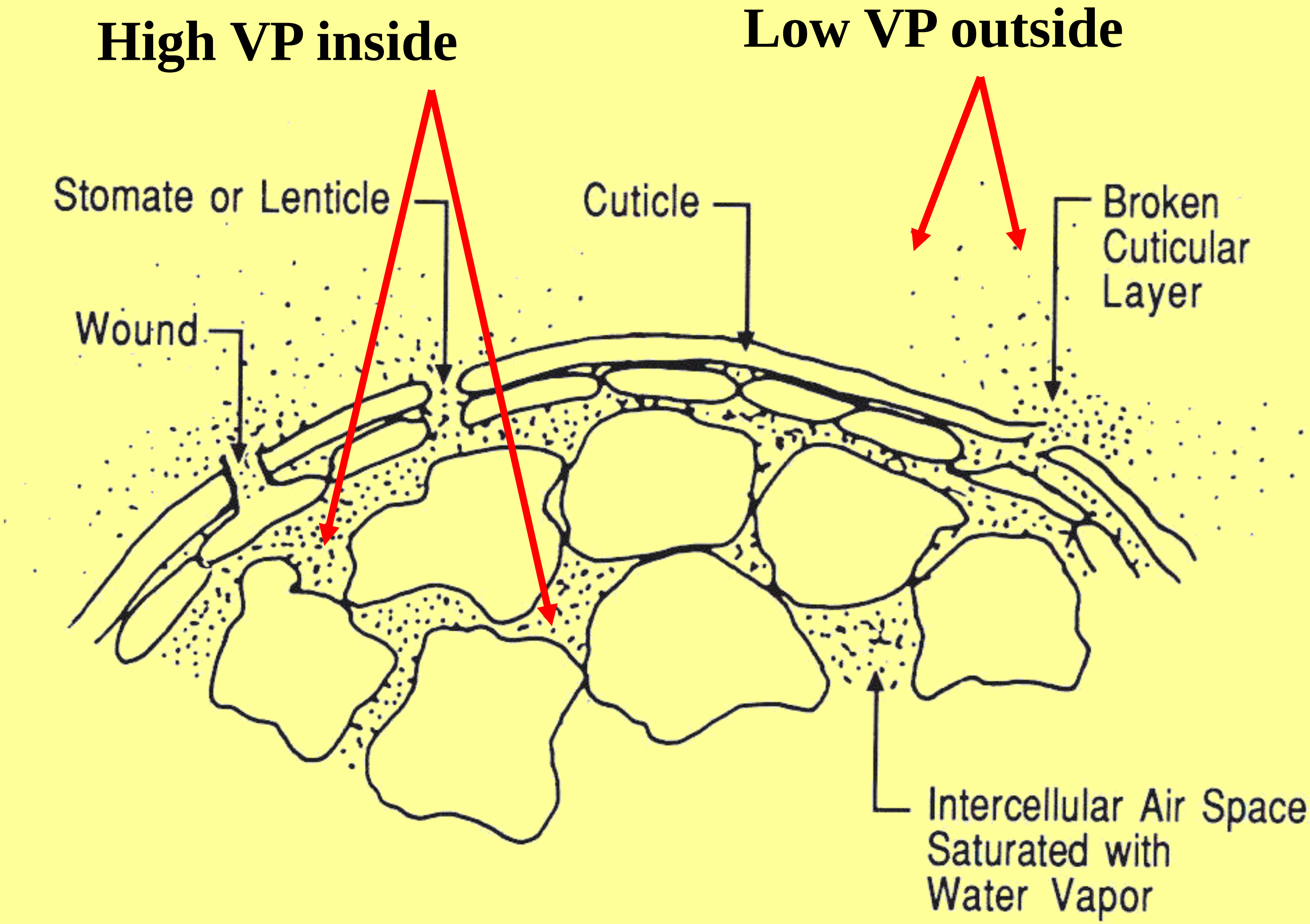
When the air space above the liquid is saturated with water vapour it to no longer has capacity to hold water in a gaseous phase



Higher temperature | Lower temperature

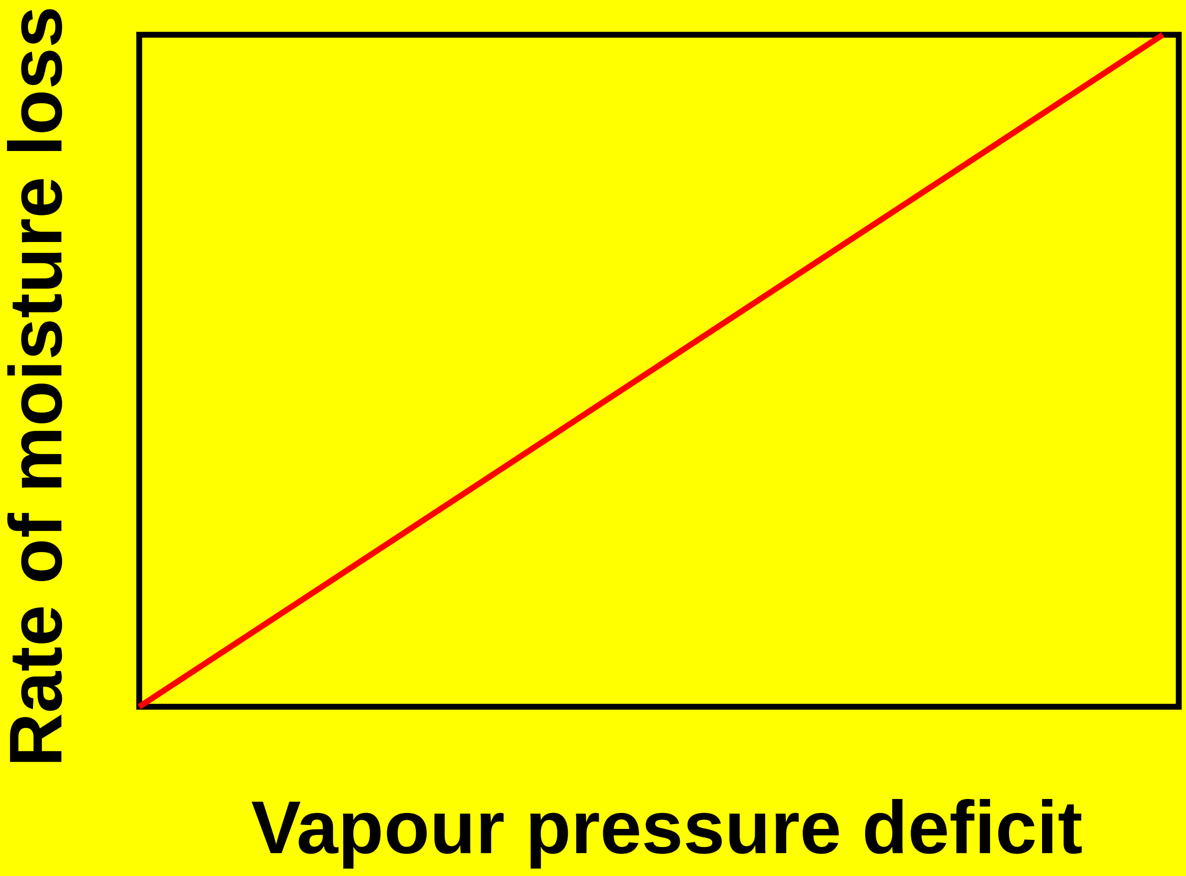
The vapour in air, being a gas, exerts pressure like any other component of the air. The more vapour there is, the higher the vapour pressure.

Moisture loss is driven by the vapour pressure deficit (VPD) between fruit and environment

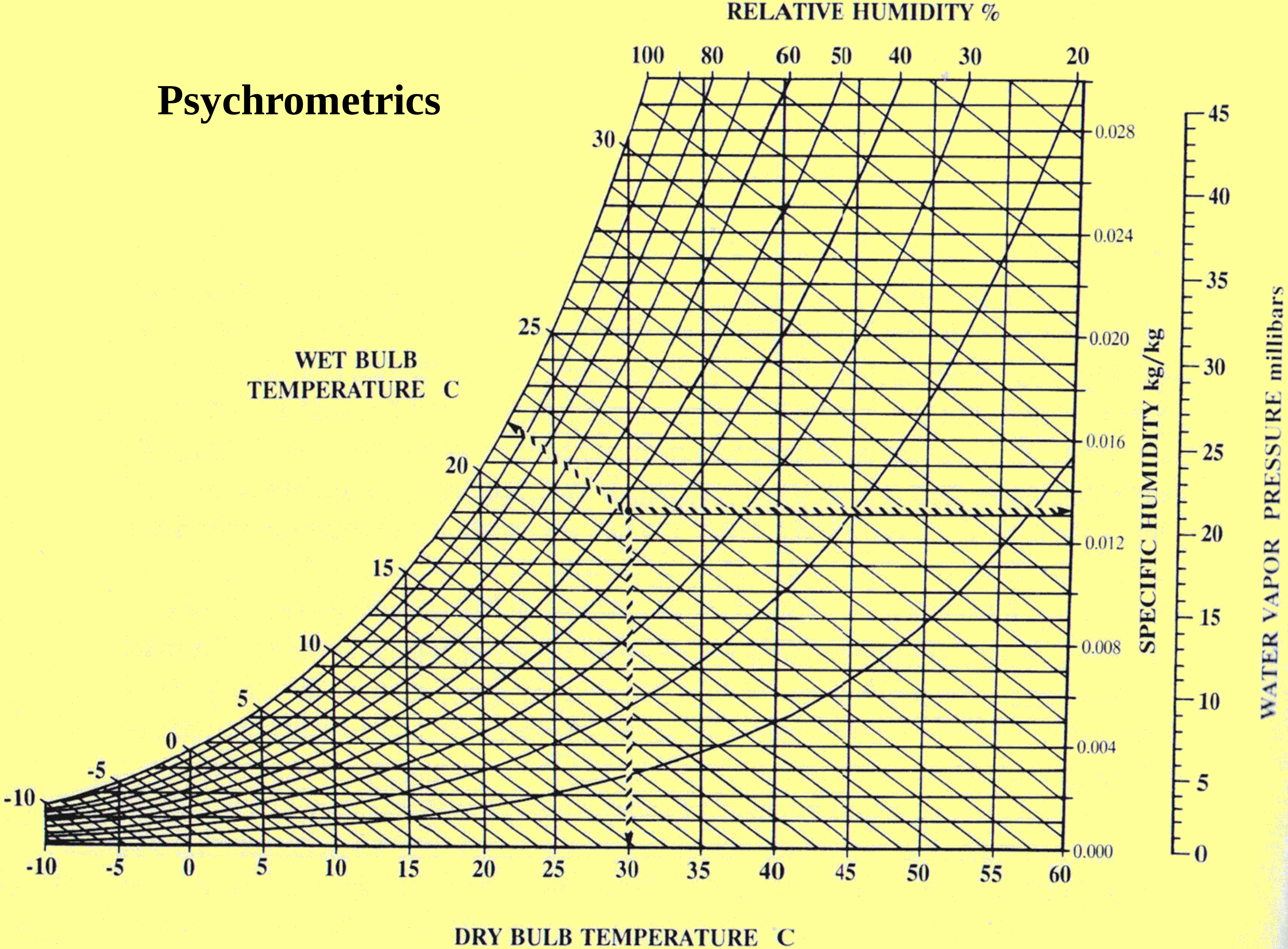


Source: Mitchell & Kader

Effect of vapour pressure deficit on rate of moisture loss

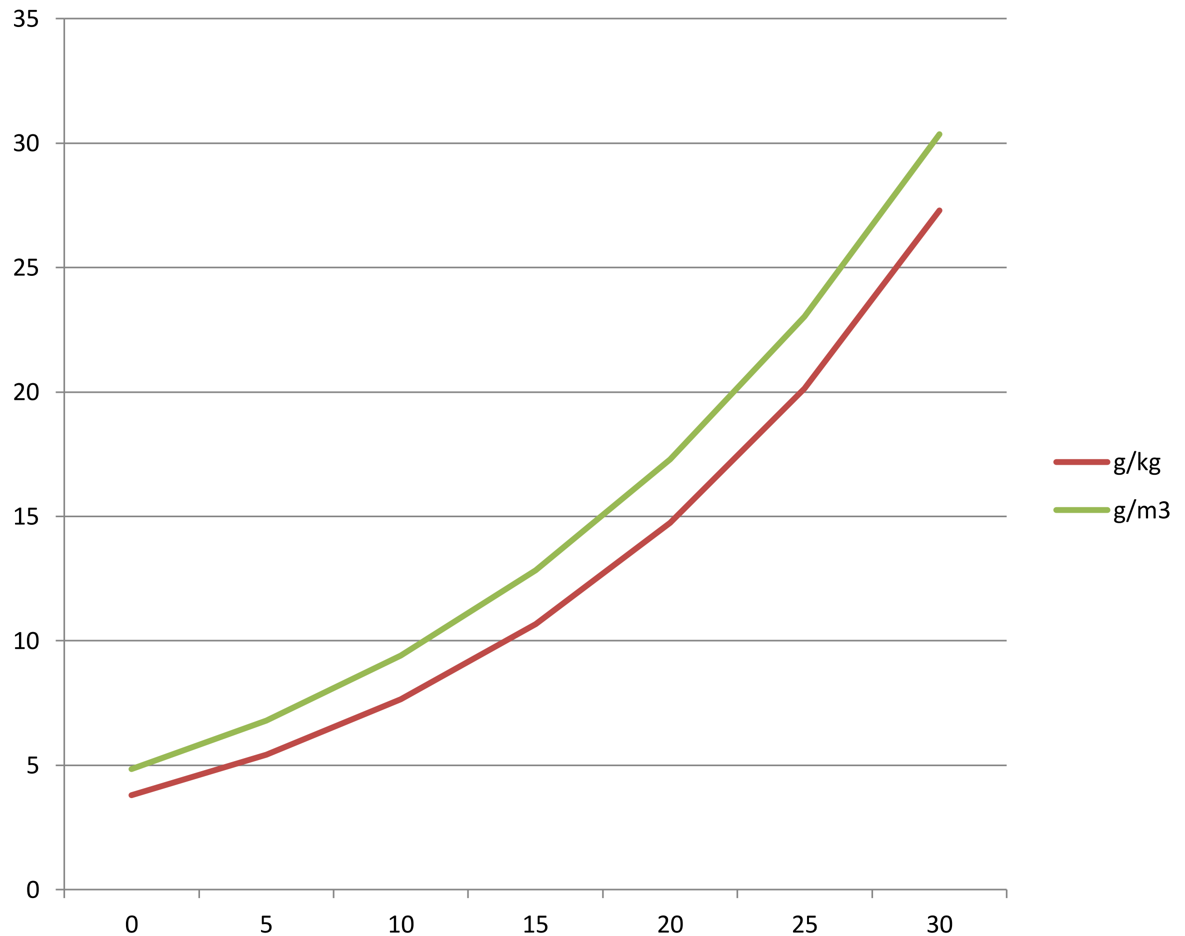


Psychrometrics



Specific or absolute humidity (mixing ratio): mass of water vapour per unit mass (or volume) of air

Absolute humidity at saturation = dew point

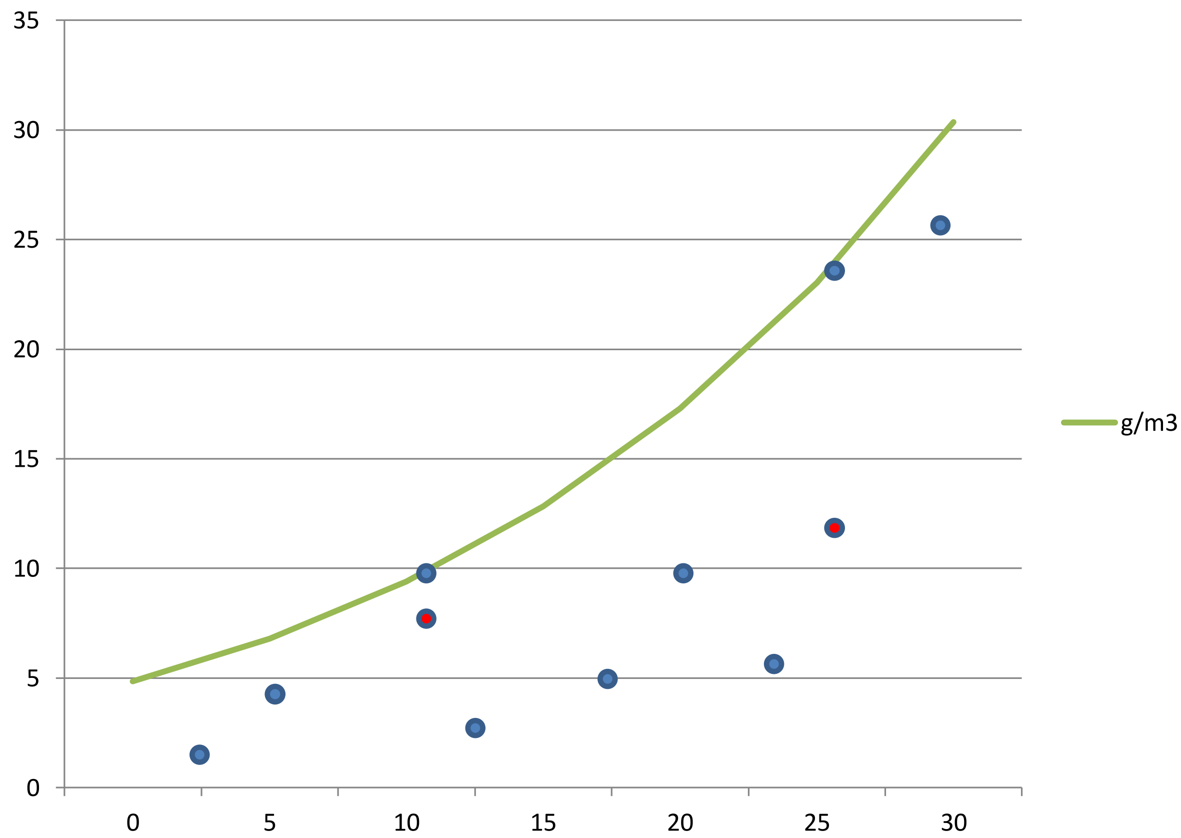


Temperature (°C)

However, the atmosphere is not always saturated with water vapour

Relative humidity: mass of water vapour present, expressed as a percentage of the mass of water vapour that can *maximally* be present at saturation at that same temperature (thus, degree of saturation)

Absolute humidity at saturation = dew point = 100% RH



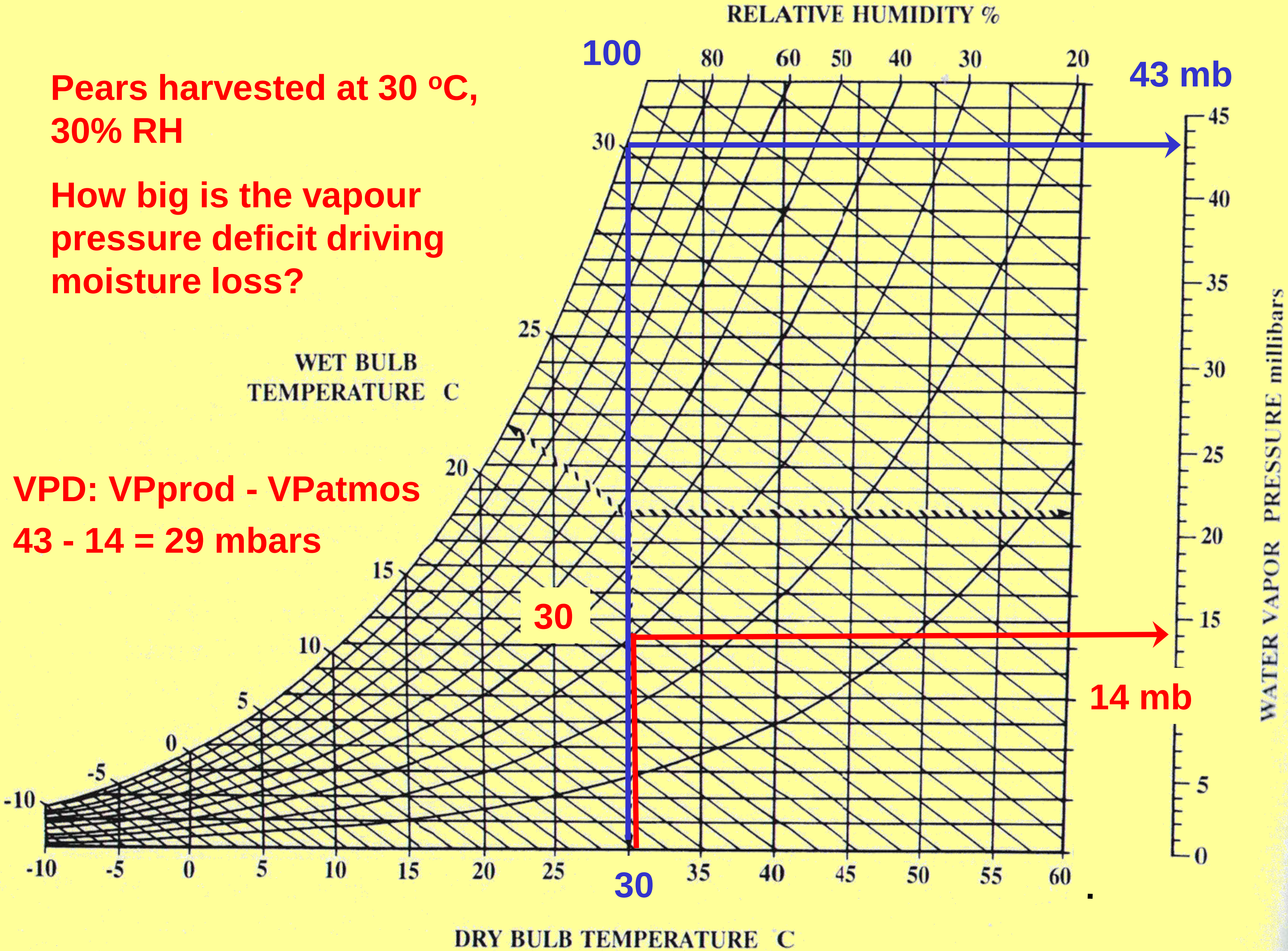
Temperature (°C)

Pears harvested at 30 ºC, 30% RH

How big is the vapour pressure deficit driving moisture loss?

VPD: VPprod - VPatmos

43 - 14 = 29 mbars



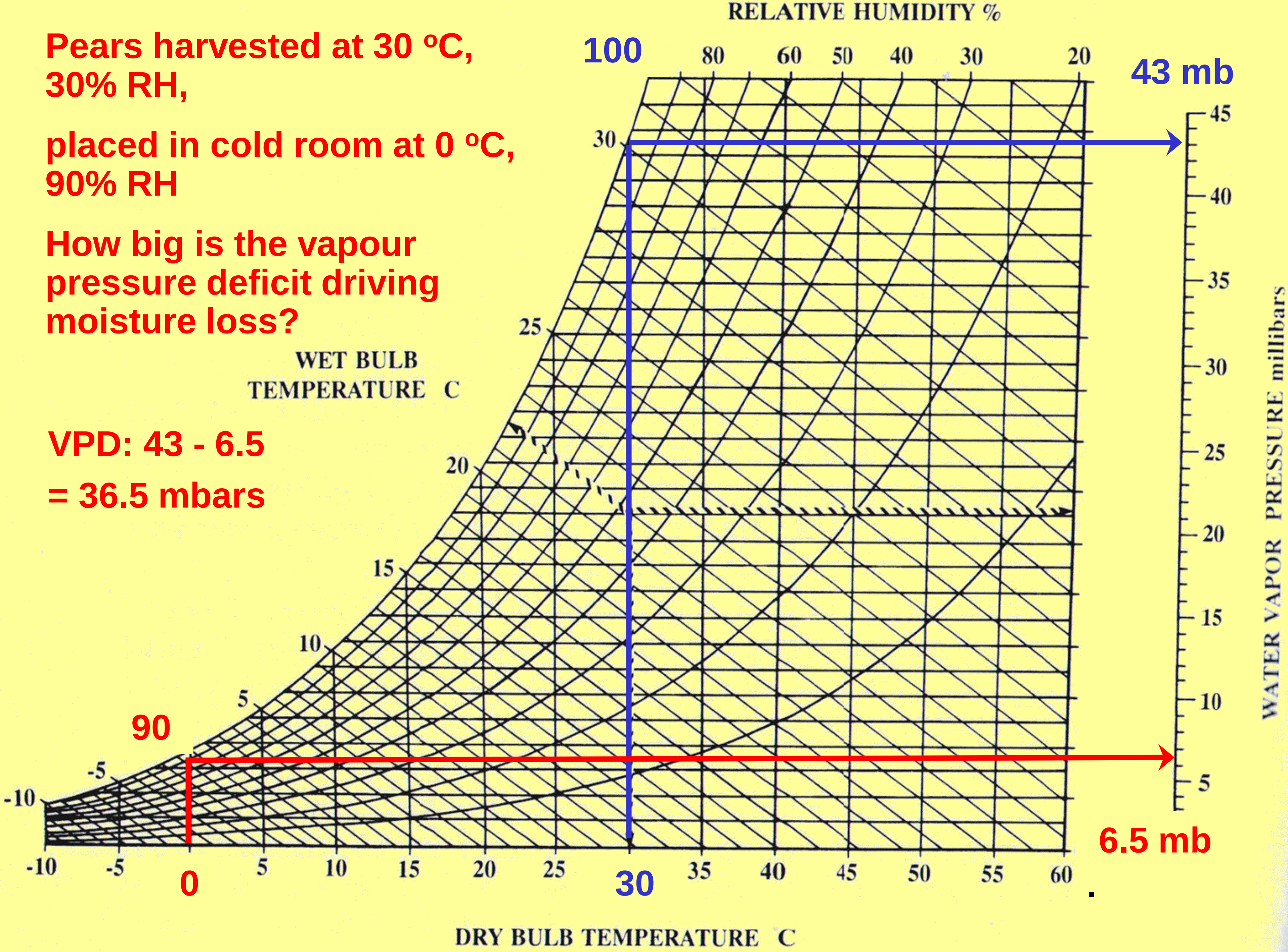
Pears harvested at 30 °C, 30% RH,

placed in cold room at 0 °C, 90% RH

How big is the vapour pressure deficit driving moisture loss?

VPD: 43 - 6.5

= 36.5 mbars



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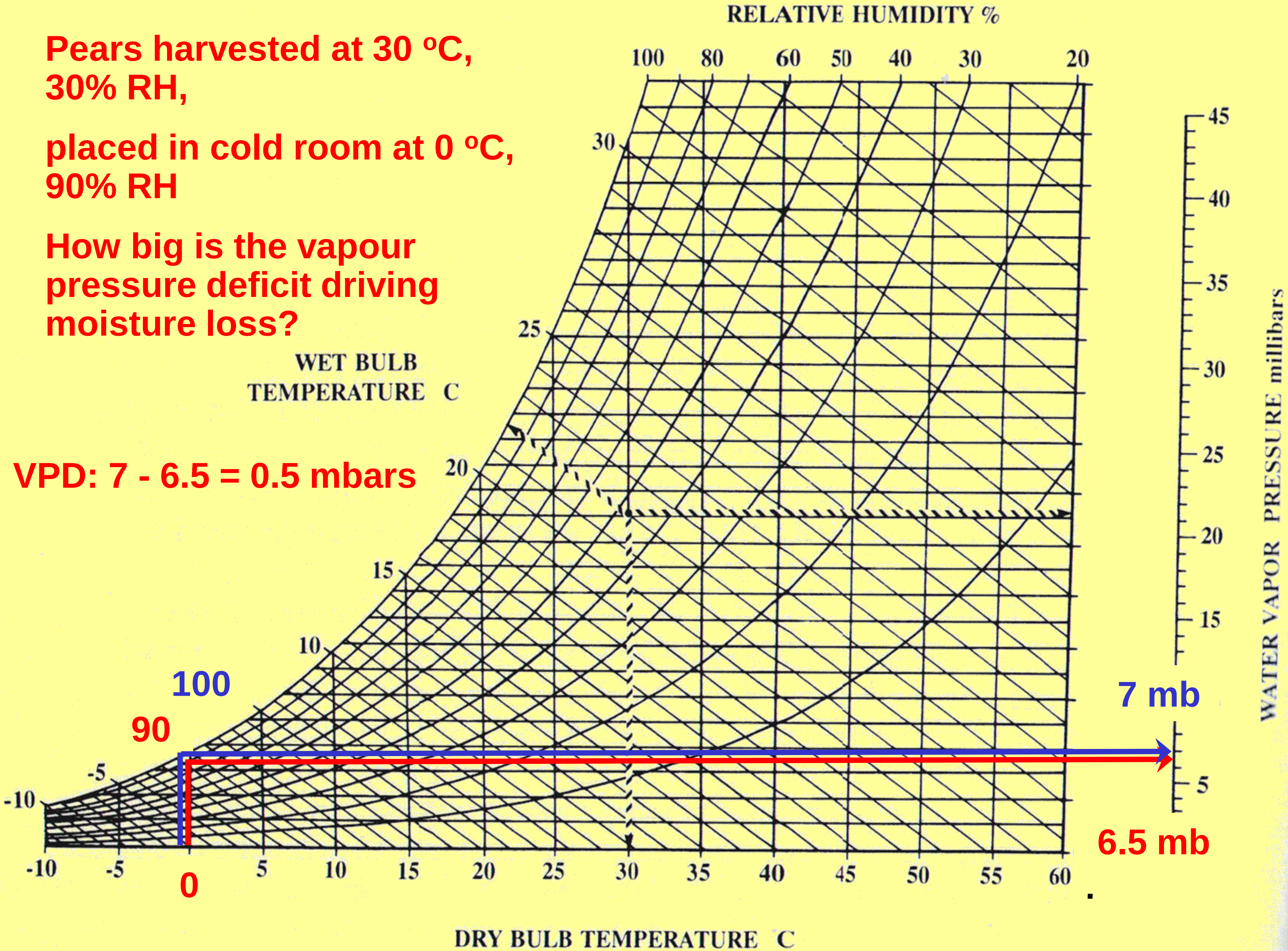


VPD: 7 - 6.5 = 0.5 mbars

Therefore

- **in orchard VPD = 29 mbars**
- **in coldroom (fruit still warm) VPD = 36.5 mbars**
- **once fruit is cold VPD = 0.5 mbars**

The driving force for moisture loss is therefore approximately 58 times higher in warm fruit than in cold fruit (29 mbars / 0.5 mbars = 58)

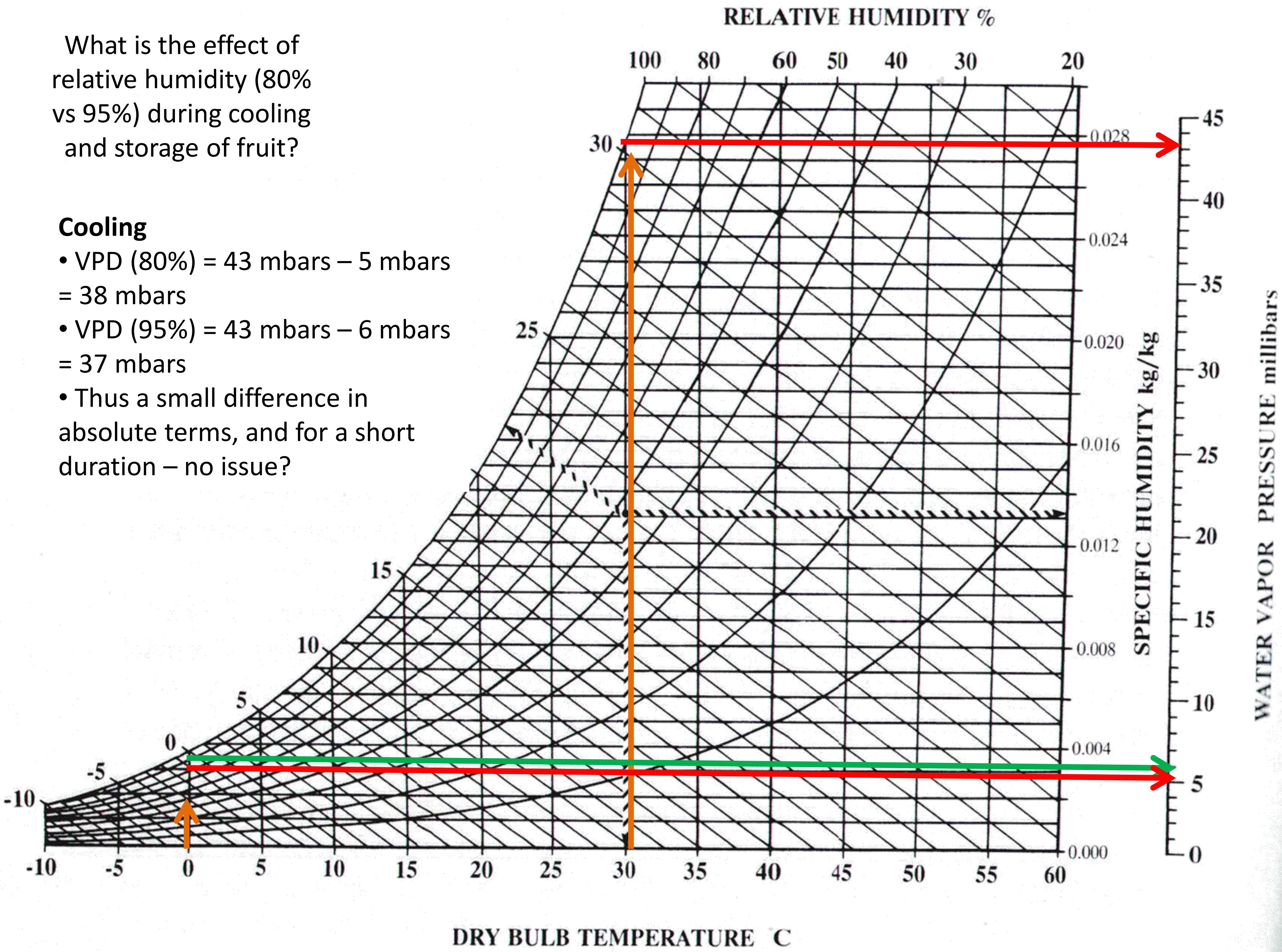
OR: 1 orchard hour = 58 cold room hours

OR: 12 orchard hours = 1 cold room month

What is the effect of relative humidity (80% vs 95%) during cooling and storage of fruit?

Cooling

- VPD (80%) = 43 mbars – 5 mbars = 38 mbars
- VPD (95%) = 43 mbars – 6 mbars = 37 mbars
- Thus a small difference in absolute terms, and for a short duration – no issue?



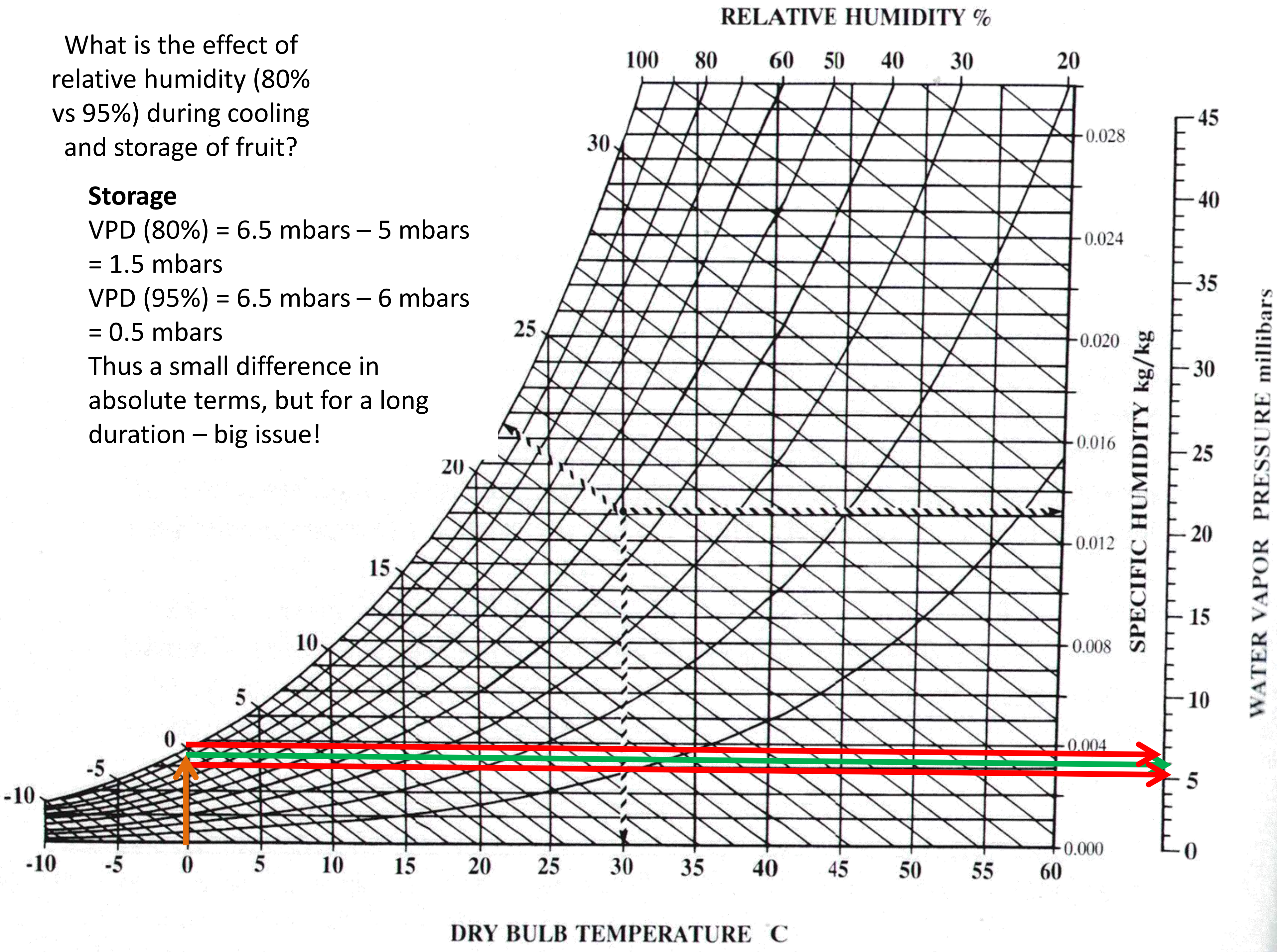
What is the effect of relative humidity (80% vs 95%) during cooling and storage of fruit?

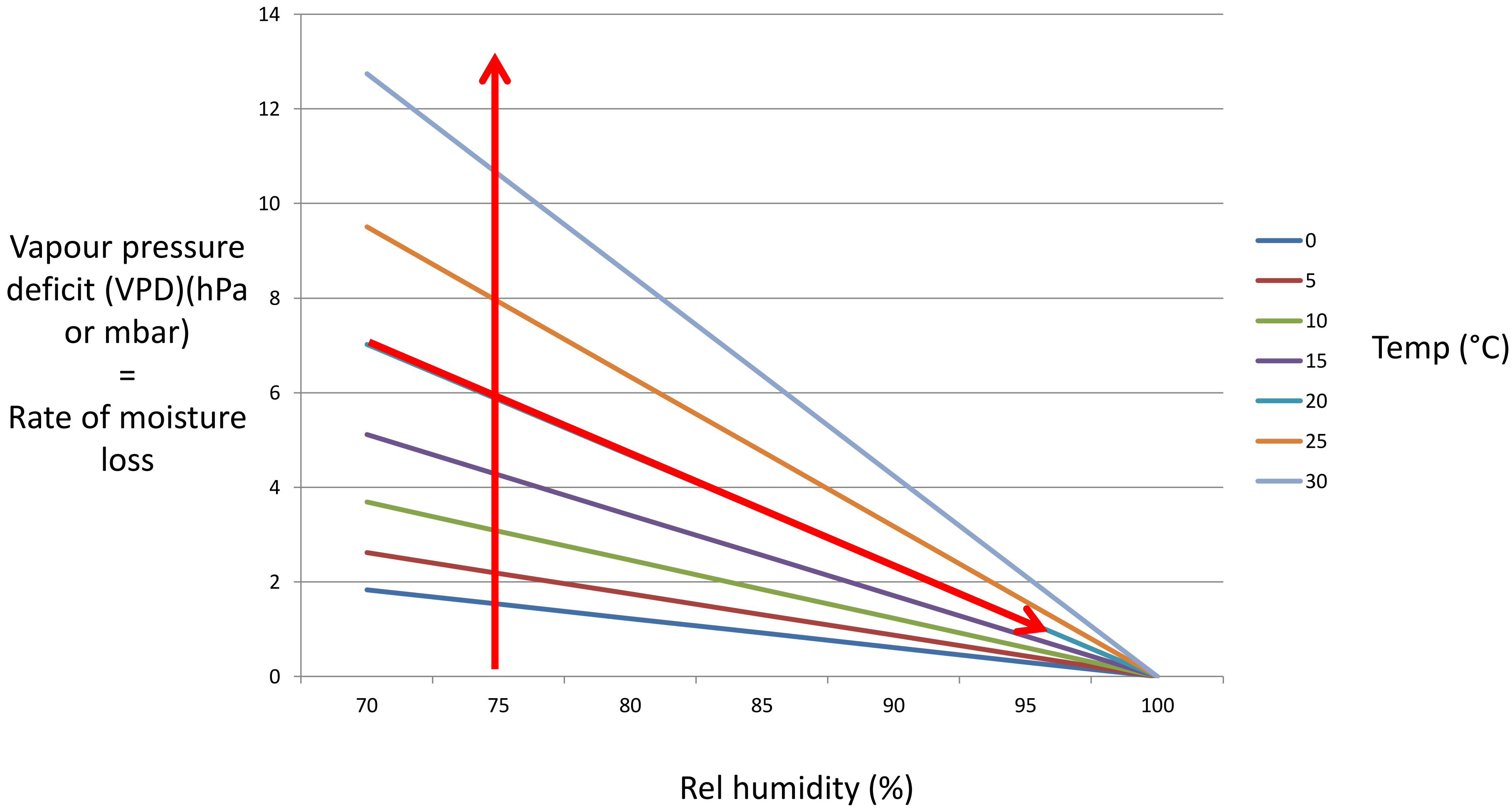
Storage

VPD (80%) = 6.5 mbars – 5 mbars = 1.5 mbars

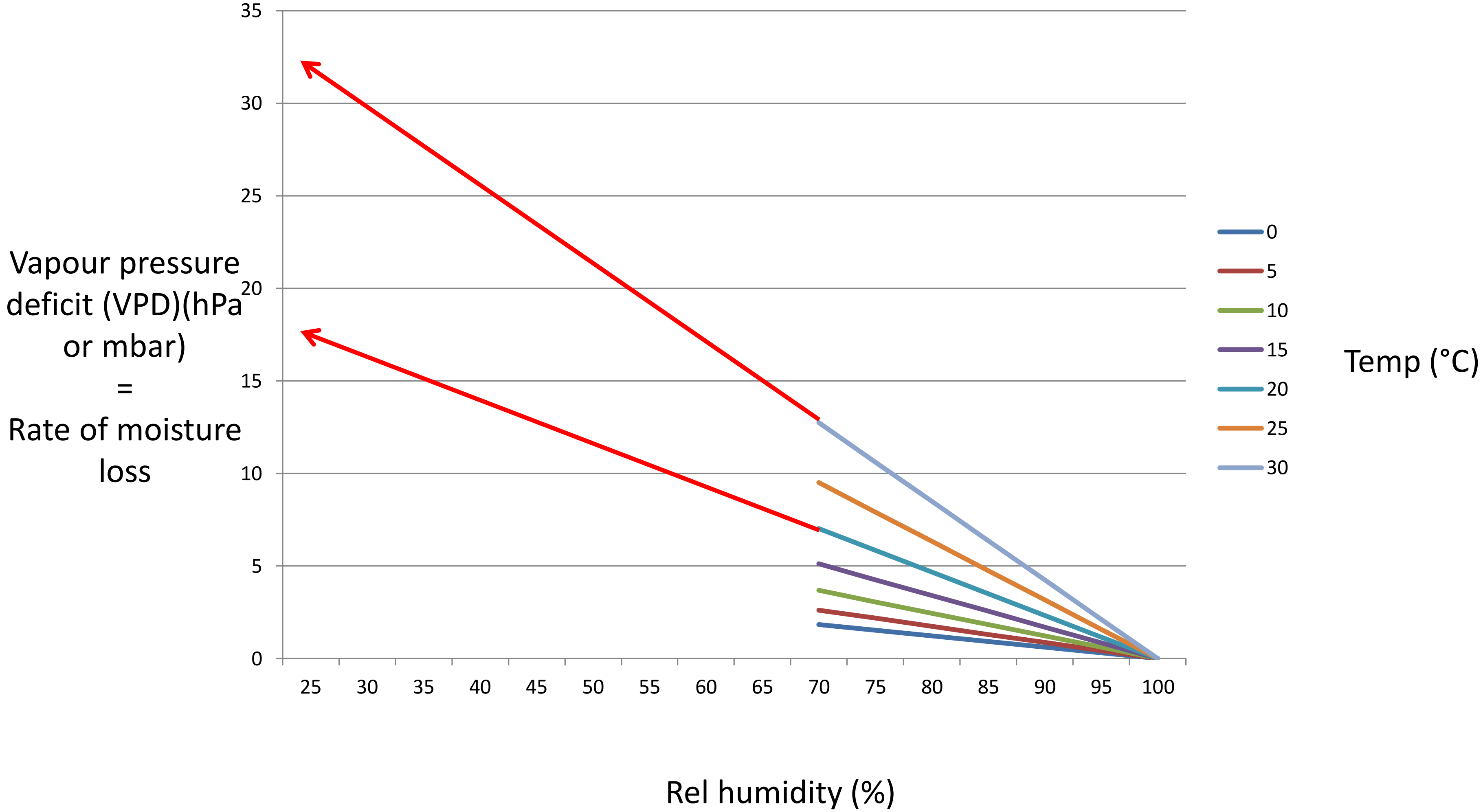
VPD (95%) = 6.5 mbars – 6 mbars = 0.5 mbars

Thus a small difference in absolute terms, but for a long duration – big issue!





Vapour pressure deficit (VPD)(hPa or mbar) = Rate of moisture loss
14
12
10
8
6
4
2
0
70
75
80
85
90
95
100
Rel humidity (%)
0
5
10
15
20
25
30
Temp (°C)



Vapour pressure deficit (VPD)(hPa or mbar)
=
Rate of moisture loss
35
30
25
20
15
10
5
0
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
Rel humidity (%)
0
5
10
15
20
25
30
Temp (°C)

Temperature,°: 0 Celsius RH,%: 95 Pressure: 1010 hectopascal = mbar

precision: 2 Calculate ×

Formulas | About

Mixing ratio: mass of water vapor per mass of dry air

3.6 GPK or **25.18** GPP

Saturated mixing ratio: mass of saturated water vapor per mass of dry air

3.79 GPK or **26.51** GPP

GPK – *Grams Per Kilogram* (g/kg)
GPP – *Grains Per Pound* (gr/lb)

Enthalpy

8.99 kJ/kg or **3.87** Btu/lb

Parts Per Million (PPM)

Volume as compared to dry air:
5782.27

Mass as compared to dry air:
3596.52

Volume as compared to wet air:
5749.03

Mass as compared to wet air:
3575.84

Unit all	Temperature		
	Ambient	Dew-point	Wet-bulb
Celsius	**0**	**0.71**	**0.28**
Fahrenheit	32	30.73	31.5

show all units

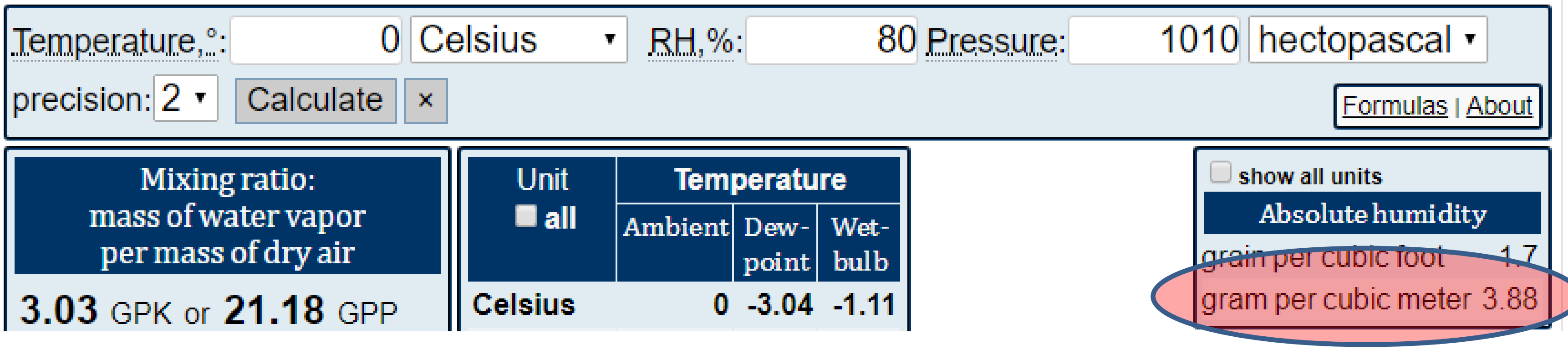
Ambient pressure	
atmosphere	1
hectopascal	**1 010**
kilopascal	101
megapascal	0.1
pascal	101 000

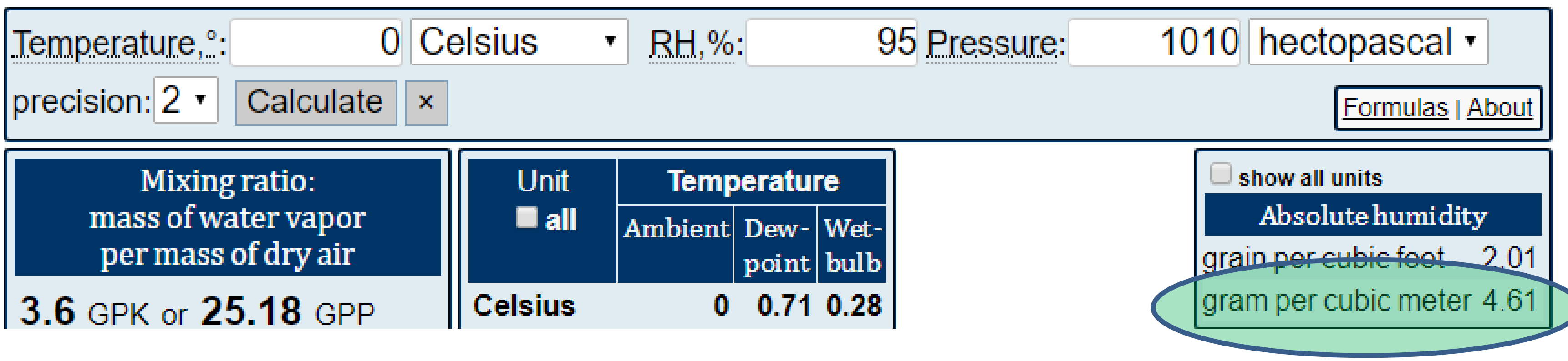
show all units

Absolute humidity	
grain per cubic foot	2.01
gram per cubic meter	4.61

Unit all	Water vapor pressure		
	Actual	Saturated at 0°C	Saturated at -0.28°C
atmosphere	0.01	0.01	0.01
hectopascal	**5.81**	**6.11**	**5.99**
kilopascal	0.58	0.61	0.6
megapascal	0	0	0
pascal	580.65	611.21	599.09

https://www.aqua-calc.com/calculate/humidity

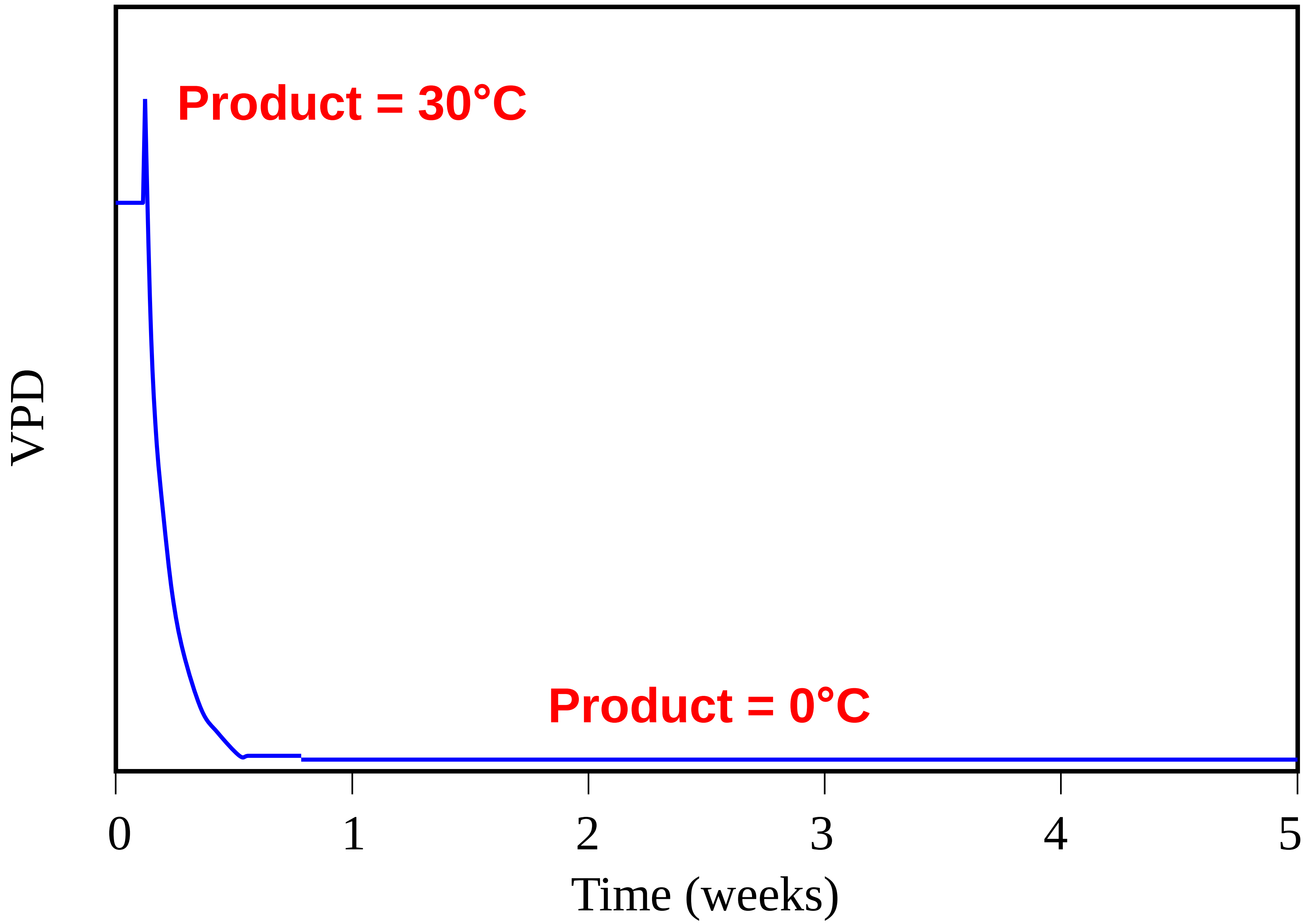




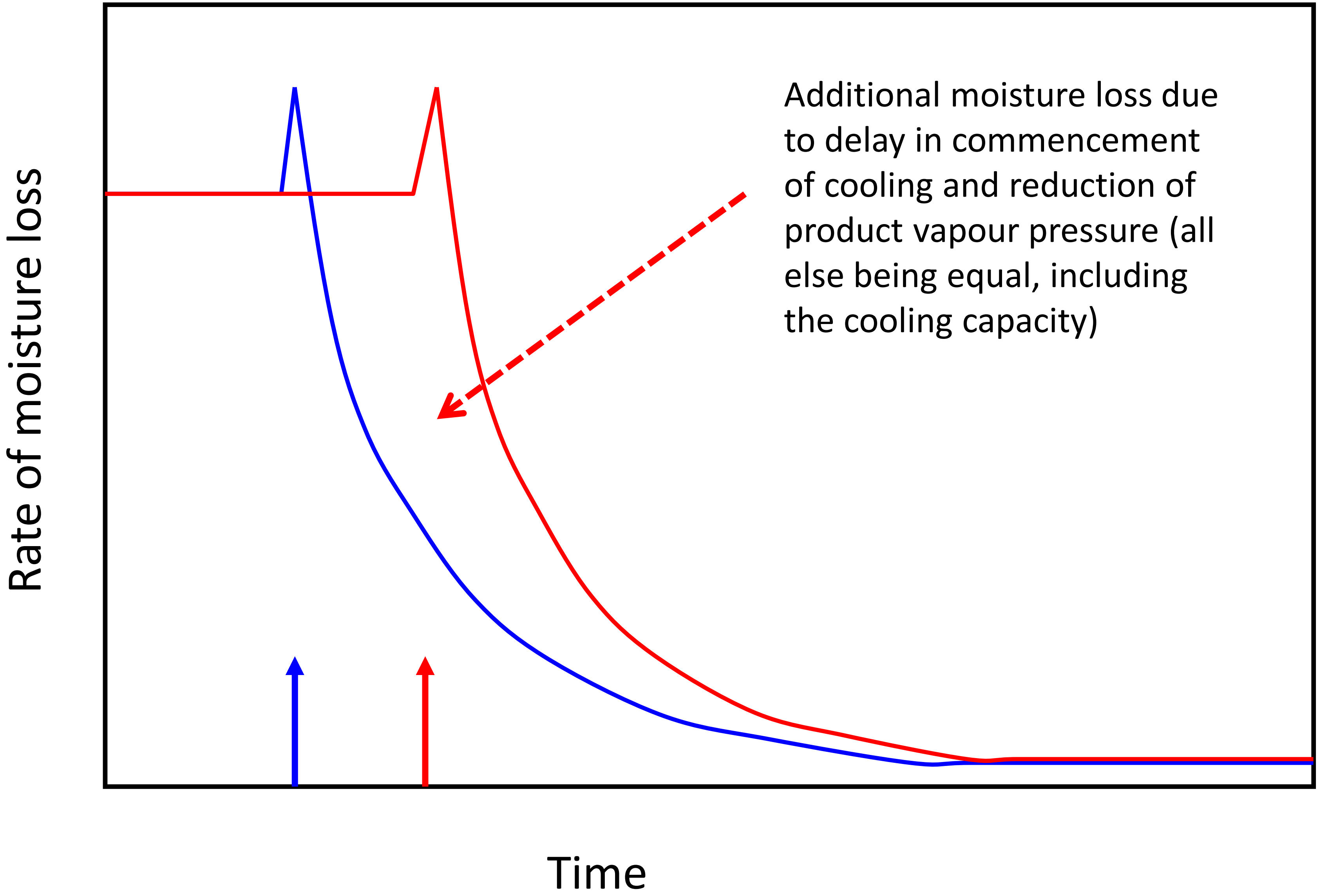
4.61 – 3.88 = 0.73 g water evaporated per m^3 cold room space to raise RH from 80% to 95%

WHY is RH only 80%? Design fault or ‘cost saving’ on equipment, influencing TD?

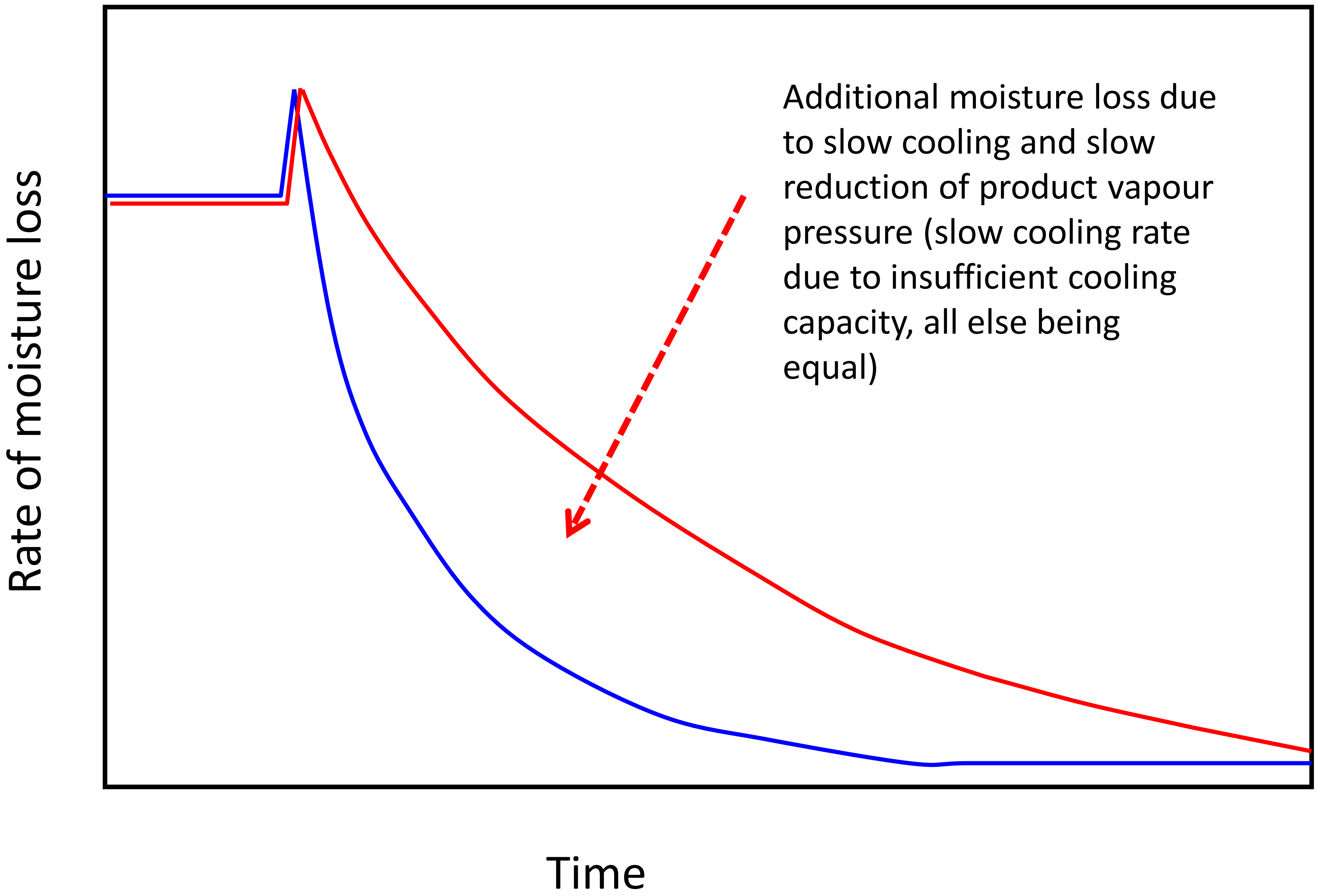
Effect of cooling on VPD



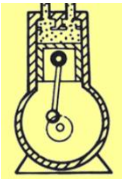
Effect of cooling delay on moisture loss



Effect of slow cooling rate on moisture loss



How do we determine the size of the system?



$$\text{kW needed} = \frac{2.1 \times (A - B) \times C \times D}{E \times 3600} \quad \begin{matrix}\text{(heat load)} \\ \text{(cooling time)}\end{matrix}$$

where:

A = pulp temperature (°C)

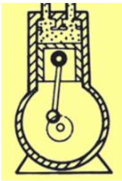
B = air temperature (°C)

C = mass of product (kg)

D = specific heat of product (3.77 kJ/kg/°C)

E = desired 7/8 cooling time (hours)

How can we manipulate the system to reduce cooling time?



$$\text{kW needed} = \frac{\text{heat load (= product mass and temperature)}}{\text{cooling time}}$$

Two scenarios

1. **Existing capacity cannot change**

- reduce heat load (less product and/or cooler incoming product and/or higher DAT): with no change in system capacity, cooling time is reduced

2. **New facility**

- need a larger system if heat load is unchanged
- need a smaller heat load (less product and/or cooler product and/or higher DAT) for the same sized system

Olympic swimming pool: 25 m x 50 m x 2 m = 2,500 m^3 = 2,500,000 litres

Heat load

Swimming pool pump
12,500 litres per hour: 200 hours to empty pool

Cooling capacity Cooling time

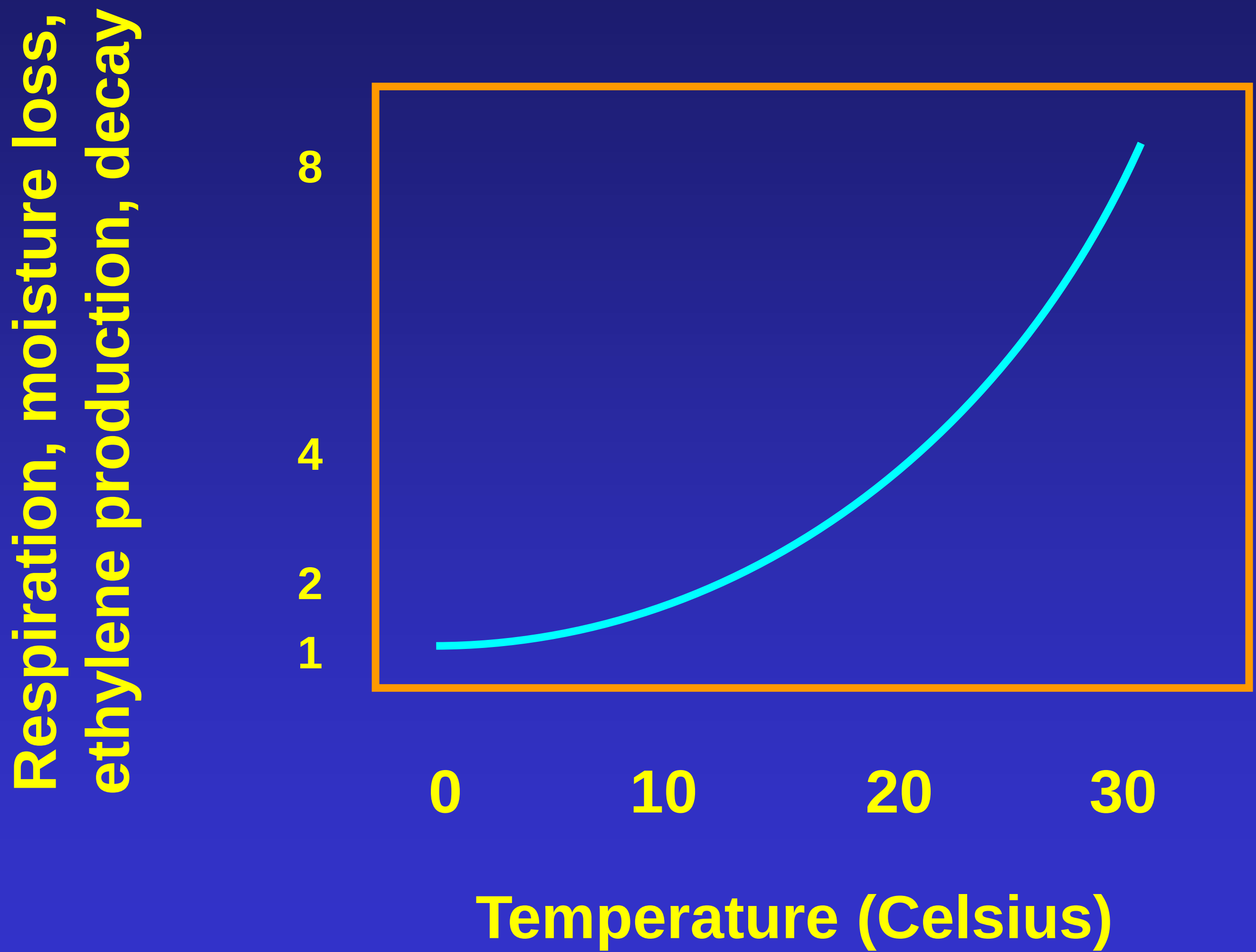
Irrigation pump
125,000 litres per hour: 20 hours to empty pool

Cooling capacity Cooling time

Bottom line

- moisture loss is a physical phenomenon easily explained by physics
- it is practically impossible to avoid, so the focus should be on minimising it’s impact
- our primary tool is proper refrigeration
- our handling protocols are probably too lax as far as cooling times are concerned
- we are not sensitive (sensible!) enough about adapting protocols to address problem situations (like heat waves) and problem cultivars

Control of respiration + moisture loss + ethylene production + decay = control of temperature



Questions