Moisture calculations

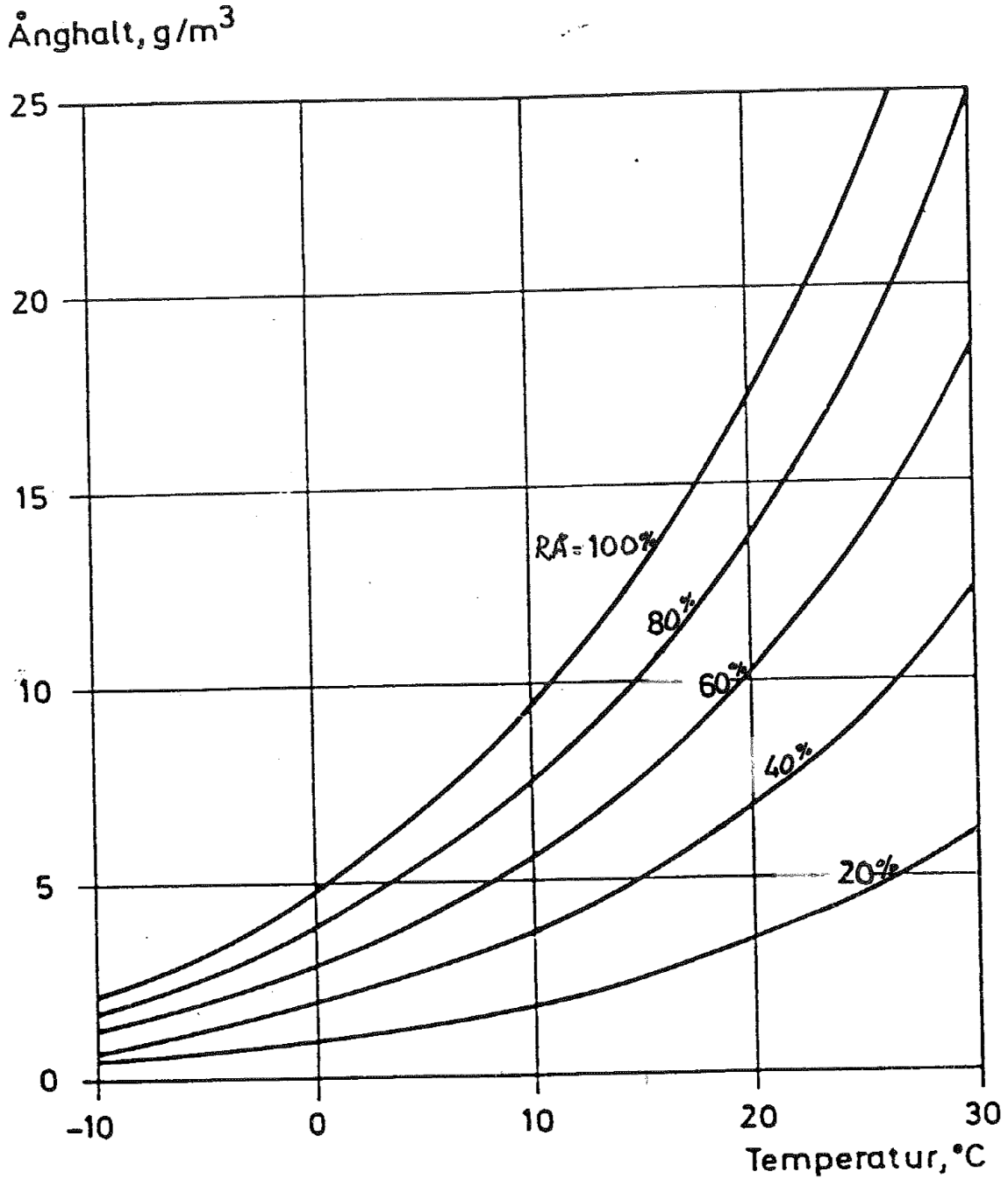
- Calculate moisture distribution in a structure
- Compare the calculated relative humidity (RH) with the critical moisture condition of each material
- Calculate if moisture condenses on a surface
- Calculate where the vapour barrier can be placed in a structure without condensation occurring anywhere in the structure
- Calculation of RH in ventilated areas

How is moisture measured?

- Vapor content g/m^3
- Relative humidity RH, %

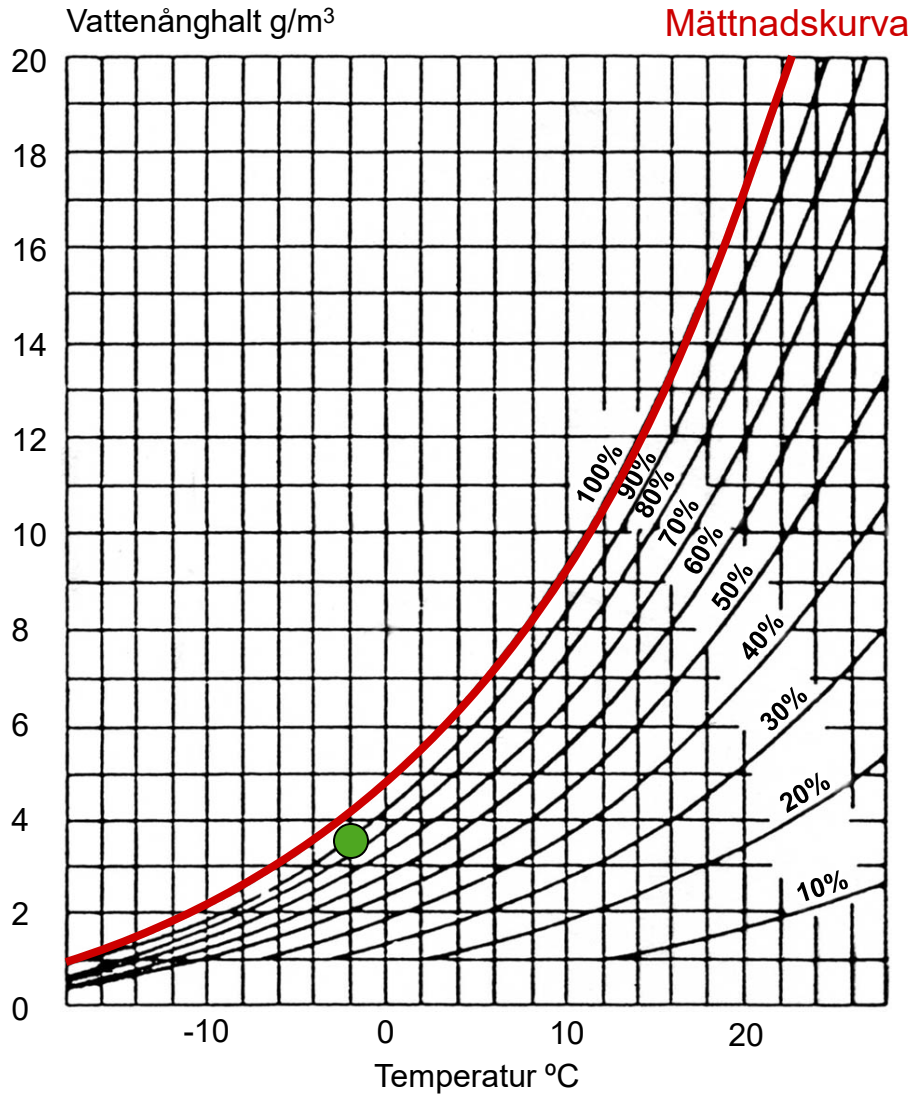
$$RH = \frac{vapor\ content}{saturation\ vapor\ content}$$

- **Saturation vapor content:** the maximum amount of water vapour that the air can contain at a certain temperature


Ånghalt, g/m3
25
20
15
10
5
0
RÅ=100%
80%
60%
40%
20%
-10
0
10
20
30
Temperatur, °C

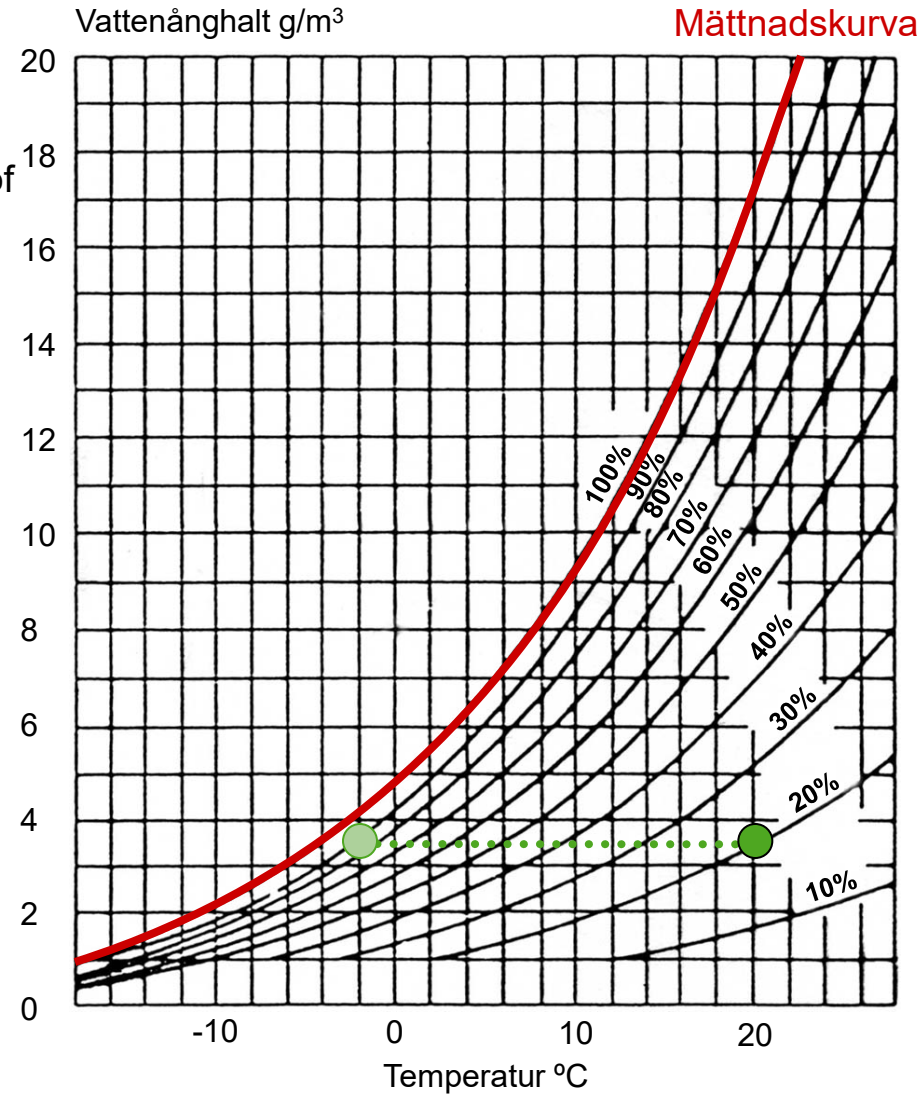
Relationship between vapour content and temperature

- If the outside air holds -2 ºC and has an RH of 90%, the vapor content of the air is 3.5 g/m^3



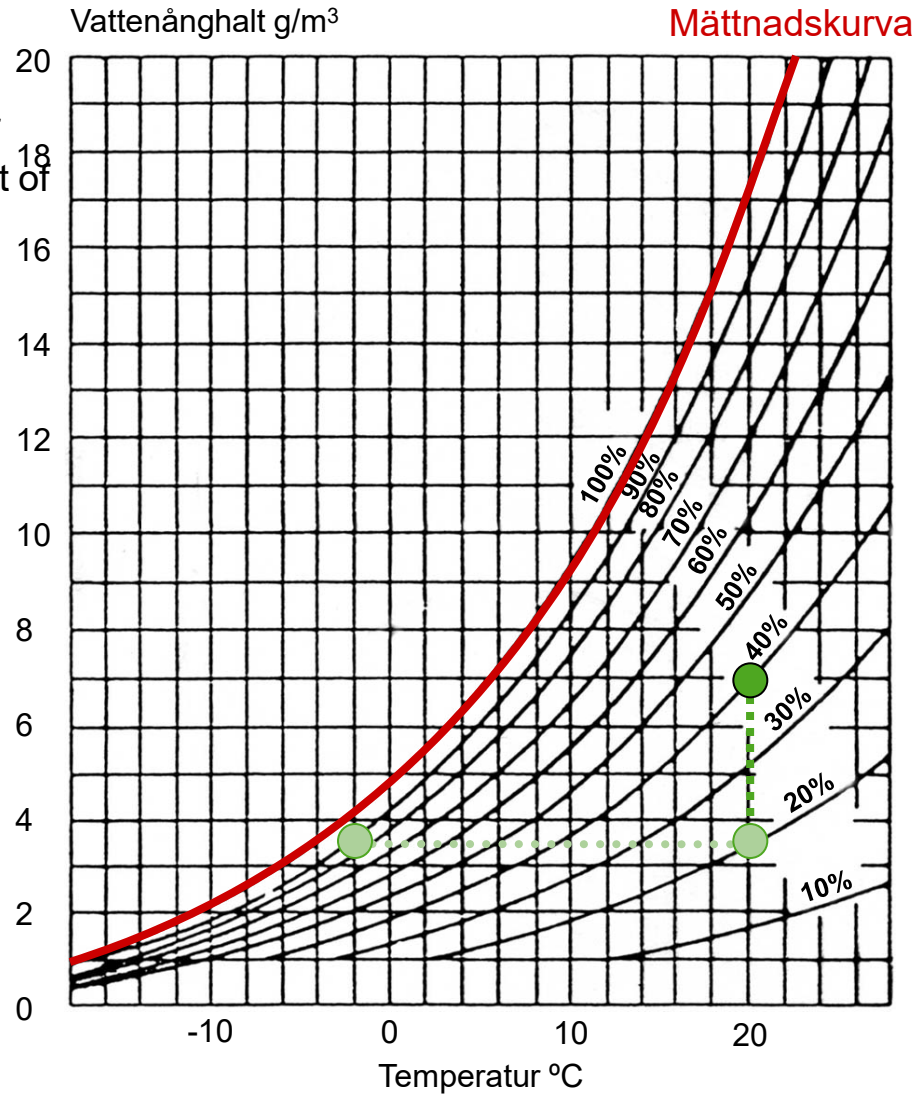
Relationship between vapour content and temperature

- If the outside air holds -2 ºC and has an RH of 90 %, the vapor content of the air is 3.5 g/m^3
- If the air is taken in and heated to 20 ºC it can carry more vapor. RH drops to 20 %

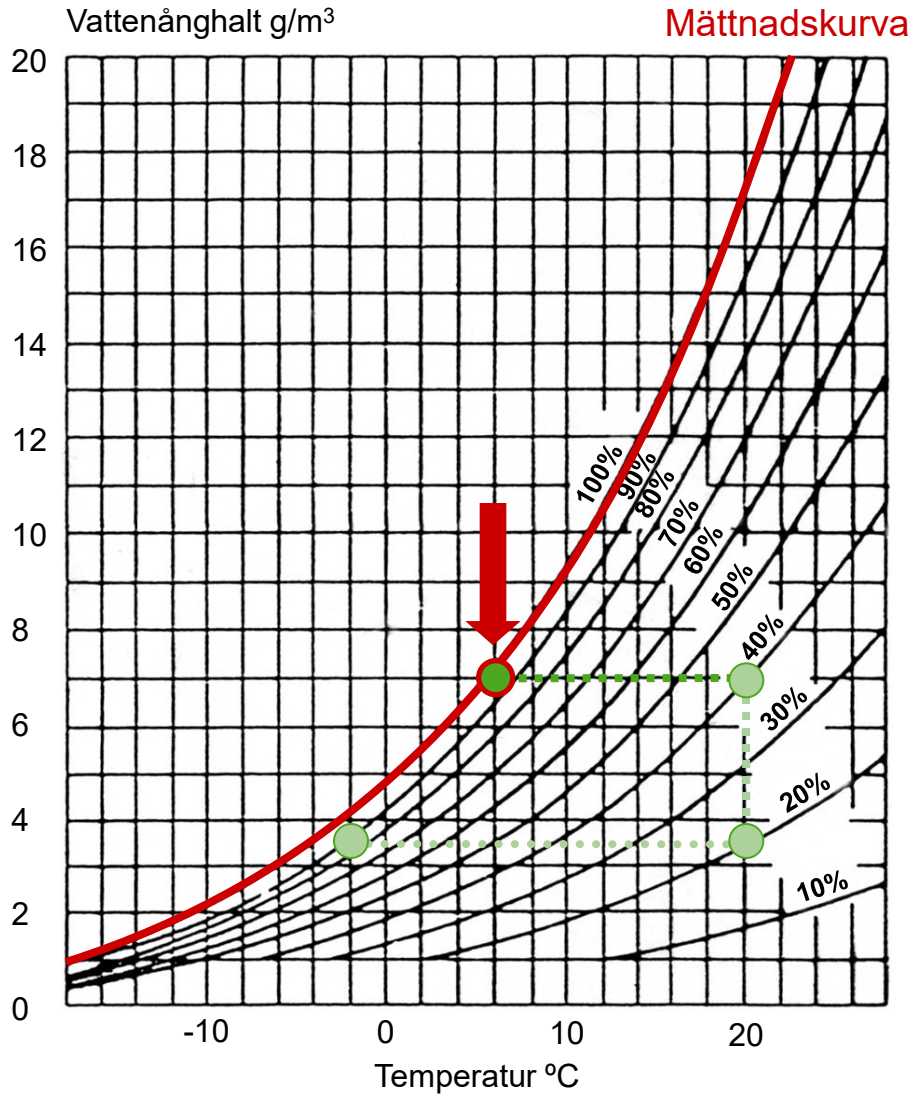


Relationship between vapour content and temperature

- If the outside air holds -2 ºC and has an RH of 90 %, the vapor content of the air is 3.5 g/m^3
- If the air is taken in and heated to 20 ºC it can carry more vapor. RH drops to 20 %
- Moisture from building materials and Human activities Increases the vapour content



Relationship between vapour content and temperature



What happens if indoor air with a high vapour content is cooled?
It reaches the dew point –
here about 6 ºC.
If the air is cooled below the dew point there will be condensation.

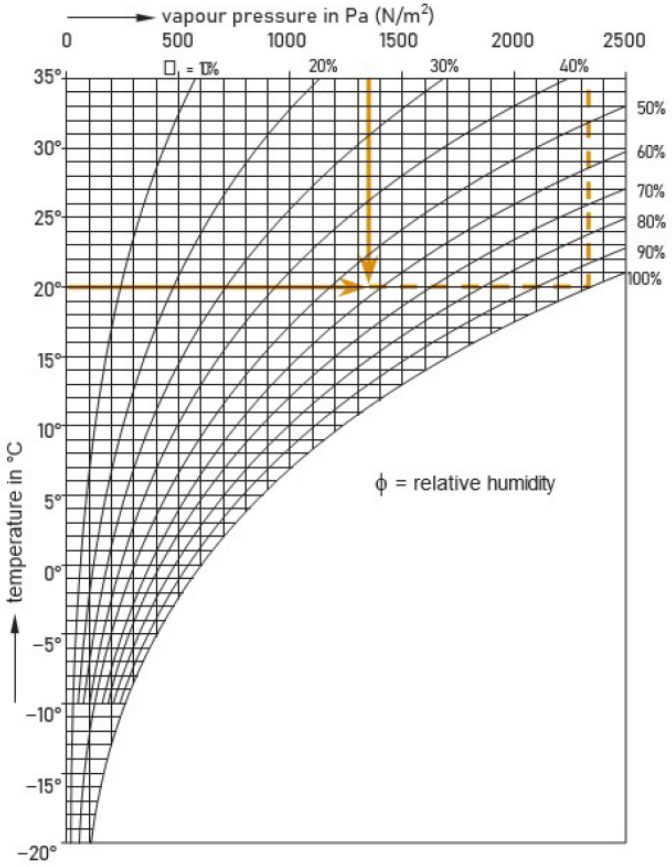


Figure 2.2 Vapour pressure p = 1350 Pa, relative humidity ϕ = 58%

Example figure 2.2

Suppose that the prevailing water vapour pressure is p = 1350 Pa. For an air temperature of 20 °C, the maximum vapour pressure p_{max} = 2340 Pa (see figure 2.1). The relative humidity is then:

$$\phi = \frac{1350}{2340} \cdot 100\% = 58\%$$

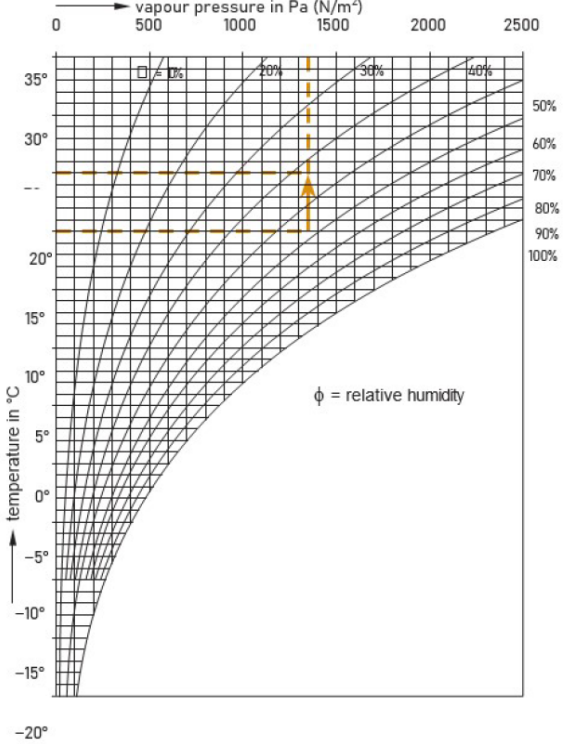


Figure 2.3 If the air heats up from 20 °C to 25 °C, relative humidity drops from ϕ= 58% to ϕ= 43%

Example figure 2.3
Initial situation (figure 2.2):
Temperature equals θ = 20 °C
Maximum vapour pressure at 20 °C is
p_{max} = 2340 Pa
Maximum vapour concentration is
c_{max} = 17.28 g/m^3
Prevailing water vapour pressure is
p = 1350 Pa
Prevailing water vapour concentration is
c = 10 g/m^3
Relative humidity ϕ = 58%
If the air is heated to 25 °C (p_{max} = 3169 Pa), the relative humidity is:

$$\phi = \frac{1350}{3169} \cdot 100\% = 43\%$$

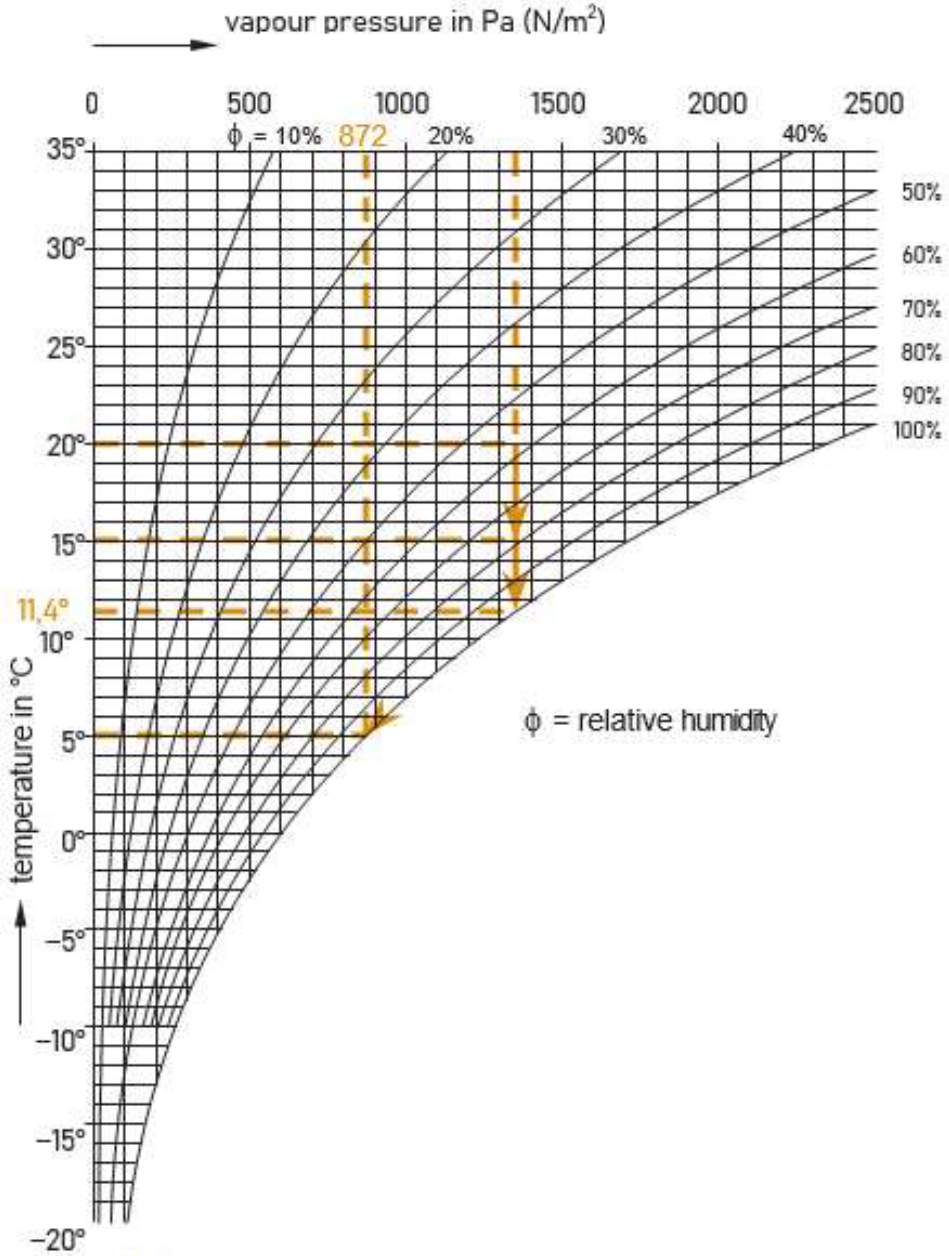


Figure 2.4 If the air cools by 5 °C, this causes the vapour in the air to condense

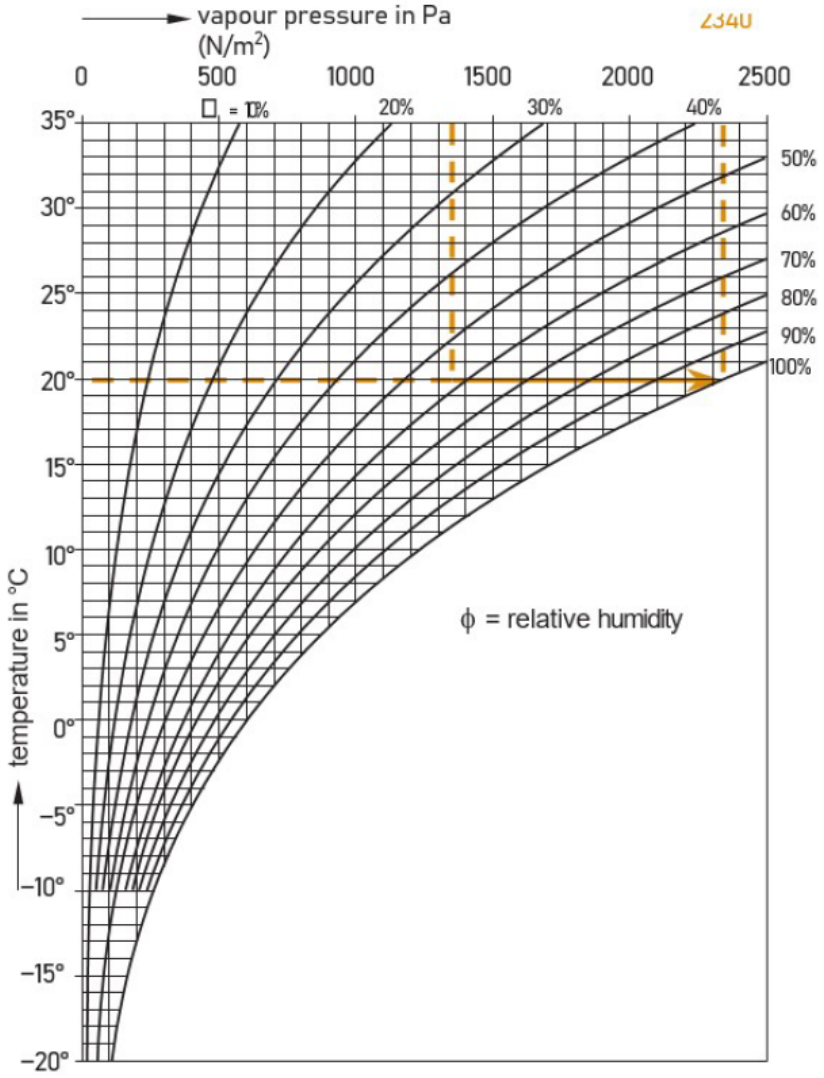


Figure 2.5 Addition of vapour also leads to condensation

Example figure 2.5
Initial situation (figure 2.2): Temperature equals $\theta = 20$ °C
Maximum vapour pressure at 20 °C equals $p_{max} = 2340$ Pa
Maximum water vapour concentration at 20 °C equals $c_{max} = 17.28$ g/m^3
Prevailing water vapour pressure equals $p = 1350$ Pa
Prevailing water vapour concentration equals $c = 10$ g/m^3
Relative humidity $\phi = 58\%$

If you supply moisture to air of 20 °C and $p = 1350$ Pa ($c = 10$ g/m^3), the vapour pressure will change. If more than 7.28 g/m^3 is supplied, condensation will take place (the maximum water vapour concentration at 20 °C is after all 17.28 g/m^3 (see figure 2.1).

Where does the moisture come from - sources of moisture

- Precipitation
- Humidity both inside and outside
- Soil moisture
- Construction moisture
- Leakage

How is the moisture transported - moisture transport

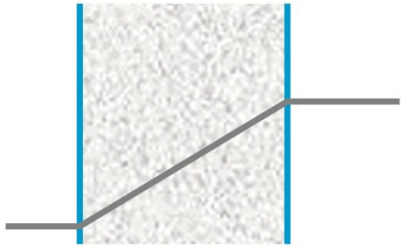
- Diffusion - vapour content differences as a driving force
- Convection – air pressure differences as a driving force
- Capillary suction

Fuktens väg genom en vägg genom diffusion

Outside
(drier air)

Insidae
(more humid air)

Homogeneous wall



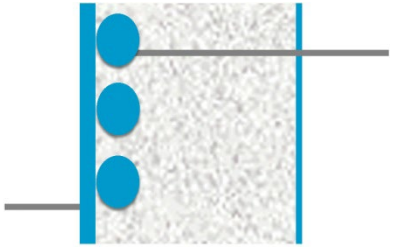
Moisture migrates from the inside out

Internal vapor barrier



Humid indoor air does not escape

Exterior vapor barrier



Moist air escapes into the wall and condenses at the cold part

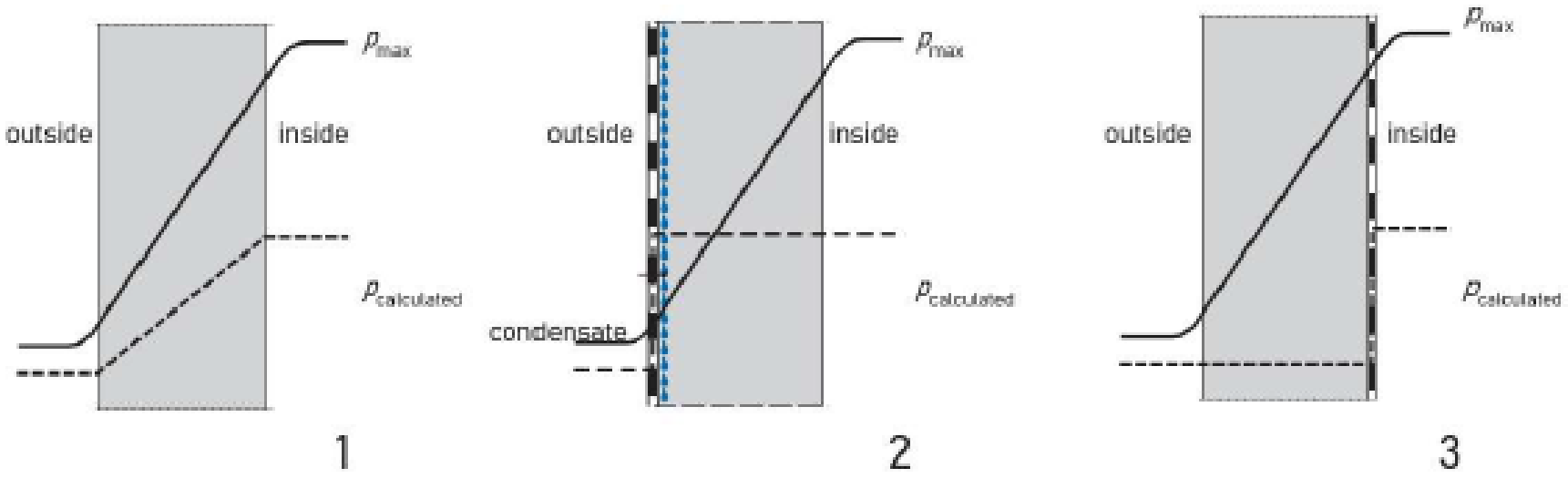


Figure 2.26 Influence of location of vapour-retardant layer on interstitial condensation

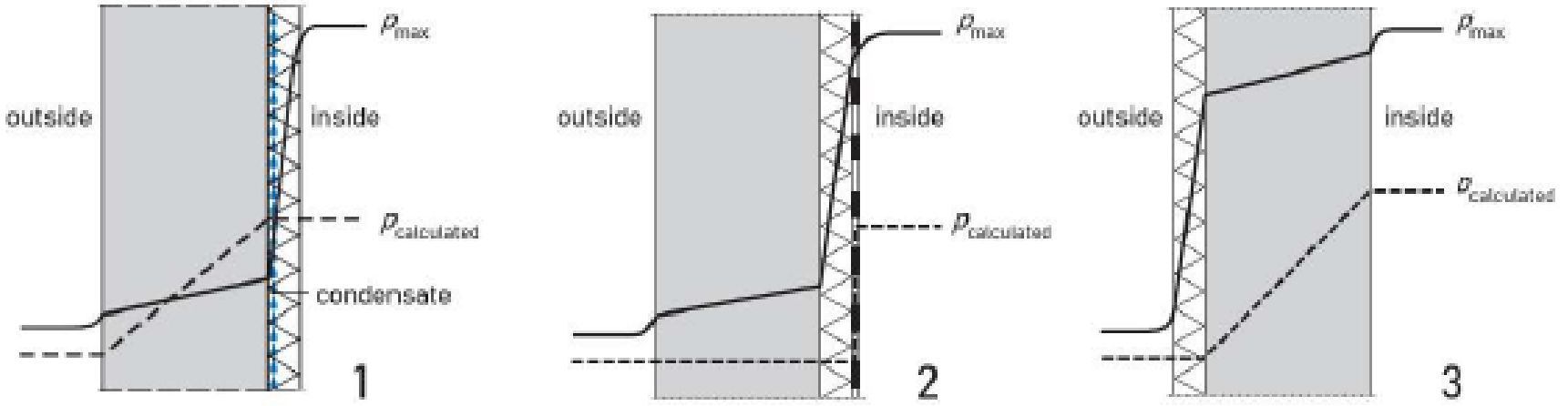


Figure 2.27 Influence of the position of the insulation on interstitial condensation

$$g = \frac{\Delta p}{R_d} \cdot 1000 \ [g//(m^2 \cdot s)]$$

$$\mu = \frac{\text{vapour diffusion resistance of a layer of material}}{\text{ditto, for a layer of air of identical thickness}}$$

$$R_d = 5.3 \cdot 10^9 \cdot \mu \cdot d \ [m/s]$$

Material	μ	d [m]	$\mu \cdot$ d [m]
Mineral wool	2	0.05	0.1
Brickwork (red)	9	0.11	1.0
Concrete	100	0.15	15.0
Roofing material	10.000	0.002	20.0
Polyethylene foil	34.000	0.0003	10.2
Aluminium foil	100.000	0.0002	20.0

Figure 2.16 Vapour diffusion resistance of a number of materials

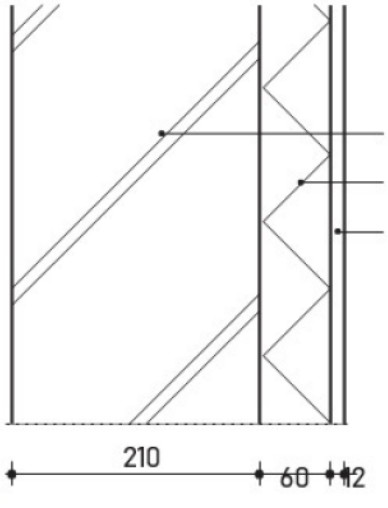
The total vapour diffusion resistance of a layered construction can be found by adding up the resistances of the individual layers:

$$(\mu \cdot \mathrm{d})_{\mathrm{tot}} = \mu_1 \cdot d_1 + \mu_2 \cdot d_2 + \mu_3 \cdot d_3 + \ldots \; [\mathrm{m}]$$

$$g = \frac{\Delta p}{5.3 \cdot 10^9 \cdot (\mu \cdot d)_{\mathrm{tot}}} = \frac{\Delta p_n}{5.3 \cdot 10^9 \cdot (\mu_n \cdot d_n)}$$

$$\Delta p_n = \Delta p \cdot \frac{\mu_n \cdot d_n}{(\mu \cdot d)_{tot}}$$

Compare $\Delta T_{m;i} = \frac{R_{m;i}}{R_T} \cdot \Delta T \; [°C]$



Construction layer	d [m]	μ	$\mu_n \cdot d_n$ [m]	Δp_n	p_n [Pa]
Outside air					208
R_{se}	–	–	–	–	208
Brickwork	0.210	13.5	2.84	232	440
Insulation material	0.06	100	6.00	490	930
Gypsum cardboard	0.012	6	0.07	6	936
R_{si}	–	–	–	–	
Inside air					936
					Δp = 728
		$(\mu \cdot d)_{tot}$ = 8.91			

Figure 2.17 Calculation of the progression of vapour density in a construction ($\Delta p = p_i - p_e$ = 936 – 208 = 728 Pa)

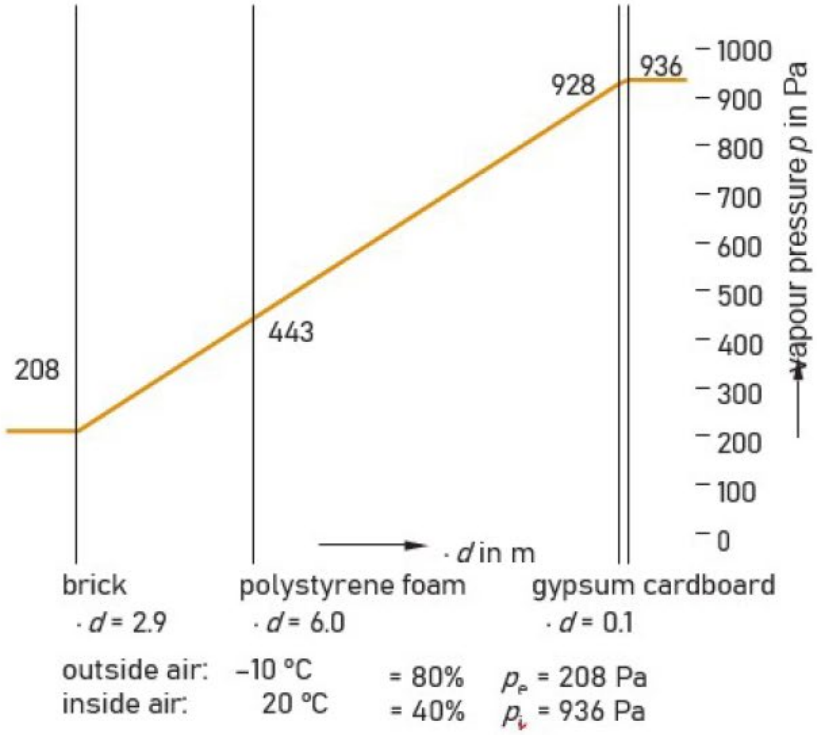


Figure 2.18 Graphic calculation of progression of vapour concentration in a wall construction

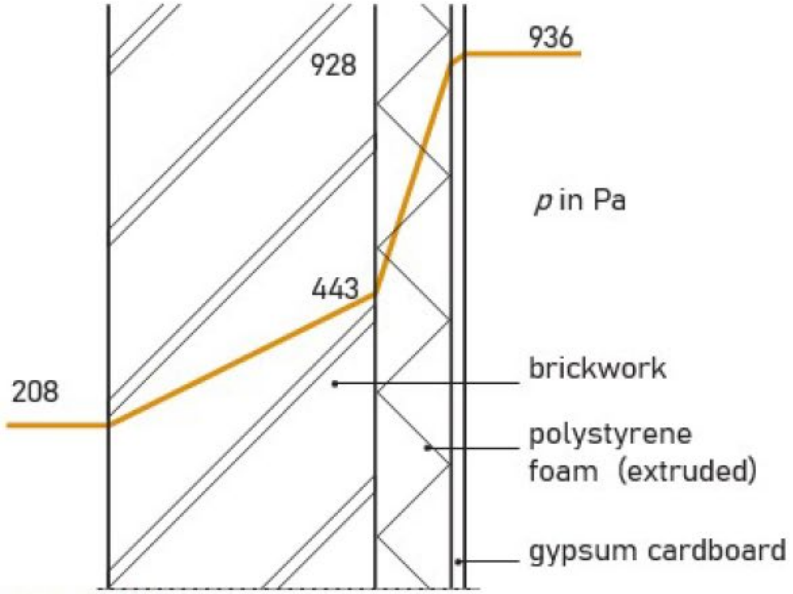


Figure 2.19 Progression of the vapour density in a wall construction

Glaser Method

The following steps are necessary to determine whether condensation will occur in a construction and what the actual profile of the vapour pressure will be:

1. Determine the temperature profile in the construction.
2. Determine the maximum vapour pressure for the temperature given (see figure 2.2 or the vapour pressure table in the book of tables).
3. Determine the vapour pressure p_{calc} that has been calculated.
4. Calculate the amount of condensation.

Construction layer	d [m]	λ [W/(m·K)]	R [m²·K/W]	$\Delta\theta$ [°C]	θ [°C]	p_{max} [Pa]	μ	$\mu \cdot d$ [m]	Δp_n [Pa]	p_{calc} [Pa]
Outside air					-10	260				208
R_{se}			0.04	0.4	-9.6	269	-	-	-	208
Roof cladding	0.006	0.2	0.03	0.3	-9.2	276	10.000	60	545	753
Insulation	0.08	0.03	2.67	26.9	17.6	2014	2	0.2	2	755
Concrete	0.2	1.9	0.11	1.1	18.7	2157	100	20	181	936
R_{si}			0.13	1.3			-	-	-	
Inside air					20	2340				936
Total			2.98	30				80.2	728	

Figure 2.21 Calculation of a construction in terms of physical parameters

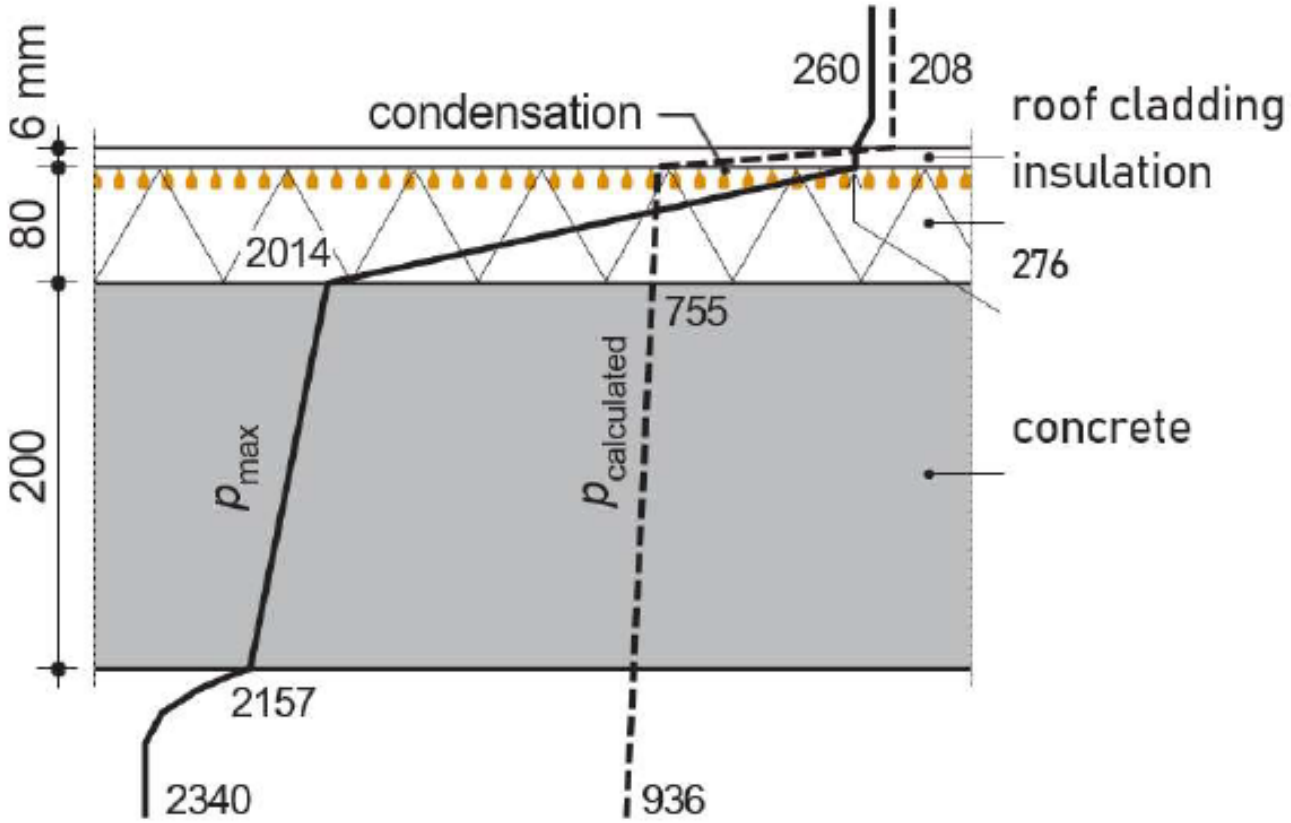


Figure 2.23 Interstitial condensation in a roof construction

$$g = 60 \cdot 24 \cdot 3600 \cdot \left(\frac{\Delta p_{in}}{R_d \cdot \sum \mu \cdot d_{in}} - \frac{\Delta p_{out}}{R_d \cdot \sum \mu \cdot d_{out}} \right) \cdot 1000 \ [g/m^2]$$

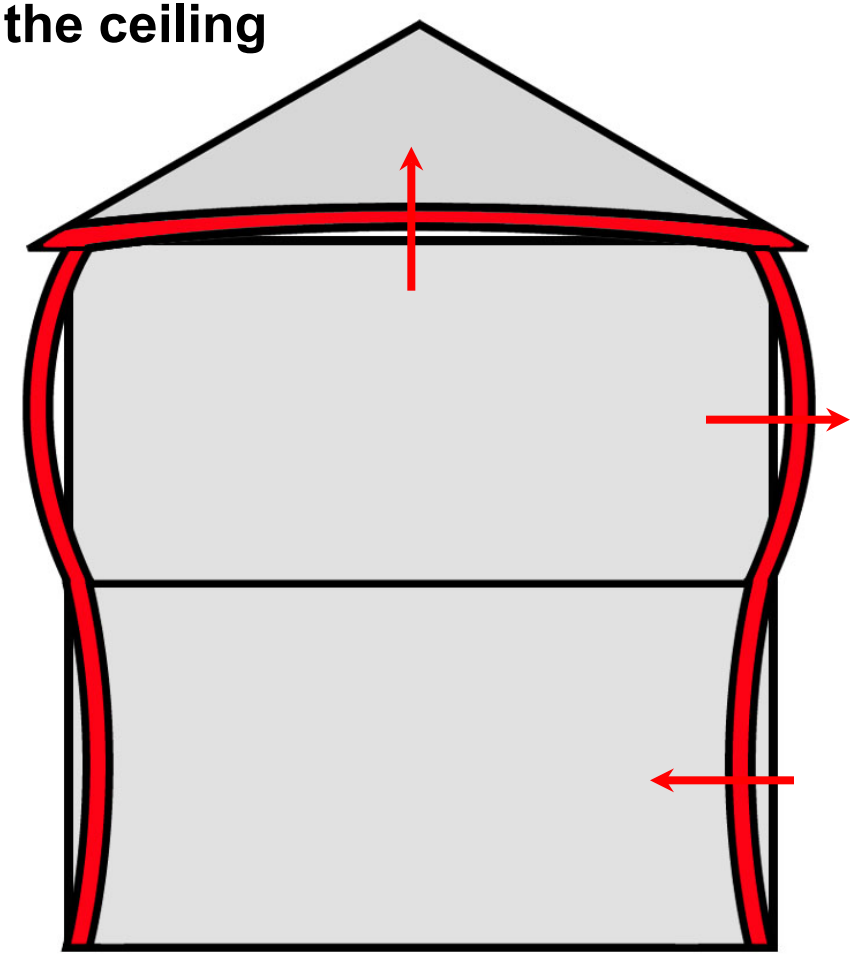
$$\frac{(936 - 276) \cdot 1000}{5.3 \cdot 10^{-6} \cdot (20 + 0.2)} = 6.2 \cdot 10^{-6}\ \mathrm{g/(m^2 \cdot s)}$$

And the outgoing moisture flow is:

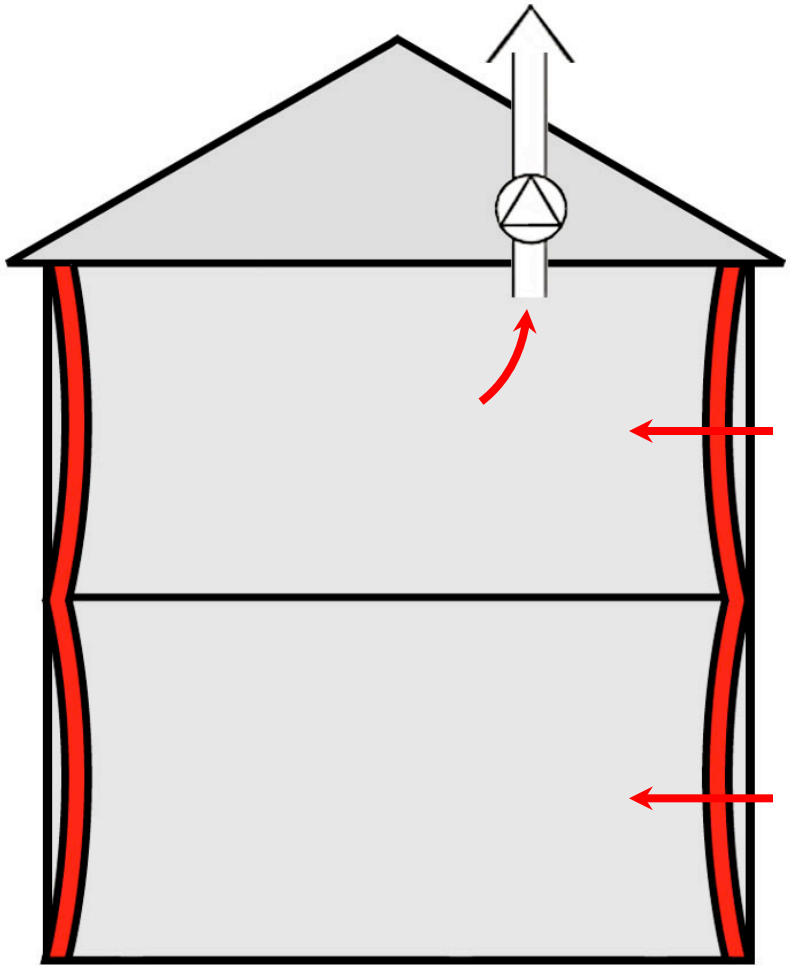
$$\frac{(276 - 208) \cdot 1000}{5.3 \cdot 10^{-6} \cdot 60} = 0.2 \cdot 10^{-6}\ \mathrm{g/(m^2 \cdot s)}$$

So $g = 60 \cdot 24 \cdot 3600 \cdot (6.2 \cdot 10^{-6} \cdot 0.2 \cdot 10^{-6}) = 31.1\ \mathrm{g/m^2}$ for a period of 60 days

Overpressure at the ceiling

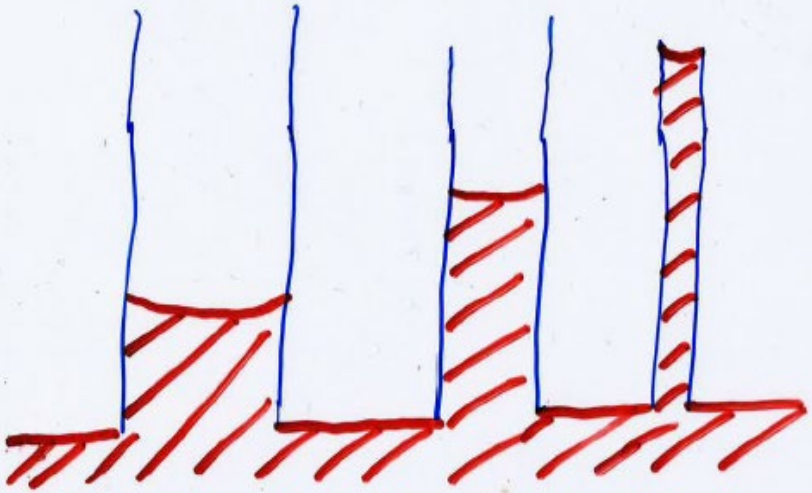


Suppress inside



- Large amounts of moisture can be quickly transported through small leaks due to convection. Good airtightness reduces the risk of moisture damage due to convection
- Joints and connections must be completely airtight. Large volumes of air flow even through small holes
- If you cannot make the structure airtight, you must ensure a negative pressure indoors

Kapillärsugning



Material med **fina porer** har stor sugkraft och stor sughöjd men liten sughastighet.

För material med **stora porer** gäller motsatsen.

Vid tillräckligt storporigt material uteblir stighöjden helt, ett s.k kapillärbrytande material.

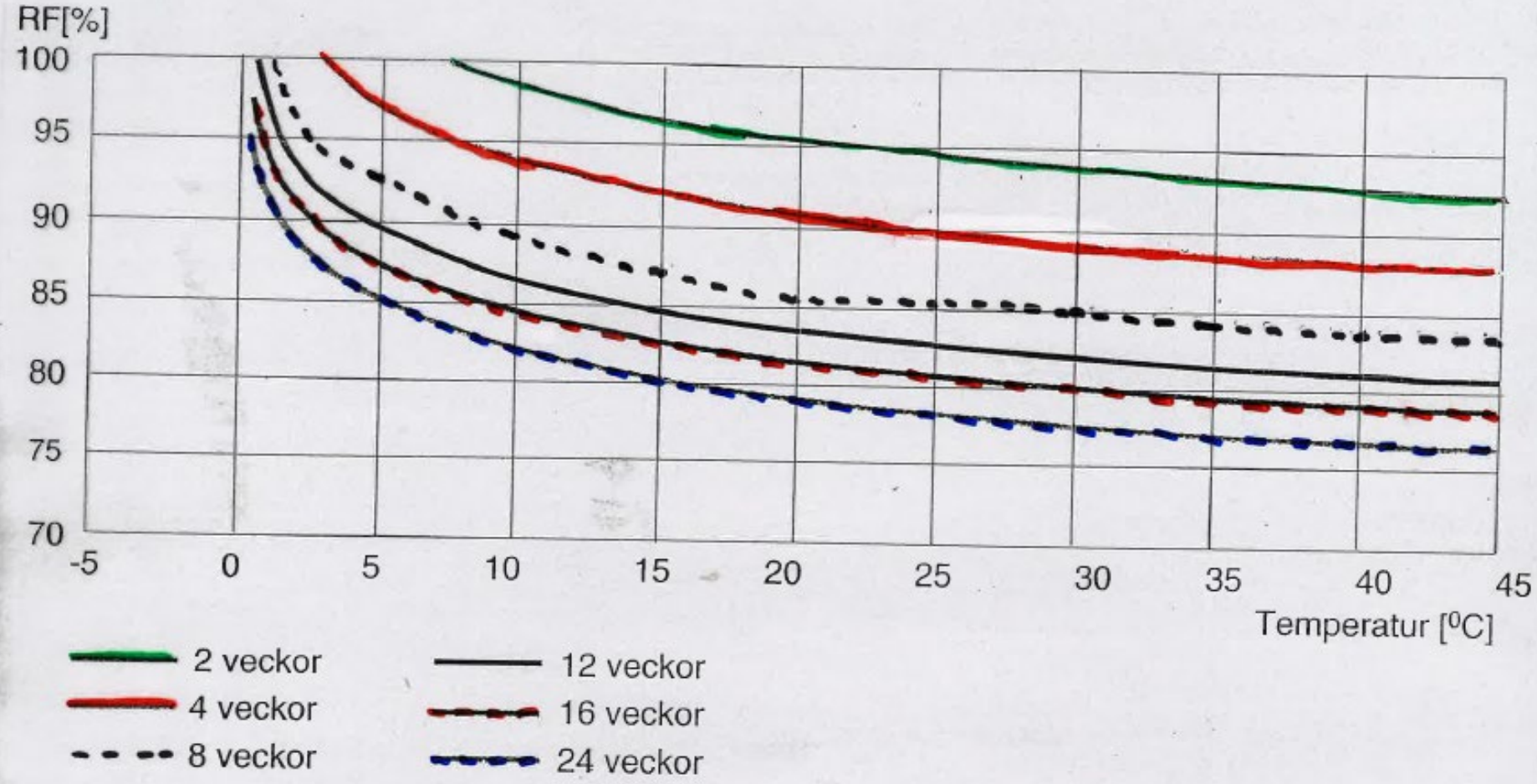
- Capillary suction is a problem in fine-porous materials in contact with moisture.

- Capillary-breaking materials in foundation structures

- Diffusion - vapour barrier (plastic film)
- Capillary suction - capillary-breaking material
- Convection - airtight construction

Kritiskt fukttillstånd, RÅ:

• Smutsade material	75-80 %
• Trä och träbaserade material	75-80 %
• Gipsskivor med papp	80-85 %
• Mineralullsisolering	90-95 %
• Cellplastisolering (EPS)	90-95 %
• Betong	90-95 %
• Limmade plastmattor; alkalisk förtvålning	85-90 %



Figur 16: Erforderlig tid innan mögelpåväxt börjar på gran och furu vid olika fukt- och temperaturtillstånd. (Viitanen, 1996)