UNIT CONVERSION IN CONDENSATION RISK ASSESSMENT

1. Introduction

Understanding the process of water vapour diffusion through building materials is critical for accurately assessing the risk of interstitial condensation. Vapour transport of building materials can be described by several quantities. Most common are: **Vapour permeability (δ), Vapour permeance (P), Vapour resistivity (R)** and **Vapour diffusion resistance (Z)**. In addition, often derived quantities like the Vapour resistance factor (μ) and Equivalent air layer thickness (s_d) are used in practice.

The main quantities can be categorized into two groups based on their scope of application, illustrated in Figure 1.

- **Properties of bulk materials**: These include vapour permeability (δ) and vapour resistivity (R), which are measured per unit thickness of the material.
- **Properties of composite materials with given thickness:** These include vapour permeance (P) and vapour diffusion resistance (Z), which account for the material's specific thickness in their calculation.

This document aims to clarify the definitions, standard units, and interrelations between these terms.

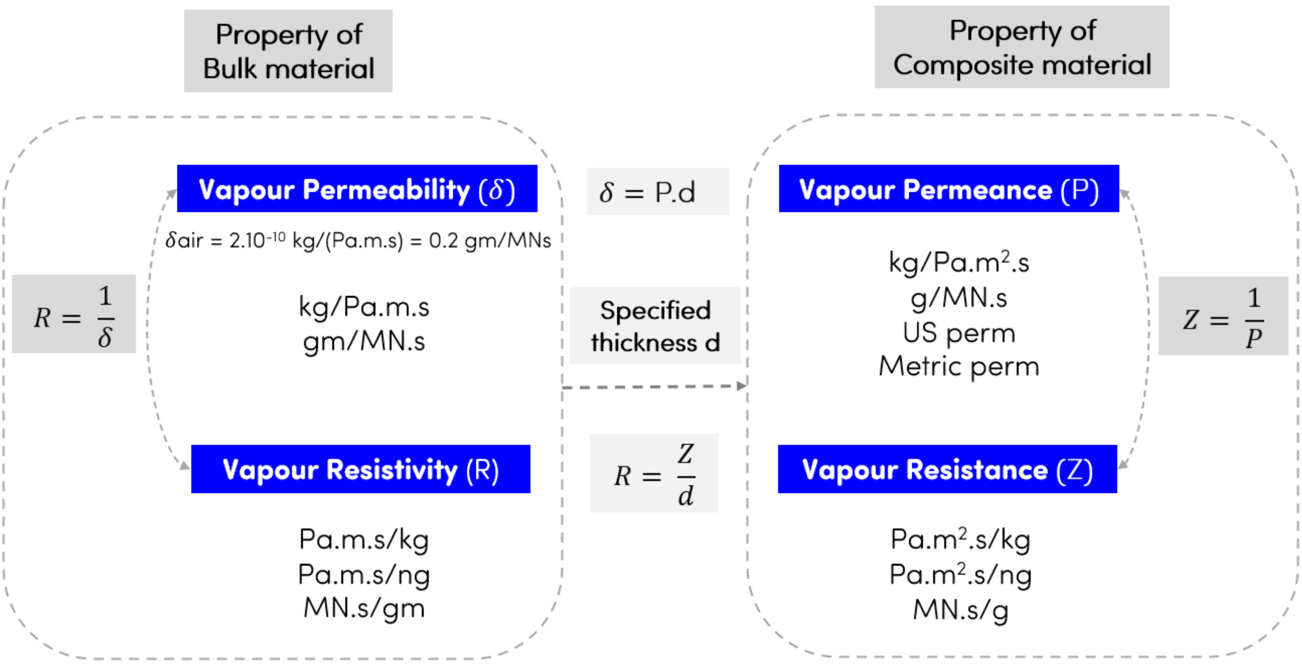


Figure 1. Vapour transport primary terms

2. Primary terms, units and conversions

a. Vapour resistance factor (μ)

Vapour resistance factor (μ) is a dimensionless property of a material that indicates its resistance to water vapour diffusion compared to the resistance of still air.

$$\mu = \frac{\delta \mathrm{air}}{\delta} \quad (-)$$

with δair: Water vapour permeability of still air (2.10^{-10} kg/Pa.m.s)

b. Equivalent air layer thickness (s_d)

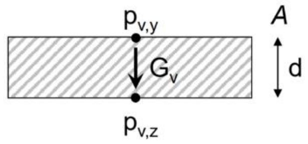
Equivalent air layer thickness (s_d) is defined as the thickness of a layer of air that has the same vapour diffusion resistance as the given material. It can be calculated as:

$$s_d = \mu \times d \quad (\mathrm{m})$$

c. Vapour permeability (δ)

The vapour permeability is defined as the rate at which water vapour passes through a unit area of homogenous material of **unit thickness** induced by a unit water vapour pressure difference between its two surfaces.

$$G = A.\delta.\frac{\Delta p}{d} \rightarrow \delta = \frac{G.d}{A.\Delta p}$$



Where: G = water vapour flow rate (kg/s) across an area A (m^2)
d = thickness of the specimen (m)
Δp = difference in water vapour pressure across the specimen surface

The units used for vapour permeability are **kg/(Pa.m.s)** or **gm/(MN.s).**

Unit	Conversion	
kg/Pa.m.s	1 kg/Pa.m.s = 10^9 gm/MN.s	1 N = 1 Pa.m^2 1 MN = 10^6 N 1 kg = 10^3 g = 10^{12} ng
gm/MN.s	2.10^{-10} Kg/Pa.m.s = 0.2 gm/MN.s	

$$1\,\frac{\mathrm{kg}}{\mathrm{Pa.m.s}} = 10^3.\frac{\mathrm{g.m}}{\mathrm{Pa.m^2.s}} = 10^3\,\frac{\mathrm{g.m}}{\mathrm{N.s}} = 10^3\,\frac{\mathrm{g.m}}{10^{-6}\,.\mathrm{MN.s}} = 10^9\,\frac{\mathrm{g.m}}{\mathrm{MN.s}}$$

In EN ISO 13788, the vapour permeability of air is given as **2.10^{-10} kg/(Pa.m.s)** whereas **0,2 gm /(MNs)** is commonly used in UK. The values are equivalent and can be easily converted as below:

$$\delta \mathrm{air} = 2.10^{-10}\frac{\mathrm{kg}}{\mathrm{Pa.m.s}} = 2.10^{-10}.10^3.\frac{\mathrm{g.m}}{\mathrm{Pa.m^2.s}} = 2.10^{-7}\,\frac{\mathrm{g.m}}{\mathrm{N.s}} = 0{,}2\,\frac{\mathrm{g.m}}{\mathrm{MN.s}}$$

d. Vapour permeance of material (P)

Unlike Vapour permeability (δ), which is a property of bulk materials, Vapour permeance (P) is used for membranes and composite materials. Vapour permeance describes the material's ability to transmit water vapour at a specific thickness from the above measurements as:

$$P = \frac{G}{A.\Delta p}$$

Where: G = water vapour flow rate (kg/s) across an area A (m^2)
Δp = difference in water vapour pressure across the specimen surface

The units of vapour permeance depends on the measurement system used:

- **In the Metric (SI) System:**
  The common units are **kg/(Pa.s.m²)**, **ng/(Pa.s.m²)** or **g/MN.s**, which indicate the amount of water vapour (in kilograms or nanograms) passing through one square meter of the material per second, per Pascal of pressure difference.
- **In the Imperial (US) System**: US perm is widely used in North America, while metric perm is less common.
  US perm: Defined as 1 grain of water vapour passing through 1 square foot of material per hour per inch of mercury of pressure difference, written as **grains/(ft²·h·inHg).**
  Metric perm: Defined as 1 gram of water vapour passing through 1 square meter of material per day per millimeter of mercury (mmHg) of pressure difference, written as **g/(m²·day·mmHg).**

	Unit	Conversion
US perm	grain/(ft²·h·inHg)	1 US perm ≈ 57.2 ng/(Pa.m².s)
Metric perm	g/(m²·day·mmHg)	1 metric perm ≈ 86.8 ng/(Pa.m².s) ≈ 1.517 US perm
SI Unit	kg/(Pa.m².s) ng/(Pa.m².s) g/MN.s	1 kg/(Pa.m².s) = 10^{12} ng/(Pa.m².s) = 10^9 g/MN.s ≈ 1.74784x10^{10} US perm ≈ 1.15191x10^{10} metric perm

For a material with a thickness of d meter and a vapour resistance factor μ, the vapour permeance of the material can be calculated as follows: (δair = 2.10^{-10} kg/Pa.m.s)

$$\mathrm{P} = \frac{\delta\mathrm{air}}{\mathrm{Sd}} = \frac{2.10^{-10}}{Sd}\left[\frac{\mathrm{kg}}{\mathrm{Pa.m^2.s}}\right] = \frac{2.10^{-10}}{Sd}.1{,}75.10^{10}\,[\mathrm{US\ perm}] = \frac{3{,}5}{\mu d}\,[\mathrm{US\ perm}]$$

e. Vapour resistivity (R)

In term of bulk material, Vapour resistivity is the reciprocal of vapour permeability (δ). It is usually measured in Pa.m.s/kg or MN.s/gm.

Unit	Conversion	
Pa.m.s/kg Pa.m.s/ng	1 MN.s/gm = 10^{-3} Pa.m.s/ng = 10^{6} Pa.m.s/g = 10^{9} Pa.m.s/kg	1 N = 1 Pa.m^2 1 MN = 10^6 N 1 kg = 10^3 g = 10^{12} ng
MN.s/gm		

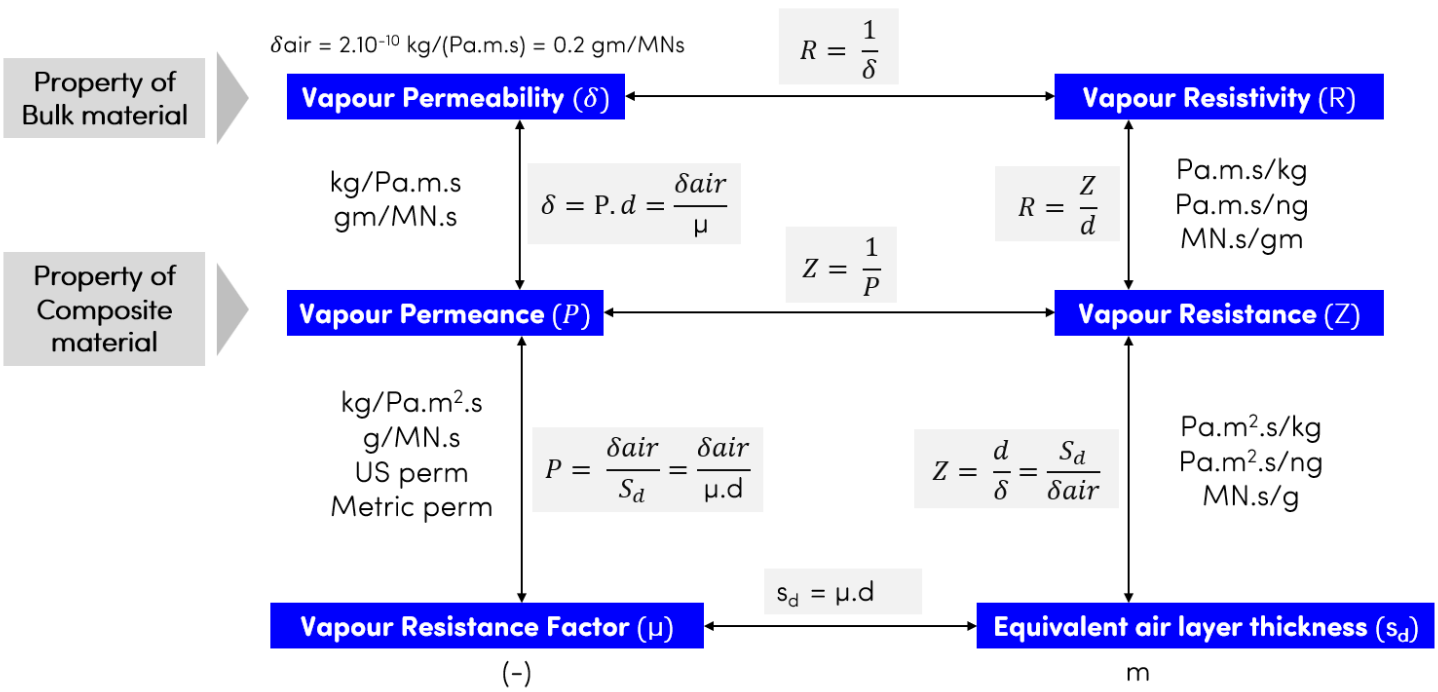
f. Vapour diffusion resistance (Z)

Similarly, Vapour diffusion resistance (Z) is the reciprocal of vapour permeance (P) in term of composite materials with specified thickness. The unit used for vapour diffusion resistance in EN ISO 13788 and ASHRAE Handbook Fundamentals are **Pa.m^2.s/kg** and **Pa.m^2.s/ng**. The unit **MNs/g** (meganewton-seconds per gram) is less common but can be used in certain fields.

Unit	Conversion	
Pa.m^2.s/kg Pa.m^2.s/ng	1 MN.s/g = 10^{-3} Pa.m^2.s/ng = 10^{6} Pa.m^2.s/g = 10^{9} Pa.m^2.s/kg	1 N = 1 Pa.m^2 1 MN = 10^6 N 1 kg = 10^3 g = 10^{12} ng
MN.s/g		

g. Summary

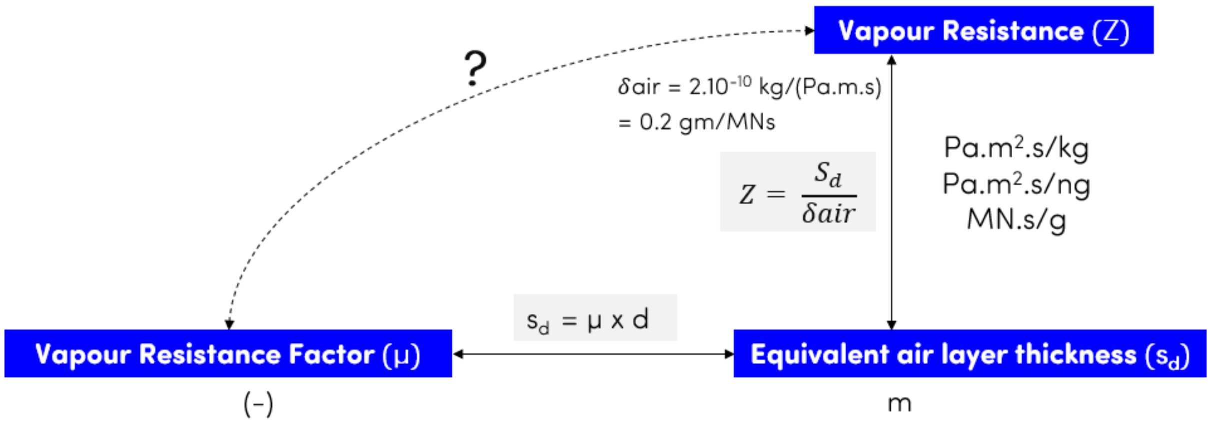
Below is a summary of the discussed quantities and their interrelations. If one of these quantities and the thickness are given, the remaining ones can be easily calculated.



3. Examples

a. Convert a vapour resistance Z (MN.s/g) to a μ - value.

For a material with vapour resistance Z = 10 000 MN.s/g and thickness d = 100mm.



We have:

$$s_d = \mathrm{Z\,x\,\delta air} = 10000\,\frac{\mathrm{MN.s}}{\mathrm{g}}.\ 0{,}2\,\frac{\mathrm{g.m}}{\mathrm{MN.s}} = 2000\ (\mathrm{m})$$

$$\mu = \frac{\mathrm{sd}}{\mathrm{d}} = \frac{2000\ \mathrm{m}}{100\ \mathrm{mm}} = \frac{2000\ \mathrm{m}}{0{,}1\ \mathrm{m}} = 20\,000\ (-)$$

$$\mathrm{P} = \frac{1}{\mathrm{Z}} = \frac{1}{10^4} = 10^{-4}\,\frac{\mathrm{g}}{\mathrm{MN.s}}$$

$$\mathrm{R} = \frac{Z}{\mathrm{d}} = \frac{10^4}{0{,}1} = 10^5\,\frac{\mathrm{MN.s}}{\mathrm{gm}}$$

b. Convert a μ - value to a vapour resistance Z (MN.s/g)

For a material with μ - value = 4000 and thickness d = 3mm. Similarly, we have:

$$\mathrm{sd} = \mu\,.\,\mathrm{d} = 4000\,.\,3\mathrm{mm} = 12\ \mathrm{m}$$

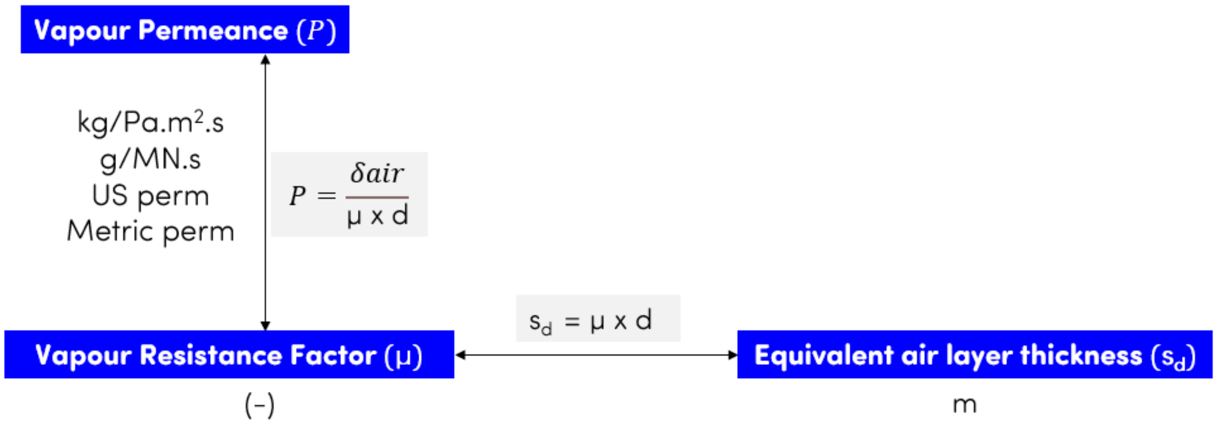
$$\mathrm{Z} = \frac{\mathrm{Sd}}{\mathrm{\delta air}} = \frac{12\ \mathrm{m}}{0{,}2\,\frac{\mathrm{g.m}}{\mathrm{MN.s}}} = 60\,\frac{\mathrm{MN.s}}{\mathrm{g}}$$

$$\mathrm{P} = \frac{1}{\mathrm{Z}} = \frac{1}{60} = 0{,}0167\,\frac{\mathrm{g}}{\mathrm{MN.s}}$$

$$\mathrm{R} = \frac{Z}{\mathrm{d}} = \frac{60}{0{,}003} = 20\,000\,\frac{\mathrm{MN.s}}{\mathrm{gm}}$$

c. Convert vapour permeance P (US perms) to a μ-value.

A 50mm thick sample of material has a water vapour permeance of P = 1.2 US perms.



We have:

$$P = 1{,}2 \text{ US perm} = 1{,}2 \,.\, 57{,}2 \frac{\text{ng}}{\text{Pa.m}^2\text{.s}} = 68{,}64 \frac{\text{ng}}{\text{Pa.m}^2\text{.s}}$$

$$P = \frac{\delta\text{air}}{\text{sd}} = \frac{\delta\text{air}}{\mu\text{.d}}$$

$$\rightarrow \mu = \frac{\delta\text{air}}{\text{P.d}} = \frac{200 \frac{\text{ng}}{\text{Pa.m.s}}}{68{,}64 \frac{\text{ng}}{\text{Pa.m}^2\text{.s}} . 0{,}05m} = 58{,}57\ (-)$$

$$Z = \frac{\mu\text{.d}}{\delta\text{air}} = \frac{58{,}57 . 0{,}05 \text{ m}}{0{,}2 \frac{\text{g.m}}{\text{MN.s}}} = 14{,}64 \frac{\text{MN.s}}{\text{g}}$$

$$R = \frac{Z}{\text{d}} = \frac{14{,}64}{0{,}05} = 292{,}85 \frac{\text{MN.s}}{\text{gm}}$$

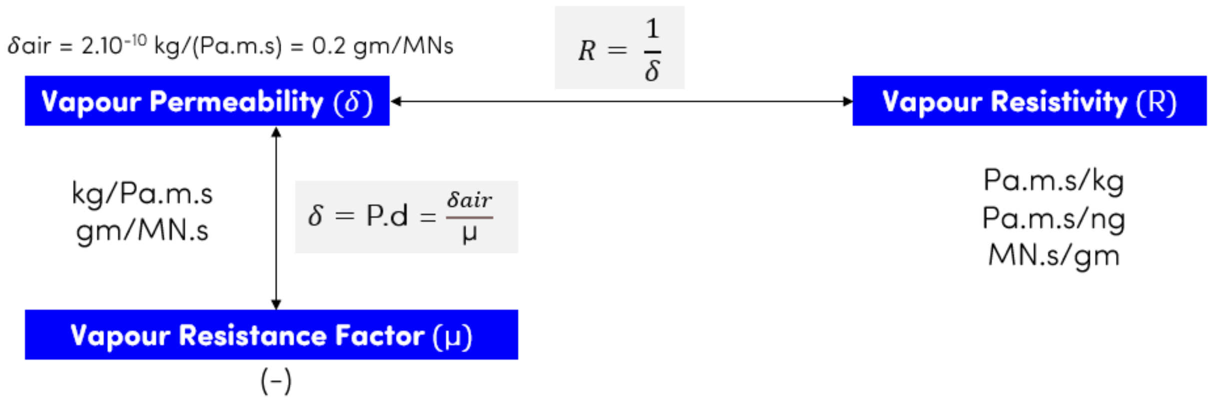
It is also possible to directly convert P (US perms) to s_d (=μd) by:

$$\mu d = \frac{3{,}5}{US\ perm}$$

which gives for the above example:

$$\mu d = \frac{3{,}5}{1.2\ US\ perms} = 2.92 \text{ m}$$

d. Convert vapour resistivity R = 1000 MNs/gm to μ - value.



We have:

$$\delta = \frac{1}{R}$$

$$\rightarrow \ \mu = \frac{\delta air}{\delta} = \frac{\delta air}{1/R} = \ \delta air. R = 0.2 \ \frac{gm}{MNs} \ . 1000 \ \ \frac{MNs}{gm} \ = 200 \ (-)$$

Reference:
Heinz R. Trechsel. (2021). Moisture analysis and condensation control in building envelopes.
Hugo Hens. (2003). Warmte- en massatransport.
https://www.builddesk.co.uk/wp-content/uploads/2013/01/vapourResistances.pdf
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