BRE2031 – Environmental Science: Lecture 6 – Condensation in Buildings

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Objectives

After studying this lecture, you will be able to:

1. Perform simple analysis on mass transfer process
2. Determine whether condensation can occur or not in buildings

- Did you observe **water droplets** on the windows in **cold winter days** (especially after you take a shower)?
- Did you observe **water droplets** on the external surface of your **cold drink bottles**?
- Did you observe **water droplets** on the external surface of your **refrigerators** in **humid and hot days**?
- Where did the water droplets come from? From the inside of your refrigerator/cold drink bottles?

Condensation in Buildings

What is condensation?

- We learned in Psychrometrics – when moist air is cooled down with its relative humidity reaching 100%, the moist air is **saturated** and water vapor starts to condense (becomes liquid water). The corresponding dry bulb temperature is called **dew point temperature** of the moist air.

Sources of water vapor

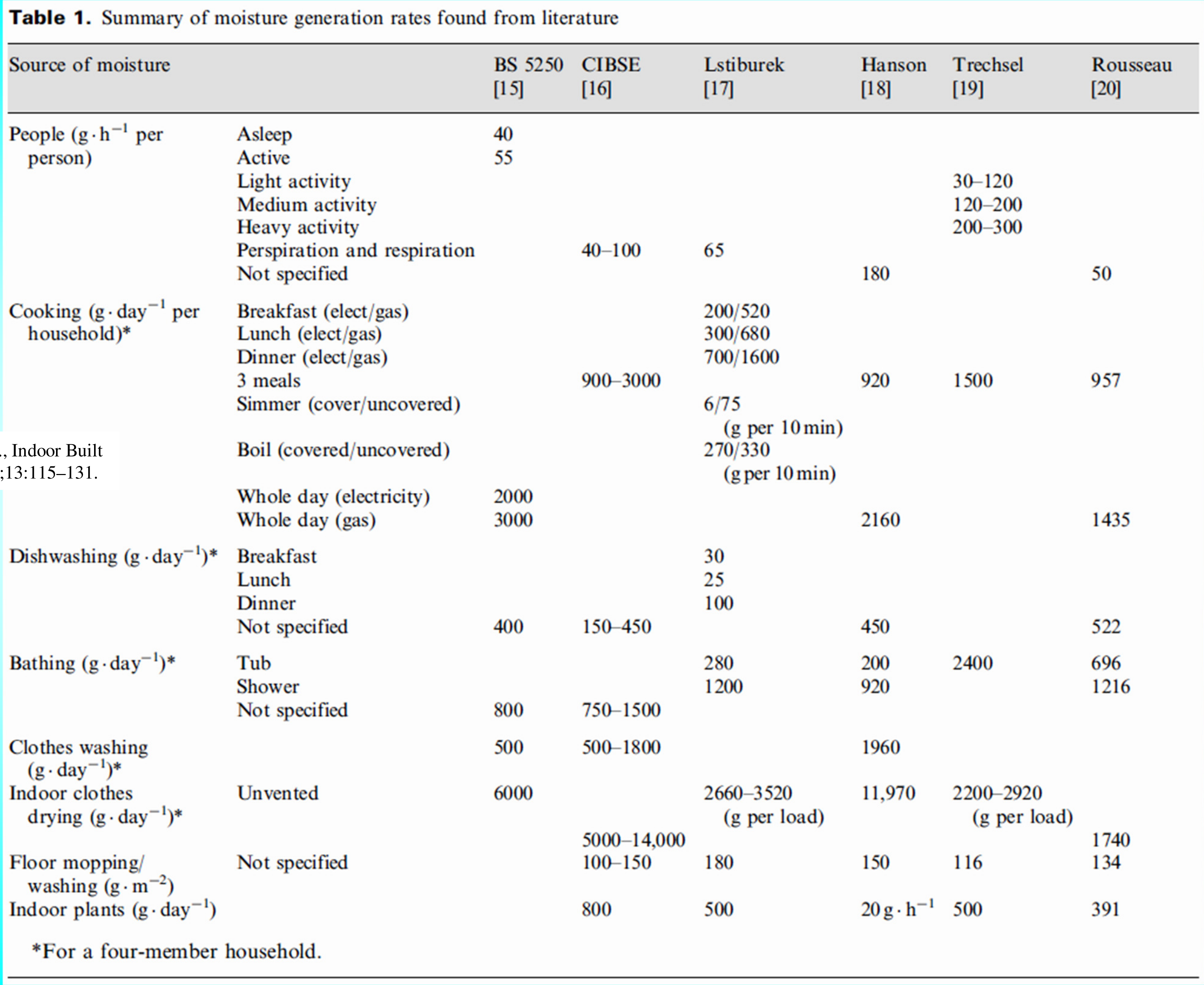


Table 1. Summary of moisture generation rates found from literature

Source of moisture		BS 5250 [15]	CIBSE [16]	Lstiburek [17]	Hanson [18]	Trechsel [19]	Rousseau [20]
People ($g \cdot h^{-1}$ per person)	Asleep	40					
	Active	55					
	Light activity					30–120	
	Medium activity					120–200	
	Heavy activity					200–300	
	Perspiration and respiration		40–100	65			
	Not specified				180		50
Cooking ($g \cdot day^{-1}$ per household)*	Breakfast (elect/gas)			200/520			
	Lunch (elect/gas)			300/680			
	Dinner (elect/gas)			700/1600			
	3 meals		900–3000		920	1500	957
	Simmer (cover/uncovered)			6/75 (g per 10 min)			
	Boil (covered/uncovered)			270/330 (g per 10 min)			
	Whole day (electricity)	2000					
	Whole day (gas)	3000			2160		1435
Dishwashing ($g \cdot day^{-1}$)*	Breakfast			30			
	Lunch			25			
	Dinner			100			
	Not specified	400	150–450		450		522
Bathing ($g \cdot day^{-1}$)*	Tub			280	200	2400	696
	Shower			1200	920		1216
	Not specified	800	750–1500				
Clothes washing ($g \cdot day^{-1}$)*		500	500–1800		1960		
Indoor clothes drying ($g \cdot day^{-1}$)*	Unvented	6000		2660–3520 (g per load)	11,970	2200–2920 (g per load)	
			5000–14,000				1740
Floor mopping/washing ($g \cdot m^{-2}$)	Not specified		100–150	180	150	116	134
Indoor plants ($g \cdot day^{-1}$)			800	500	$20\,g \cdot h^{-1}$	500	391

*For a four-member household.

Ref: Yip et al., Indoor Built Environ 2004;13:115–131.

Consequences of condensation in buildings

- Moisture control is necessary to **avoid** moisture-related **problems** with **building energy performance**, **building maintenance** and **durability**, and **human comfort and health**. Moisture degradation is the largest factor limiting the useful life of a building and can be visible or invisible.
- **Invisible degradation** includes degradation of the **thermal resistance** of building materials and decrease in the **strength and stiffness** of some materials.
  - Moisture content affects the effective thermal conductivity of porous mediums, like soil, building materials (concrete et al.), insulations and thus affect the heat transfer through them. For example, an insulation material with a **5% moisture content** by volume has **15 to 25% greater energy transfer** than the dry insulation material.
  - Moisture also affects the **thermal storage capacity** of certain hygroscopic building materials. At **10% moisture content**, nearly **30% of the heat storage capacity** of wood is in the **water** held in the cell walls.

Consequences of condensation in buildings – continued

- **Visible moisture degradation** may be in the form of:
  - mold and mildew, - Mold and mildew in buildings are offensive, and the spores can cause respiratory problems and other allergic reactions in humans. Mold and mildew will grow on most surfaces if the relative humidity at the surface is above a critical value and the surface temperature is conducive to growth. can seriously affect occupant health and comfort.
  - the **decay** of wood-based materials, **spalling** (脹裂, 剝落) of masonry and concrete caused by freeze-thaw cycles, **corrosion** of metals, **damage** due to expansion of materials (e.g., buckling of wood floors) –

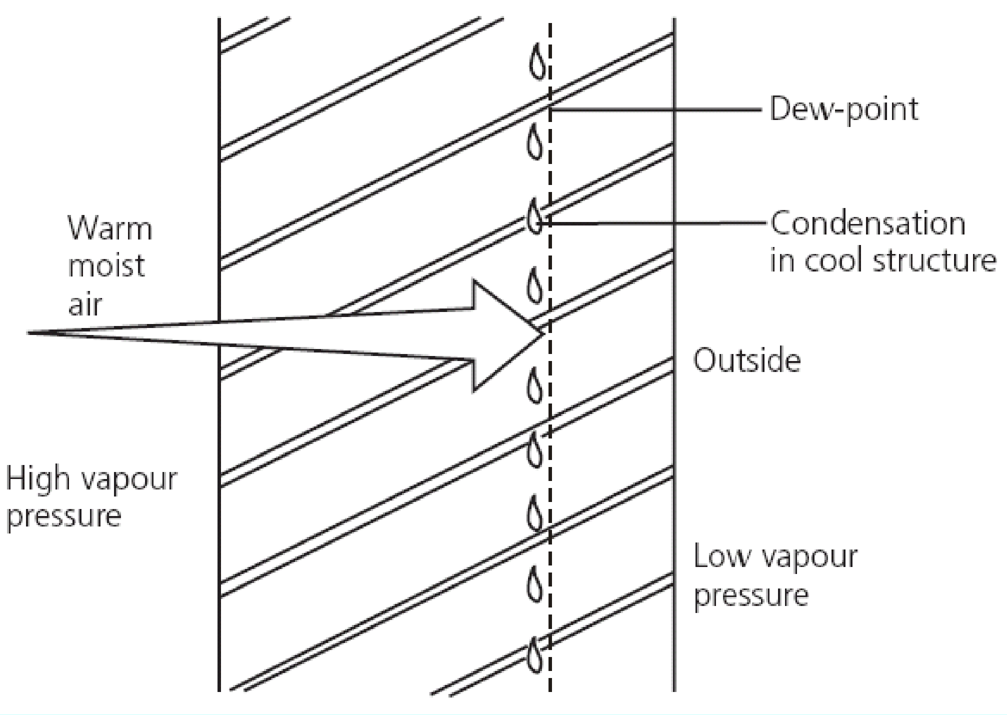
    Structural failures due to decay of **wood** are rare but have occurred (e.g., Merrill and Ten Wolde 1989). Decay generally requires wood moisture content at fiber saturation (usually about 30%) or higher and temperatures between 10 and 40°C. **Rusting** or corrosion of nails, nail plates, or other **metal building components** is also a **potential cause of structural failure**. Corrosion may occur at high relative humidities near the metal surface or as a result of liquid water from elsewhere. **(Invisible or visible)**
  - a decline in visual appearance.

When condensation occurs?

Condensation occurs if warm **moist air** meets surfaces (or inside a structure) **at** or **below** the **dew point** of that air. (the dew point temperature can be determined from the Psychrometric chart).

Surface condensation: occur on the surface of windows, walls, ceilings, floors. Moist air can't transport through the material

Interstitial condensation: occur **within the building construction**, as the materials are permeable to water to some extent. When moist air is transporting through the structures and getting cooled, condensation begins at the dew-point temperature



Condensation in Buildings

Condensation needs: (1) moist air and (2) cold structure

Factors influencing condensation:

Moisture source (determine the moisture content):

- occupants – average family produce 10-20 kg moisture per day.
- from outside moist air
- during construction process water is used

Temperatures – of the buildings and the moist air

Ventilation – lowers moisture content if outdoor air has lower moisture content

Use of buildings: how building is used (change with time), can affect the temperature of building structures

Remedies: ventilation (reduce moisture content), heating and insulation (keep the inside of building warm enough to reduce condensation), Use of vapor barriers/retarders.

Condensation in Buildings – how to predict?

1. Although there are many factors influencing condensation phenomena, they are all related to the temperature (of building structure) and dew point temperature of moist air.

2. We can use the knowledge learned in the second lecture to find the **temperature distribution** in the building structure.

$$\frac{\Delta T}{\Delta T_{total}} = \frac{R}{R_{total}}$$

3. We can find the **local** **dew point temperature** of the moist air (from the psychrometric chart) by using its **local** **vapor pressure**.

4. Then we can judge whether condensation occurs or not by comparing the **local temperature of the structure** and **local dew point of the moist air**.

Condensation in Buildings
– how to predict?

- To find the **vapor pressure** distribution, we need to look at the **mass transfer** process through building materials.

Mass Transfer

- When a system contains two or more components (chemical species) **whose concentrations vary from point to point**, there is a natural **tendency** for **mass to be transferred**, minimizing the **concentration difference** within the system. The transport of one species from a region of a **higher concentration** to that of a **lower concentration** is called ***mass transfer***.
- Mass transfer can occur by **molecular motion** (diffusion) or **bulk motion** (convection).
- Mass transfer is the basis for many biological/chemical and various engineering processes.

Mass diffusion – about concentration

For mass diffusion, the driving force is **concentration difference** (gradient). The concentration of chemical species can be expressed in different ways.

Mass Basis

V is a small volume at a location within the mixture, m_i is the mass of species *i* (**in V);** m is the total mass of the mixture in V.

Density (kg/m^3) of species *i* $\rho_i = \dfrac{m_i}{V}$

Total density of mixture $\rho = \dfrac{m}{V} = \dfrac{\sum m_i}{V} = \sum \rho_i$

It means that the density of a mixture at a location is equal to the sum of the densities of its components at that location.

In addition to density, mass concentration can also be expressed in dimensionless form *by* ***mass fraction***.

Mass fraction of species *i*:

dimensionless

$$w_i = \frac{m_i}{m} = \frac{m_i / V}{m / V} = \frac{\rho_i}{\rho}$$

$$0 \le w_i \le 1$$

$$\sum w_i = 1$$

Mass diffusion – about concentration

Mole Basis

On a mole basis, concentration can be expressed by molar concentration (molar density), usually **the amount (moles) of matter** per unit volume (mol/m^3 or kmol/m^3)

Partial molar concentration of species *i*

$$C_i = \frac{N_i}{V}$$

V is a small volume at a location within the mixture, N$_i$ is the number of moles of species *i* (**in V**); N is the total number of moles of the mixture in V.

Total molar concentration of mixture

$$C = \frac{N}{V} = \frac{\sum N_i}{V} = \sum C_i$$

Similarly, molar concentration can be expressed in dimensionless form by ***mole fraction of species*** *i*:

$$y_i = \frac{N_i}{N} = \frac{N_i / V}{N / V} = \frac{C_i}{C}$$

$$0 \le y_i \le 1$$

$$\sum y_i = 1$$

Mass diffusion – about concentration

The mole number N and mass (m) can be related by m = NM (M is molecular weight or molar mass, kg/kmol).

Thus, we have

$$N = \frac{m}{M} \qquad N_i = \frac{m_i}{M_i}$$

Linkage between mole basis and mass basis

$$C_i = \frac{N_i}{V} = \frac{m_i / M_i}{V} = \frac{m_i / V}{M_i} = \frac{\rho_i}{M_i} \qquad C = \frac{\rho}{M}$$

Here M is the molar mass of the mixture that can be determined from

$$M = \frac{m}{N} = \frac{\sum N_i M_i}{N} = \sum \frac{N_i}{N} M_i = \sum y_i M_i$$

The mass and mole fractions of species *i* of a mixture are related to each other by

$$w_i = \frac{\rho_i}{\rho} = \frac{C_i M_i}{CM} = y_i \frac{M_i}{M}$$

Mass diffusion – about concentration

For ideal gases

At low pressures, gas or gas mixtures can be approximated as **ideal gas** with excellent accuracy. For example, a mixture of **dry air** and **water vapor** at **atmospheric conditions** can be treated as ideal gas with an error much less than 1%.

For gas mixture considered as ideal gas, the total pressure P is equal to the **sum** of the **partial pressures** P_i of the individual gases in the mixture.

$$P = \sum P_i$$

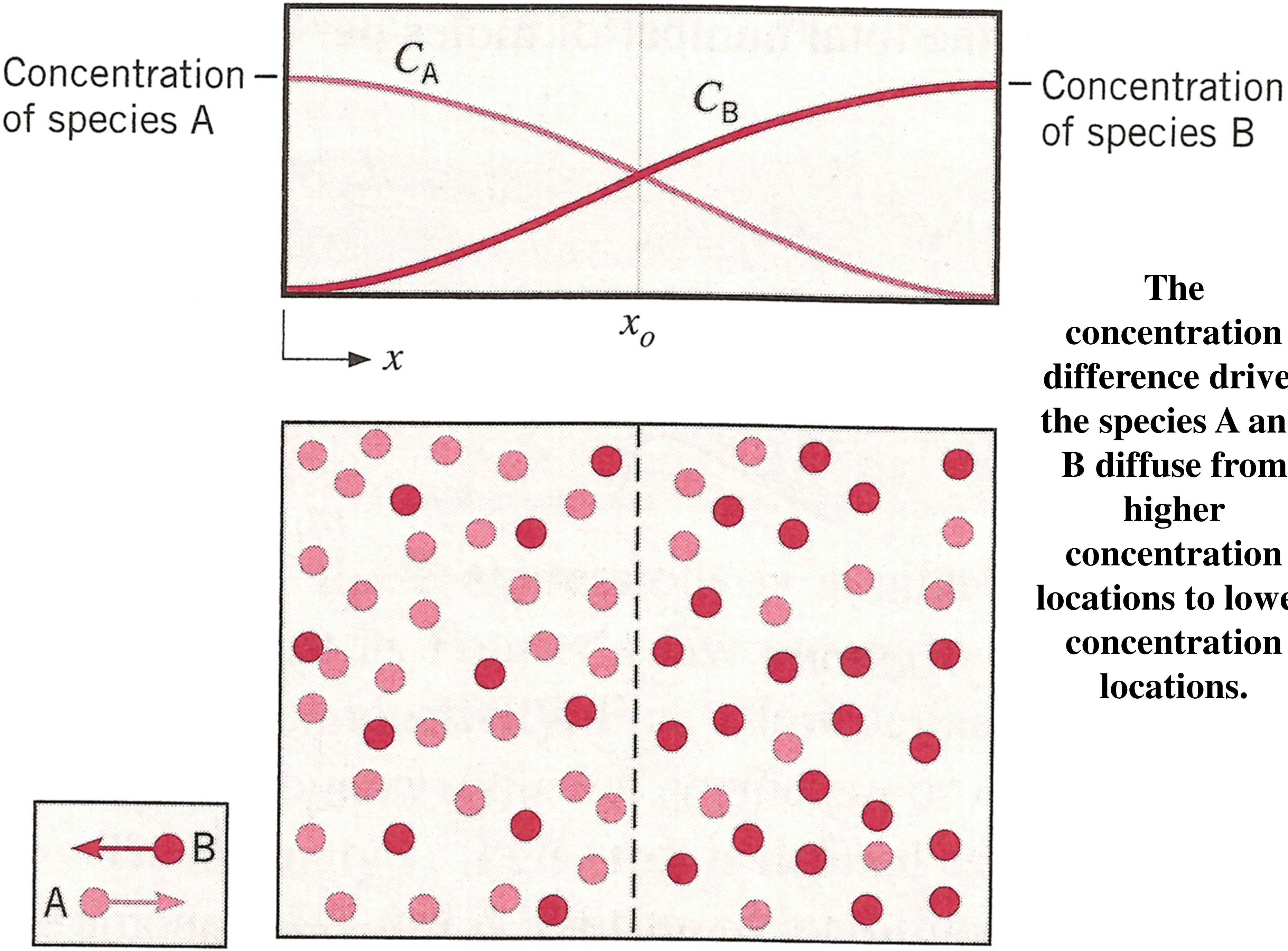
$\boldsymbol{P_i}$ is the **partial pressure** of species i, which is the pressure that species i would exert if it **existed alone** at the mixture **T** and **volume**.

$$PV = NRT$$

$$P_iV = N_iRT$$

$$\frac{P_i}{P} = \frac{N_iRT/V}{NRT/V} = \frac{N_i}{N} = y_i$$

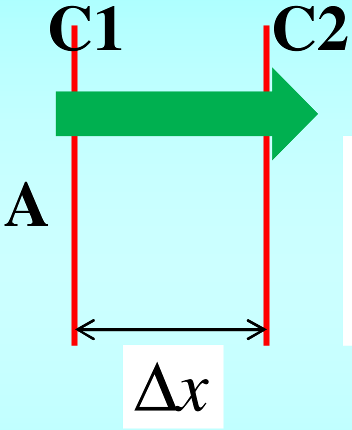
(mole fraction)



The concentration difference drives the species A and B diffuse from higher concentration locations to lower concentration locations.

Mass Diffusion

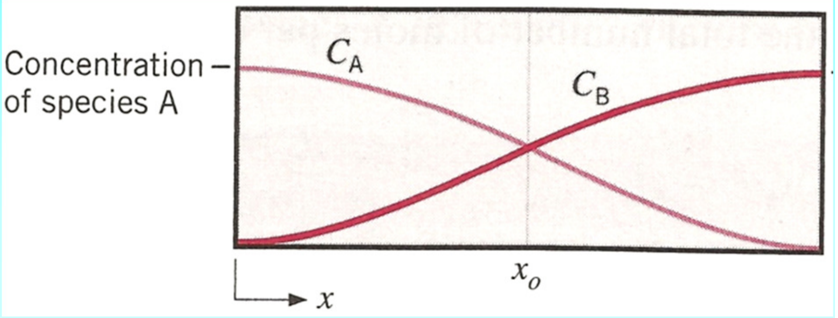
- Like heat conduction, the **rate** ($\dot{m}$) **of mass transfer** (kg/s or kmol/s) of **species A** in a mixture (A and B) by **diffusion** (molecular motion) in *x* direction (through a thin layer with thickness Δ*x*) is proportional to the **concentration difference** (more strictly the **concentration gradient** dC/d*x*) in *x* direction, proportional to the **surface area** A, but inversely proportional to the thickness of the layer. This is called Fick's law of diffusion (proposed in 1855).



C1> C2 (kmol/m^3)

$$\dot{N} = D_{AB} A \frac{C_{A,1} - C_{A,2}}{\Delta x}$$

(mole basis)



Fick's law of diffusion

$$\dot{N} = -D_{AB} A \frac{dC_A}{dx}$$

D_{AB} is the **diffusion coefficient** (diffusivity) of species A in mixture (A and B) (m^2/s)

A is the area normal to mass diffusion (m^2); **C** is concentration of **species A** (kmol/m^3);
In the above equation, the unit for mass transfer rate is **kmol/s**.

Recall the Fourier's law for heat conduction

$$\boxed{\dot{Q}_{Cond} = kA\frac{T_1 - T_2}{\Delta x} = -kA\frac{\Delta T}{\Delta x} = -kA\frac{dT}{dx}}$$

Mass Diffusion

On mole basis - continued

Consider C is constant

$$\dot{N} = -D_{AB} A \frac{dC_A}{dx} = -D_{AB} A \frac{d\left(Cy_A\right)}{dx} = -CD_{AB} A \frac{d\left(y_A\right)}{dx}$$

$$= -CD_{AB} A \frac{d\left(P_A / P\right)}{dx} = -\frac{C}{P} D_{AB} A \frac{d\left(P_A\right)}{dx}$$

On mass basis

Consider ρ is constant

$$\dot{m} = -\rho D_{AB} A \frac{dw_A}{dx} = -\rho D_{AB} A \frac{d\left(\rho_A / \rho\right)}{dx} = -D_{AB} A \frac{d\left(\rho_A\right)}{dx}$$

(kg/s)

$\dot{m} = M \, \dot{N}$ M is the molecular weight of the chemical species under consideration.

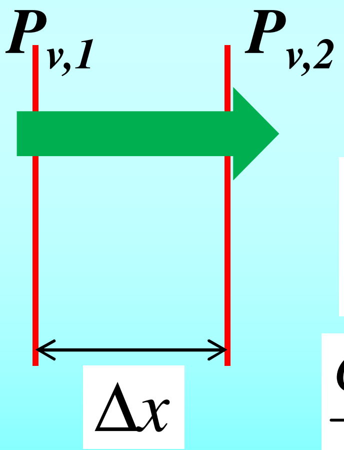
Thus, for gas species

$$\dot{m}_{gas} = M_{gas} \dot{N}_{gas} = M_{gas} \left(-\frac{C}{P} D_{AB} A \frac{d\left(P_A\right)}{dx} \right)$$

Mass Diffusion

$$\dot{m}_{gas} = M_{gas}\dot{N}_{gas} = M_{gas}\left(-\frac{C}{P}D_{AB}A\frac{d\left(P_A\right)}{dx}\right)$$ kg/s

- For transport of water vapor through building structures, the total pressure (P) is usually constant, thus the total molar concentration (C)is also constant (at a given temperature). The molecular weight (M_{gas}) of water vapor is about 18g/mol (constant).



The mass transfer rate of **water vapor through building structure** can be written as,

$$\dot{m}_{vapor} = -\frac{CM_{vapor}D_v}{P}A\frac{d\left(P_v\right)}{dx} = \frac{CM_{vapor}D_v}{P}A\frac{P_{v,1}-P_{v,2}}{\Delta x}$$ (kg/s)

$$\frac{CM_{vapor}D_v}{P}$$ is the permeability (κ) of the material (building structure) for water vapor transport. $\kappa \quad \left(ng/\left(s\cdot m\cdot Pa\right)\right)$

$$\dot{m}_{vapor} = \kappa A\frac{P_{v,1}-P_{v,2}}{\Delta x}$$

$$\frac{\frac{mol}{m^3}\times\frac{g}{mol}\times\frac{m^2}{s}}{Pa} = g/\left(m\cdot s\cdot Pa\right)$$

1 ng = 10^{-9} g = 10^{-12} kg

ng: nano gram

Water vapor diffusion

$$\dot{m}_{vapor} = \kappa A \frac{P_{v,1} - P_{v,2}}{\Delta x}$$

(kg/s, or g/s, ng/s)

$$\dot{Q}_{Cond} = kA\frac{T_1 - T_2}{\Delta x} = -kA\frac{\Delta T}{\Delta x}$$

- Similar to heat conduction and current flow, we can define a resistance for vapor diffusion.

$$\dot{Q} = A\frac{\Delta T}{R}$$

$$\dot{m}_{vapor} = A\frac{P_{v,1} - P_{v,2}}{\frac{\Delta x}{\kappa}} = A\frac{P_{v,1} - P_{v,2}}{R_v}$$

$$R_v = \frac{\Delta x}{\kappa}$$

$$\kappa \quad \left(kg/\left(s \cdot m \cdot Pa\right)\right)$$

$$R_v \quad \left(\left(s \cdot m^2 \cdot Pa\right)/kg = \left(s \cdot N\right)/kg\right)$$

$$R_v = r_v \Delta x$$

$$r_v = \frac{1}{\kappa}$$

resitivity

r_v: $\quad \mathrm{Pa \cdot s \cdot m/g = Pa \cdot s \cdot m^2/(g \cdot m) = N \cdot s/(g \cdot m)}$

Note: 1 Pa = 1N/m^2

The unit for vapor transport resitivity (r_v) is usually:

$$\mathrm{MN \cdot s/(g \cdot m)}$$

$$1\mathrm{MN} = 10^6 N$$

$$\mathrm{GN \cdot s/(kg \cdot m)}$$

$$1\mathrm{GN} = 10^9 N$$

MN: Mega Newton; GN: Giga Newton

Typical vapor transfer properties of materials

Material	**Vapor resistivity (MN.s/g.m; or GN.s/kg.m)**
Brickwork	25-100
Concrete	30-100
Fibre insulating board	15-16
Wood wool	15-40
Stone	150-450
Timber	45-75

Membrane	**Vapor resistance (GN.s/kg)**
Aluminium foil (typical thickness)	4000 +
Bitumenised paper	11
Polythene sheet (0.06mm)	125
Paint glass (average thickness)	6-20
Vinyl wallpaper (average)	6-10

Condensation in Buildings

- The total vapor resistance of a compound structure is the sum of the vapor resistances of all the separate components.

$$R_{vT} = R_{v1} + R_{v2} + R_{v3} + R_{v4} + \ldots$$

Different from heat transfer, the **surface resistances** for water vapor transport are usually **neglected**. Only the resistances across each component are considered.

Condensation in Buildings

From lecture 2, we know that the **temperature change** across any particular component is given by

$$\frac{\Delta T}{\Delta T_{total}} = \frac{R}{R_{total}}$$

ΔT	is the temperature difference across a particular layer
R	is the resistance of that layer;
ΔT_{total}	is the total temperature difference across the whole structure
R_{total}	is the total resistance of the whole structure.

Similarly, the **vapor pressure drop** across a component can be obtained by this formula,

$$\frac{\Delta P}{\Delta P_{total}} = \frac{R_v}{R_{v,total}}$$

Condensation in Buildings

The **vapor pressure drop** across a component can be obtained

$$\frac{\Delta P}{\Delta P_{total}} = \frac{R_v}{R_{v,total}}$$

ΔP is the vapor pressure drop across a particular layer

R_v is the vapor resistance of that layer;

ΔP_{total} is the total vapor pressure drop across the whole structure

$R_{v,total}$ is the total vapor resistance of the whole structure.

After determining the local temperature and the local water vapor pressure, we can find the dew point temperature from the Psychrometric Chart.

Example – 1

- Consider a 20cm-thick brick wall of a house. The permeability of the wall is 20 ng/(s.m.Pa) The indoor conditions are 25^{o}C and 50% relative humidity while the outdoor conditions are 40^{o}C and 50% relative humidity. Assuming that there is no condensation or freezing within the wall, determine the amount of moisture flowing through a **unit surface area (1m^2)** of the wall during a 24 hour period.

$$\dot{m}_{vapor} = \kappa A \frac{P_{v,1} - P_{v,2}}{\Delta x}$$

We know permeability *K*, surface area A, and thickness (20cm).

We need to find the **vapor pressure** difference between indoor and outdoor.

From Psychrometrics and the definition of relative humidity:

$$\phi = \left.\frac{x_w}{x_{ws}}\right|_{t,p} = \left.\frac{p_v}{p_{v,sat}}\right|_{t,p}$$

The vapor pressure can be determined using the **relative humidity** and the **saturation vapor pressure**.

Example – 1

Temperature (^{o}C)	SVP (Pa)	Temperature (^{o}C)	SVP (Pa)
0	610	13	1497
1	657	14	1598
2	705	15	1704
3	758	16	1818
4	813	17	1937
5	872	18	2063
6	935	19	2197
7	1001	20	2337
8	1072	**25**	**3166**
9	1148	30	4242
10	1227	**40**	**7375**
11	1312	50	12351
12	1402	100	101325

Saturated Vapor Pressure (SVP) of water vapor

Example – 1

The vapor pressure can be found by:

$$p_v = p_{v,sat} \times \phi$$

Indoor:

$$p_{v,indoor} = p_{sat,indoor} \times \phi_{indoor} = 3166 Pa \times 50\% = 1583 Pa$$

Outdoor:

$$p_{v,outdoor} = p_{sat,outdoor} \times \phi_{outdoor} = 7375 Pa \times 50\% = 3687.5 Pa$$

Then the rate of water vapor diffusion is:

$$\dot{m}_{vapor} = \kappa A \frac{P_{v,1} - P_{v,2}}{\Delta x} = 20 ng/(m \cdot s \cdot Pa) \times 1m^2 \times \frac{(3687.5 - 1583)\, Pa}{0.2m}$$
$$= 210450 ng/s = 2.1 \times 10^{-4}\, g/s$$

For 24-hour period, the amount of water vapor transmission:

$$2.1 \times 10^{-4}\, g/s \times 24 hour \times 3600 s/hour$$
$$= 18.14 g$$

Example – 2

A double-glazed window consists of 2 sheets of 5mm glass, which has a 5mm airspace between them. The thermal conductivity of the glass is 1.0 W/m.K. The thermal resistances of the internal surface, the airspace and the outside surface of the window are 0.1 m^2.K/W, 0.11 m^2.K/W and 0.06 m^2.K/W, respectively. In a winter day, the indoor air has a dry bulb temperature of 24^{o}C and a relative humidity of 60%. The outdoor air temperature is 10^{o}C.

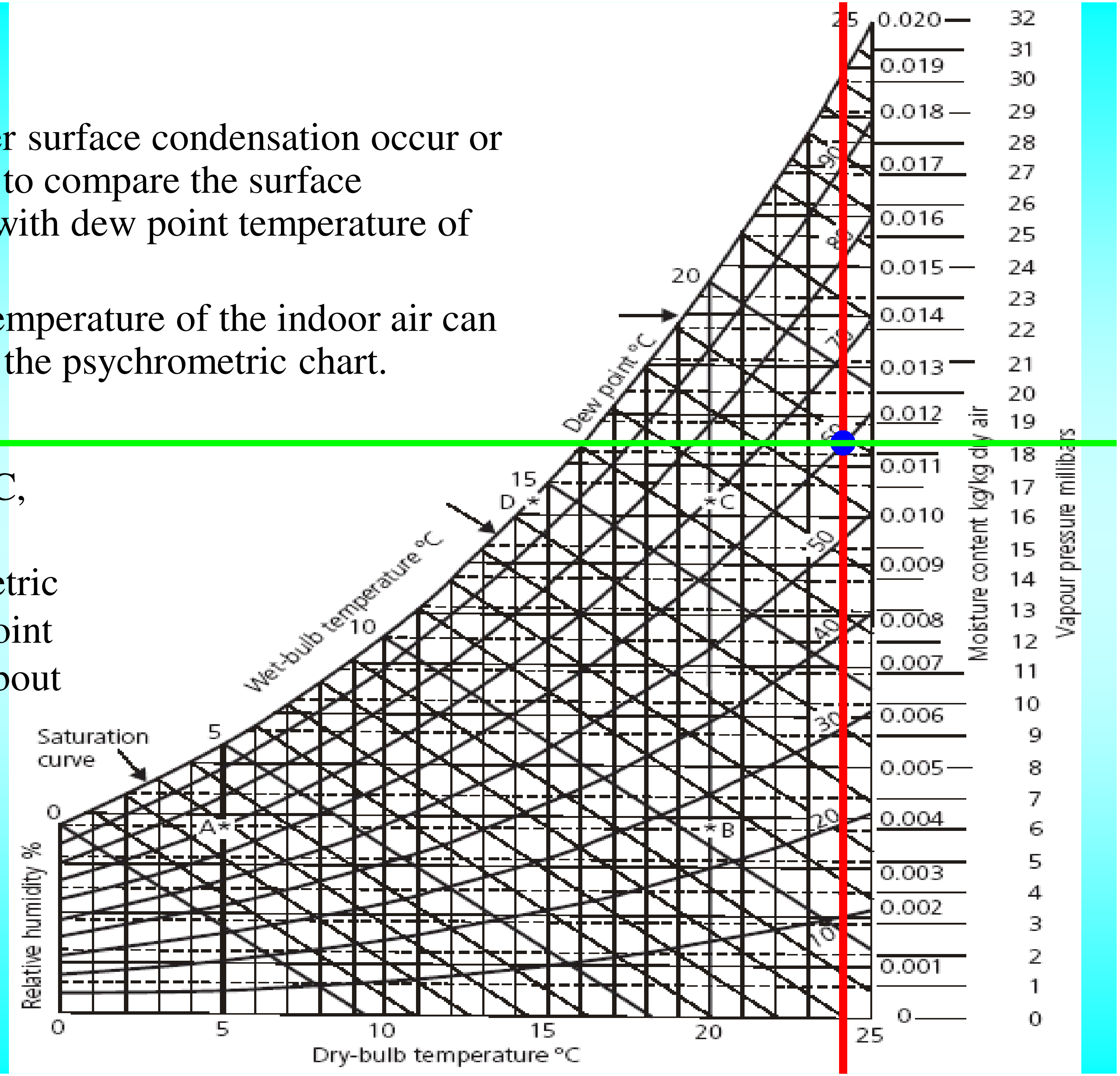
Determine whether surface condensation on the **inside surface of the window** can occur or not.

Example – 2

To judge whether surface condensation occur or not, we need to compare the surface temperature with dew point temperature of indoor air.

The dew point temperature of the indoor air can be read from the psychrometric chart.

Indoor air temperature 24°C, RH: 60%
From psychrometric chart, the dew point temperature is about 16.1°C.



Example – 2

Now the key is to find the temperature at the inside surface of the window.

What we know are:

Double-glazed window,

Thickness of glass: 5mm each, thermal conductivity: 1.0 W/m.K

Thermal resistances of the surfaces: 0.01 and 0.06 m^2.K/W

Thermal resistance of the airspace: 0.11 m^2.K/W

Indoor air temperature: 24^{o}C

Outdoor air temperature: 10^{o}C

The total thermal resistance of the double glazed window,

$$R_{total} = R_{inside,surface} + R_{outside,surface} + R_{glass,two} + R_{airspace}$$

$$= 0.1 + 0.06 + \frac{0.005m \times 2}{1.0W/m.K} + 0.11$$

$$= 0.28\left(m^2 \cdot K\right)/W$$

Example – 2

To find the temperature at the inside surface of the window, we can use the formulae,

$$\frac{\Delta T}{\Delta T_{total}} = \frac{R}{R_{total}}$$

ΔT is the temperature difference between the indoor air and the inside surface of the window, when heat is transferred from the indoor to outdoor, it is

$$\Delta T = T_{indoor,air} - T_{inside,surface}$$

ΔT_{total} is the total temperature difference between indoor and outdoor air, which is 24°C – 10°C in this problem.

$$\frac{\Delta T}{14} = \frac{0.1}{0.28} \Rightarrow \Delta T = 5^{o}C$$

$$T_{inside,surface} = T_{indoor,air} - \Delta T = 19^{o}C$$

Higher than the dew point temperature (16.1°C) of indoor air, **no surface condensation**.

Think about

- If it is a single-glazed window, same thickness (5mm) and same thermal conductivity, but only 1 layer and no air space, whether surface condensation will occur or not? (indoor and outdoor conditions are the same).

Example – 3

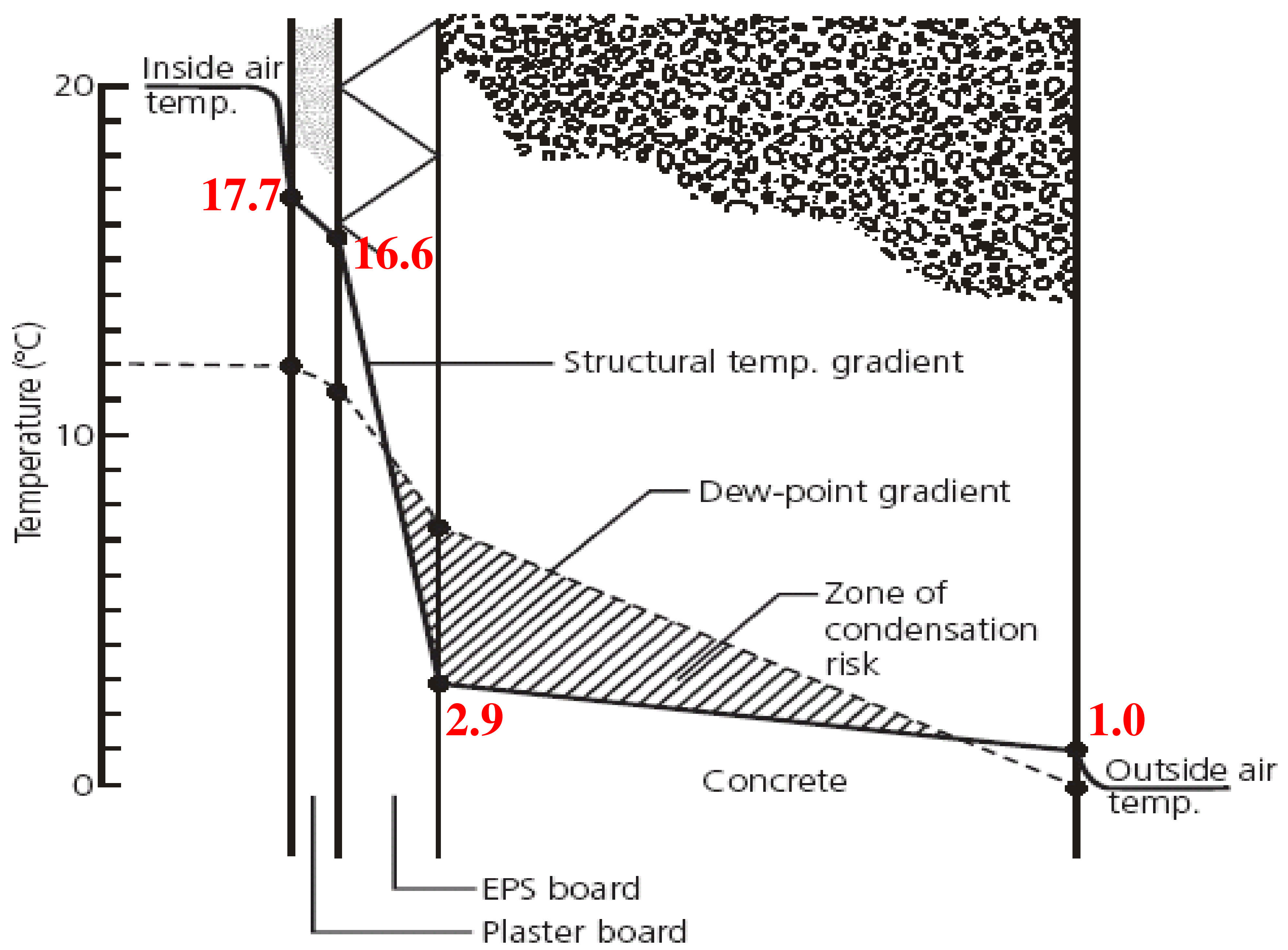
An external wall is constructed with an inside lining of plasterboard **10mm**, then expanded polystyrene board (EPS) **25mm**, then dense concrete **150mm**. The thermal resistances of the components in **m^2.K/W**, are: internal surface resistance **0.123**, plasterboard **0.06**, EPS **0.75,** concrete **0.105**, and external surface resistance **0.055**. The vapor resistivities of the components, in **MN.s/g.**m, are: plasterboard **50**, EPS **100**, and concrete **30**. The inside air is at **20^{o}C** and **59%** RH; the outside air is at **0^{o}C** and **saturated**. Use a scaled cross-section diagram of the wall to plot (1) the **structural temperature distribution** and (2) the **dew-point distribution**.

Example – 3

- ☐ Step 1 – Calculate the total temperature drop – 20°C
- ☐ Step 2 – Use the thermal resistances to calculate the temperature drops across each layer and the temperature at each boundary. Tabulate the information.

Layer	Thermal resistance ($m^2.K/W$)	Temperature drop $\Delta T = \frac{R}{R_{total}} \times \Delta T_{total}$	Boundary temperature (°C)
Inside air			**20**
Internal surface	**0.123**	**20 x 0.123/1.093=2.3**	
Boundary			**17.7 (internal surface)**
Plaster	**0.06**	**1.1**	
Boundary			**16.6**
EPS	**0.75**	**13.7**	
Boundary			**2.9**
Concrete	**0.105**	**1.9**	
Boundary			**1.0 (extern. Surface)**
External surface	**0.055**	**1.0**	
Outside air	$R_{total} = 1.093$		**0.0**

Example – 3


Inside air temp.
20
10
0
Temperature (°C)
17.7
16.6
2.9
1.0
Structural temp. gradient
Dew-point gradient
Zone of condensation risk
Concrete
Outside air temp.
EPS board
Plaster board

Example – 3

❑ Step 3 – Plot the boundary temperatures on a scaled section of the wall and join the points to produce temperature gradients, as shown in the previous slide.

❑ Step 4 – Use vapor resistances to calculate the vapor pressure drops across each of the layers then, using Psychrometric chart, find the dew-point temperature at each boundary.

Read from the **Psychrometric Chart**, we can get,

- Inside vapor pressure = 1400 Pa
- Outside vapor pressure = 600 Pa

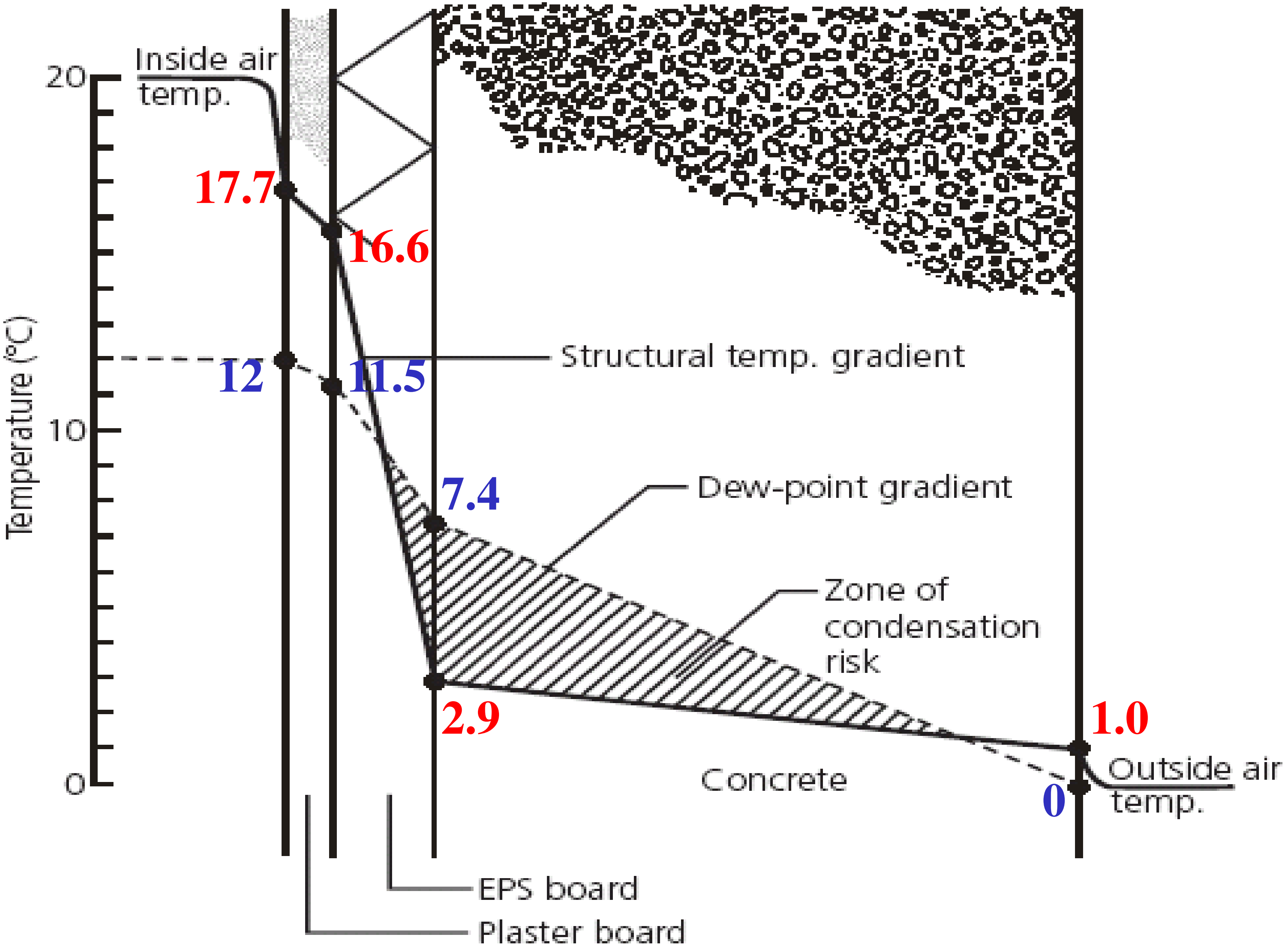
So the total vapor pressure drop is: 1400 – 600 = 800 Pa.

Example – 3

Layer	Thickness (m)	Vapor resistivity (r_v) **MN.s/g.m**	Vapor resistance $R_v = r_v L$ **MN.s/g**	Vapor pressure (VP) drop $\Delta P = \frac{R_v}{R_{v,total}} \times \Delta P_{total}$	VP at boundary (Pa)	Boundary Dew-point (°C)
Internal surface						
Boundary					**1400**	**12**
Plaster	**0.01**	**50**	**0.5**	**800x0.5/7.5 = 53**		
Boundary					**1347**	**11.5**
EPS	**0.025**	**100**	**2.5**	**800x0.25/7.5 =267**		
Boundary					**1080**	**7.4**
Concrete	**0.15**	**30**	**4.5**	**480**		
Boundary					**600**	**0**
External surface						

$$R_{v,total} = 7.5$$

Example – 3



Inside air temp.
20
10
0
Temperature (°C)
17.7
16.6
12
11.5
7.4
2.9
1.0
0
Structural temp. gradient
Dew-point gradient
Zone of condensation risk
Concrete
Outside air temp.
EPS board
Plaster board

Condensation in Buildings

- For surface condensation, it can be prevented by keeping the **surface temperature** **above** the **dew point temperature** of moist air;
- For interstitial condensation, it can be prevented by keeping the **local** (in the structure) **temperature** **above** the **local dew point temperature** throughout the building structure.
- Often, the moisture transport in the walls, floors, or ceilings of buildings and in other applications is controlled by the use of **vapor barriers** or **vapor retarders**.

Condensation in Buildings – vapor barriers

Vapor barriers are materials that are ***impermeable*** to moisture, i.e. sheet metals, heavy metal foils, and thick plastic layers. They can effectively prevent vapor transmission.

Vapor retarders, ***retard*** or ***slow down*** the flow of moisture through the structures but do not completely eliminate it.

Common forms of vapor retarders are reinforced plastics or metals, thin foils, plastic films, treated papers, and polymeric paint coatings, et al.

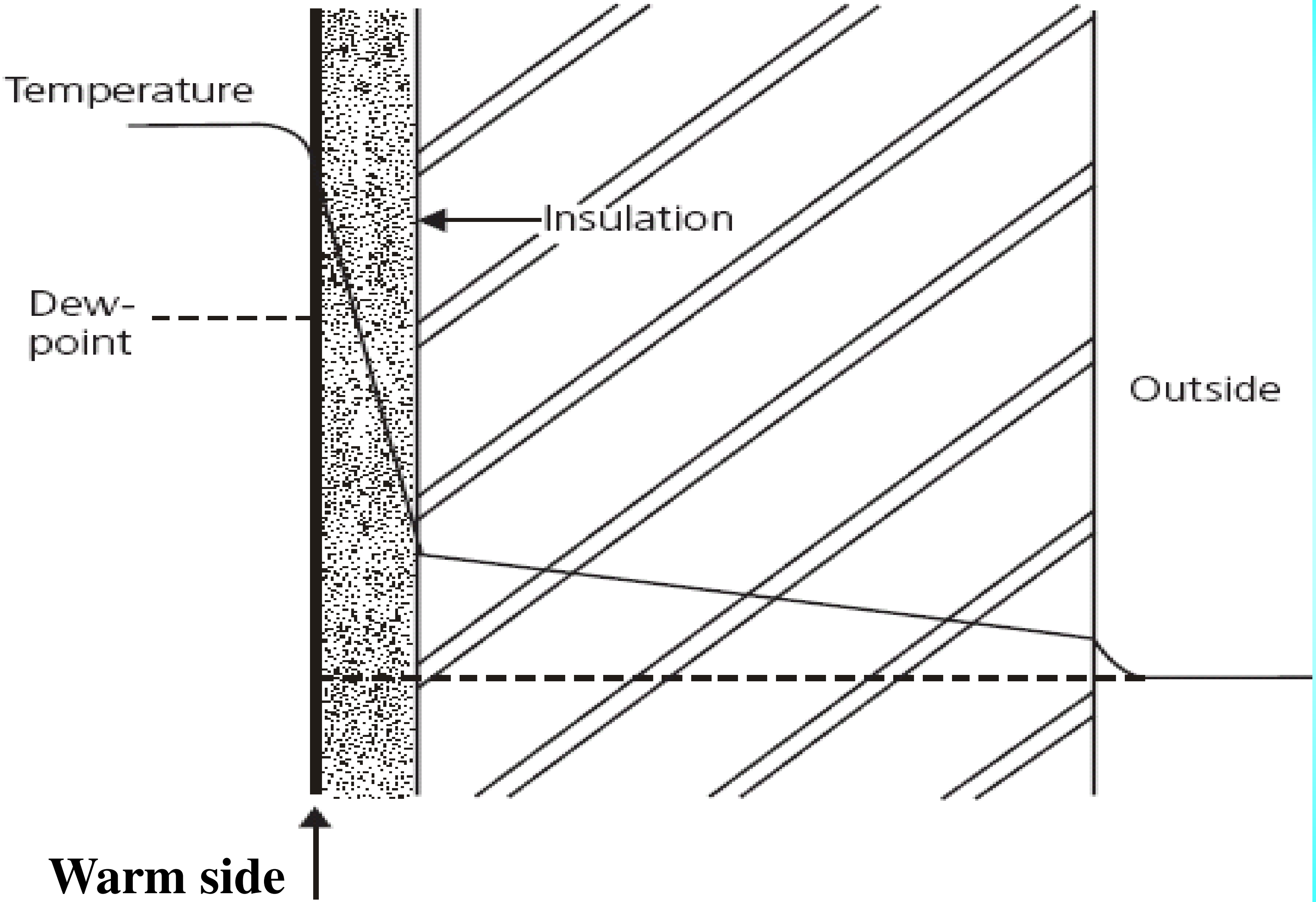
In residential buildings, **vapor retarders** are widely used, instead of vapor barriers.

This is because there are numerous **openings** such as electrical boxes, telephone lines, plumbing passages. Vapor **retarders allows vapor** that somehow leaks in **to exit to the outside**, instead of trapping it in.

The vapor retarders are usually installed at or **near the surface exposed to the higher water vapor pressure**. For residential buildings in heating climate (winter), vapor retarders should be installed on the **warm side of the insulation**.

In many books, vapor barrier refers to both vapor barrier and vapor retarder.

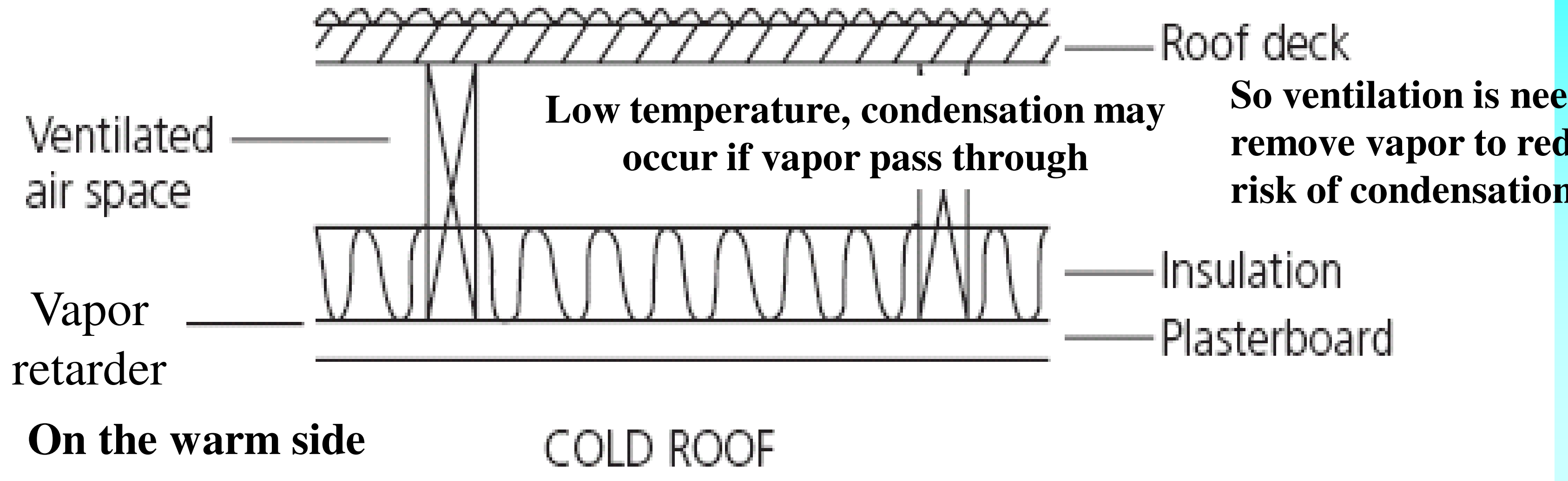
Vapor retarders – installed on the warm side



Warm side

Vapor barrier lowers dew-point in structure

Roof vapor retarders



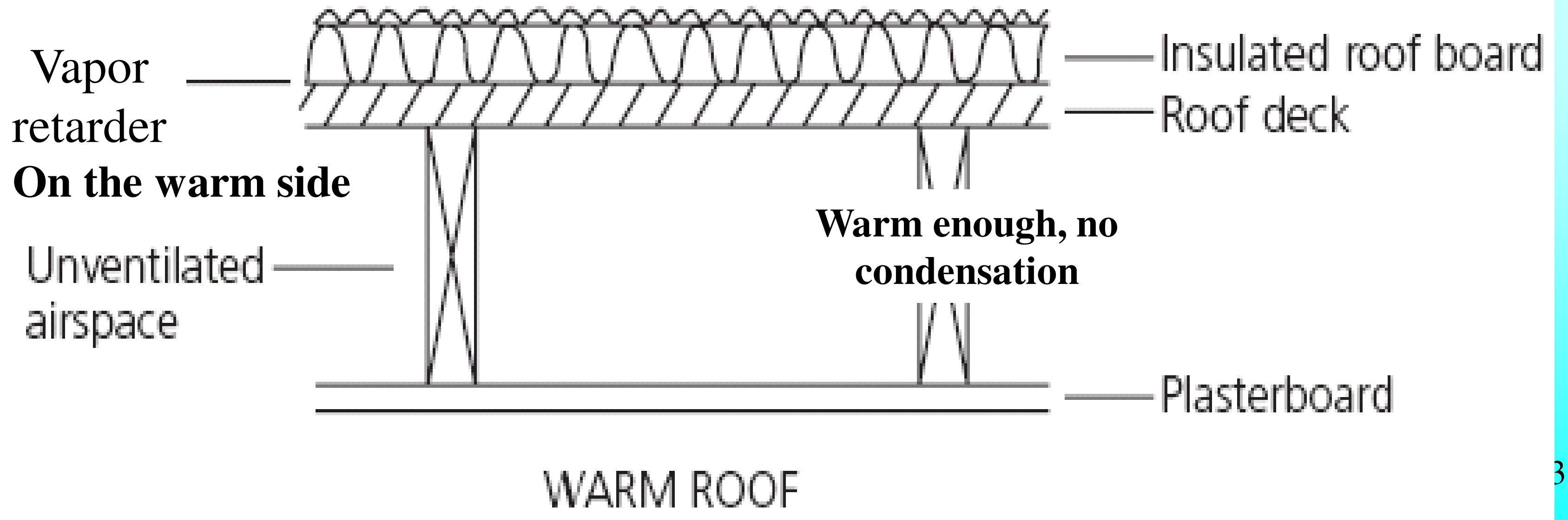
Vapor retarder

On the warm side

COLD ROOF

Low temperature, condensation may occur if vapor pass through

So ventilation is needed to remove vapor to reduce the risk of condensation.



Vapor retarder

On the warm side

Warm enough, no condensation

WARM ROOF

Are you able to

1. Perform simple mass transfer analysis?
2. Determine whether condensation can occur or not in buildings?

Thank you very much for your attention!

Please feel free to contact me if you have any questions.

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