Moisture Course

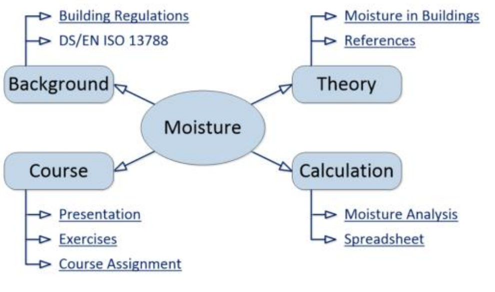
- Introduction/Theory
- Exercises and calculations using an application
- Assignment

Course aim

- Aim:
  - To show some knowledge about basic moisture theory, moisture transport mechanisms and the understanding of the water vapour diagram.
  - To be able to perform a qualified moisture analysis of a building component using a steady state diffusion model. Graphical analysis as well as computer calculations.

http://sva.ict-engineering.dk/Course/Moisture/

Moisture Course



http://sva.ict-engineering.dk/Course/Moisture/

1. Introduction questions

1. If you want to lower the moisture content in a room is it most effective to open the windows…
   - A) On a cold rainy day
   - B) On a hot summer day
2. A cold water pipe in a room condenses what can be done to avoid this?
   - A) Turn down the heat in the room and keep windows closed
   - B) Turn up the heat in the room and open the windows
3. A concrete wall with cavity insulation accumulates moisture in the insulation layer - what can be done?
   - A) Increase the insulation layer (more insulation)
   - B) Increase the concrete layer (more concrete)

Building Regulation

- Buildings has to be secured against damaging moisture accumulation as a result of
  - moisture transport from the internal air
  - moisture absorbed from the external ground
- Condensation in building components and on their surfaces may course
  - Mould growth
  - Damaging of materials
  - Reduced insulation ability

BR: Climate control measures

- Wet moisture-sensitive materials as well as materials and building elements which are affected by mould are not incorporated during the construction period
  - Materials and solutions which is unduly moisture-sensitive has to be avoided
  - Explicitly allocating time for all necessary drying out of building materials and structures
  - Facilities for storage of materials
    - providing shared facilities for storage of moisture-sensitive materials
  - Cost-benefit analysis of the benefits of fully enclosing the building during construction

Mould growth – surface humidity

- Building structures and materials may not have a moisture content which is liable to increase the risk of mould growth on moving in
  - 80% RH on the surface – DS/EN ISO 13788
  - 75% RH on the surface – SBi Guidelines 216

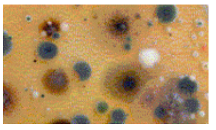
Moisture Strategy Plan

- Disposition phase
  - Construction principles and building method
- Projecting phase
  - Moisture criteria, demands for documentation and quality safety
- Constructing phase
  - Moisture measurements, principles for drying out, documentation
- Maintenance phase
  - Control measurements

Dust mites

- Best survival and reproduction terms is 17-32 °C and 55-75% RH
- Loves to eat human skin – in your bed!
- Could course dust mite allergy

Mould growth



- Grow on dead organic material
- Love surfaces with RH > 80%
- Allergic reactions
  - can develop asthma
- Reasons for mould growth:
  - Old water leeks
  - New houses with poor vent
  - Constructing with wet materials

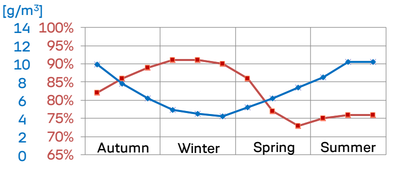
Relative humidity in the air

- Relative humidity RH [%]

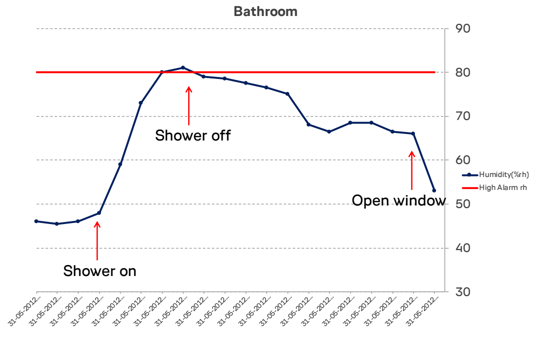
- The relative humidity is defined as the ratio between the absolute humidity in the air and absolute humidity in the air at the same temperature if it was saturated

External absolute and relative humidity

- Relative humidity varies over the year
  - Summer average: RH 75% Absolute humidity approx. 10 g/m³
  - Winter average : RH 90% Absolute humidity approx. 5 g/m³

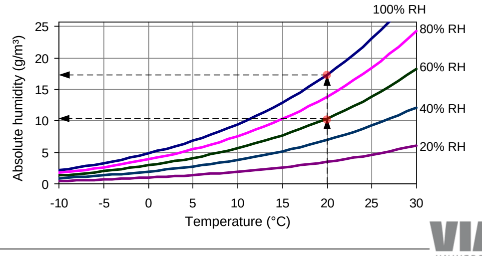


Humidity during a shower



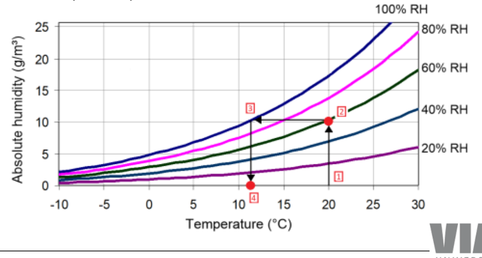
Absolute humidity

- Absolute humidity depends on the temperature and the RH
  - high temperature ⇔ high water vapour content (absolute humidity)
  - high RH ⇔ high water vapour content (absolute humidity)



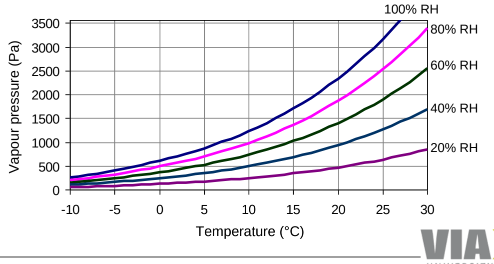
Dew point

- Dew point (temperature)
  1. Internal temperature
  2. Internal state (temperature, RH)
  3. Cooling until dew point
  4. Dew point temperature



Vapour pressure

- One-to-one conversion between absolute humidity and vapour pressure

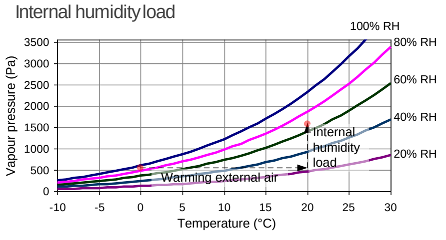


2. Water vapour diagram: 5 questions

1. How much water can be contained in air at 14 °C
2. In a normal residential building with relative humidity of 50% and room temperature 20 °C, what is the dew point temperature?
3. A soft drink is taken from the refrigerator at 5 °C. The bottle is damp (just forming condensation). The room temperature is 18 °C, what is the relative humidity in the room?
4. An uninsulated cold water pipe with temperature 8 °C is in a room with a relative humidity of 45% If the pipe condenses what is the room temperature?
5. The room temperature is decreased to 15 °C, still with a relative humidity of 45% and the pipe condenses. What is the pipe temperature?

Internal relative humidity

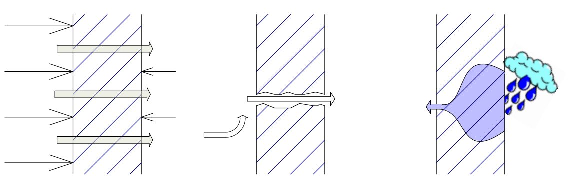
- Internal RH depends on
  - External state (temperature and RH)
  - Internal temperature
  - Internal humidity load



Humidity classes

Humidity class	Building
1	Storage areas
2	Office, shops
3	Industry with low humidity load Dwellings with low occupancy
4	Dwellings with high occupancy School and institutions Sport halls Kitchens, canteens
5	Swimming pool Damp industry Bathing and dressing room

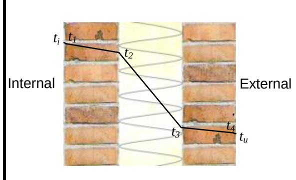
Moisture transport mechanisms

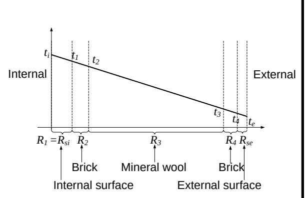


Diffusion: http://www.indiana.edu/~phys215/lecture/lecnotes/lecgraphics/diffusion2.gif

Temperature through a building component

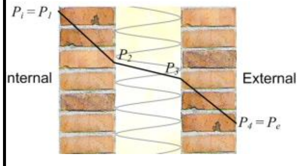
- Linearly for each homogeneous layer
- Linearly if x-axis is thermal resistances



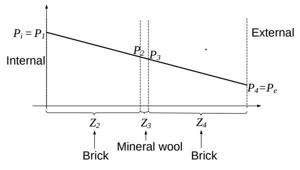


Vapour pressure through a building component

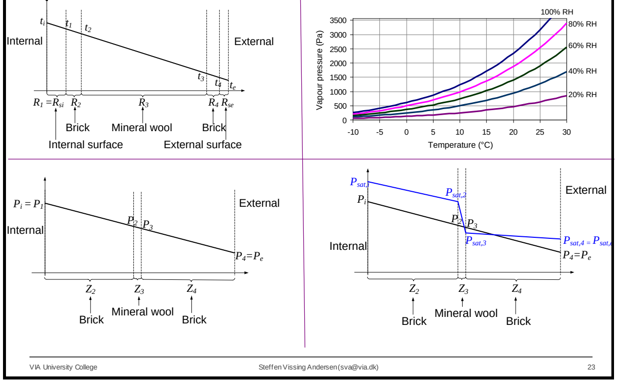
- Linearly for each homogeneous layer



- Linearly if x-axis is vapour resistances (Z-values)

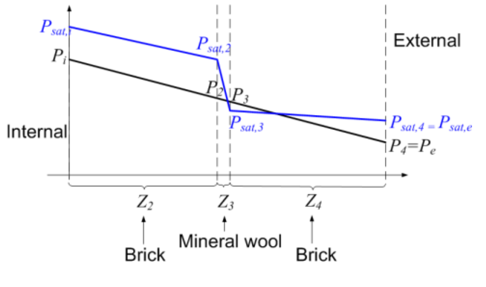


Graphical determination of dew point



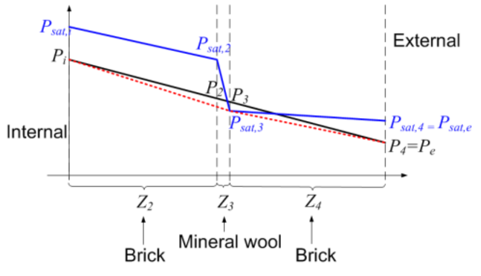
Graphical determination of condensation

- Intersection between vapour pressure curve and saturation vapour pressure curve

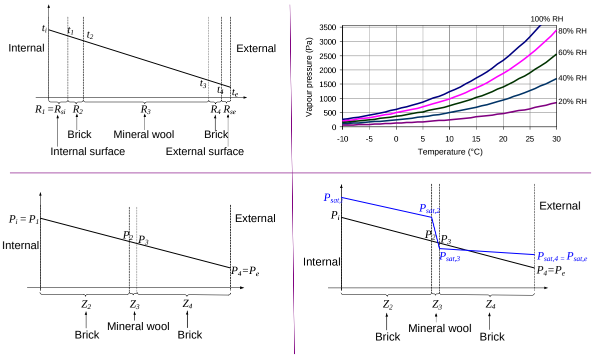


Graphical determination of condensation

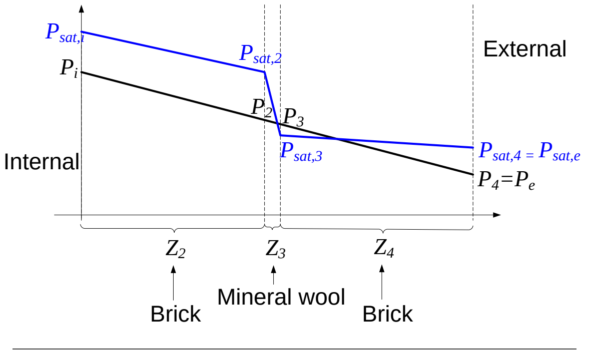
- Vapour pressure has to be modified



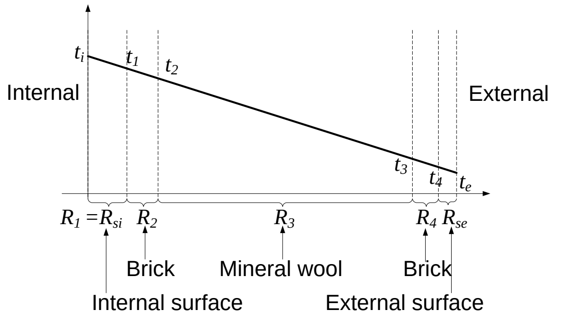
Graphical determination of dew point



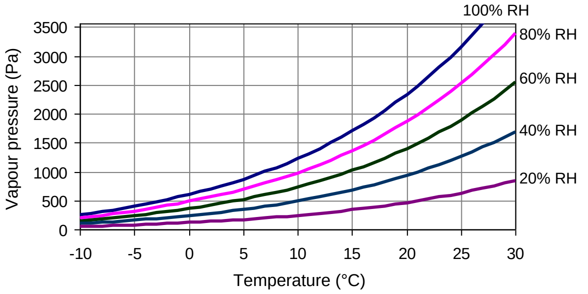
Graphical determination of dew point



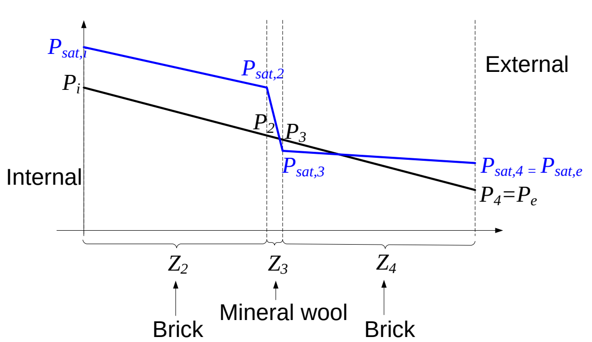
Graphical determination of dew point



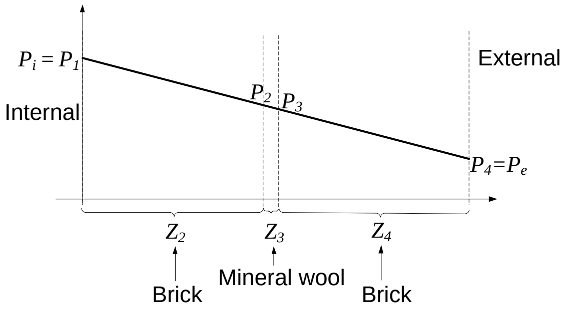
Graphical determination of dew point



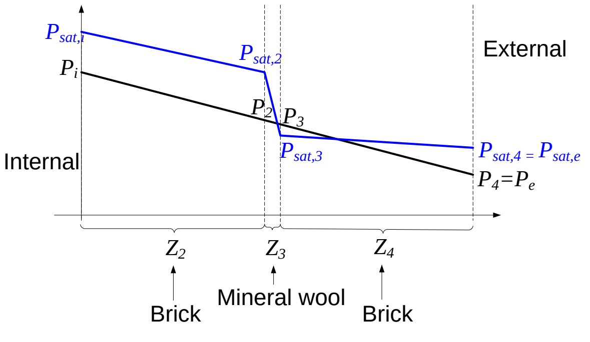
Graphical determination of dew point



Graphical determination of dew point

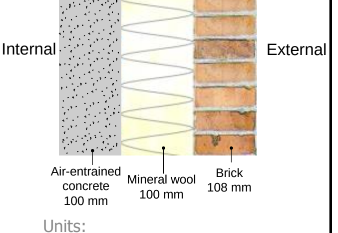


Graphical determination of dew point



Example: External wall

Internal surface, Rsi = 0,25
Air-entrained concrete (100 mm):
R = 0,45 (λ = 0,22)
Z = 4,76 (d = 0,021)
Mineral wool (100 mm):
R = 2,56 (λ = 0,039)
Z = 0,53 (d = 0,19)
Brick (108 mm):
R = 0,14 (λ = 0,78)
Z = 5,40 (d = 0,020)
External surface, Rse = 0,04
Internal condition:
20 °C, 60% RF
External condition:
0 °C, 90% RF



Units:
λ: W/(mK), R: m²K/W
d: kg/(GPa·m·s), Z: GPa·m²·s/kg

Example: External wall (Thermal resistances)

Internal surface, Rsi = 0,25
Air-entrained concrete (100 mm):
R = 0,45 (λ = 0,22)
Z = 4,76 (d = 0,021)
Mineral wool (100 mm):
R = 2,56 (λ = 0,039)
Z = 0,53 (d = 0,19)
Brick (108 mm):
R = 0,14 (λ = 0,78)
Z = 5,40 (d = 0,020)
External surface, Rse = 0,04
Internal condition:
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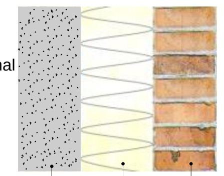
External condition:
0 °C, 90% RF



Units:
λ: W/(mK), R: m²K/W
d: kg/(GPa·m·s), Z: GPa·m²·s/kg

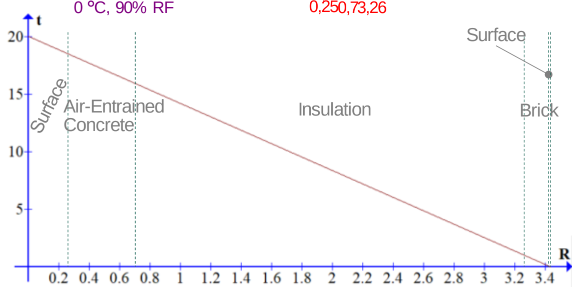
$\sum R = 0{,}25 + 0{,}45 + 2{,}56 + 0{,}14 + 0{,}04 = 3{,}44$

Example: External wall (Temperature curve)

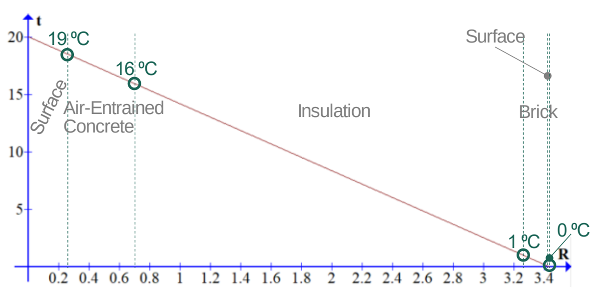
Internal condition:
20 °C, 60% RF
External condition:
0 °C, 90% RF

$\sum R = 0{,}25 + 0{,}45 + 2{,}56 + 0{,}14 + 0{,}04 = 3{,}44$

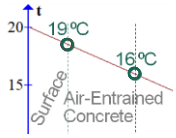
0,25 0,7 3,26



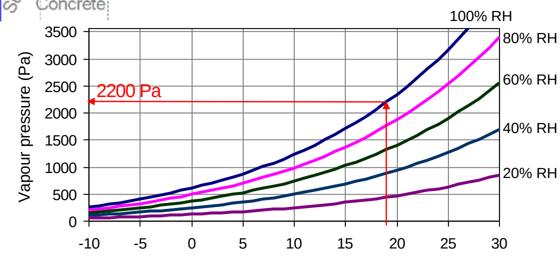
Example: External wall (Temperature curve)



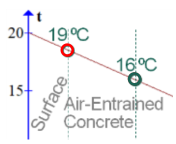
Example: External wall (Max vapour pressure)



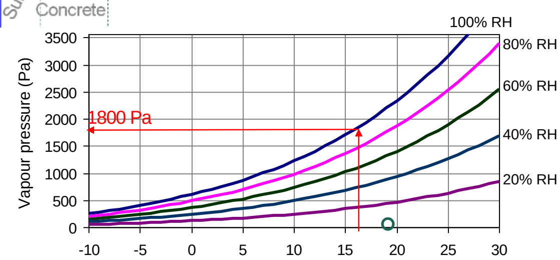
(Temperature, Vapour pressure)
Surface/A-E Concrete: (19, 2200)



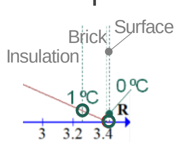
Example: External wall (Max vapour pressure)



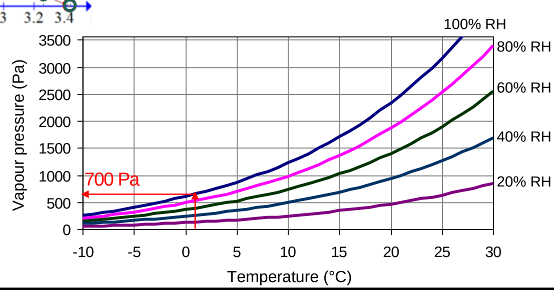
(Temperature, Vapour pressure)
Surface/A-E Concrete: (19, 2200)
A-E Concrete/Insulation: (16, 1800)



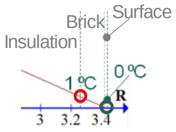
Example: External wall (Max vapour pressure)



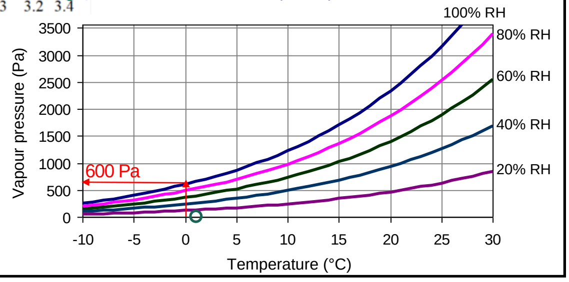
(Temperature, Vapour pressure)
Surface/A-E Concrete: (19, 2200)
A-E Concrete/Insulation: (16, 1800)
Insulation/Brick: (1, 700)



Example: External wall (Max vapour pressure)



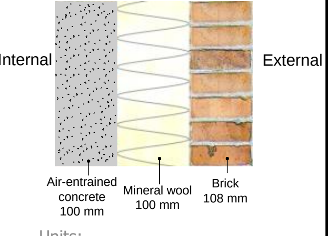
(Temperature, Vapour pressure)
Surface/A-E Concrete: (19, 2200)
A-E Concrete/Insulation: (16, 1800)
Insulation/Brick: (1, 700)
Brick/Surface: (0, 600)



Example: External wall (Vapour resistances)

Internal surface, Rsi = 0,25
Air-entrained concrete (100 mm):
R = 0,45 (λ = 0,22)
Z = 4,76 (d = 0,021)
Mineral wool (100 mm):
R = 2,56 (λ = 0,039)
Z = 0,53 (d = 0,19)
Brick (108 mm):
R = 0,14 (λ = 0,78)
Z = 5,40 (d = 0,020)
External surface, Rse = 0,04

Internal condition:
20 ºC, 60% RF
External condition:
0 ºC, 90% RF



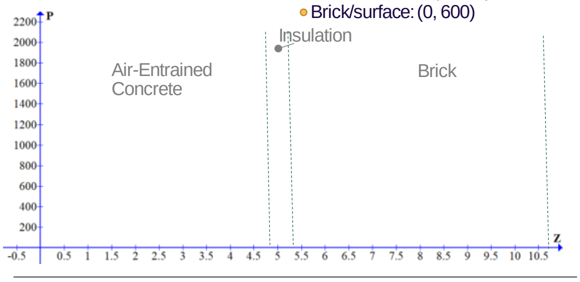
Units:
λ: W/(mK), R: m²K/W
d: kg/(GPa·m·s), Z: GPa·m²·s/kg

∑Z = 4,76 + 0,53 +5,40 = 10,69

External wall (Saturated vapour pressure)

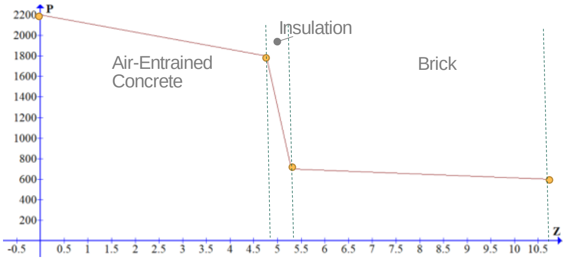
∑Z = 4,76 + 0,53 +5,40 = 10,69
4,76 ; 5,29

(Temperature, Vapour pressure)
- Surface/A-E Concrete: (19, 2200)
- A-E Concrete/Insulation: (16, 1800)
- Insulation/Brick: (1, 700)
- Brick/surface: (0, 600)



External wall (Saturated vapour pressure)

$\sum Z = 4{,}76 + 0{,}53 + 5{,}40 = 10{,}69$



Example: External wall (Conditions)

Internal surface, Rsi = 0,25

Air-entrained concrete (100 mm):

R = 0,45 (λ = 0,22)

Z = 4,76 (d = 0,021)

Mineral wool (100 mm):

R = 2,56 (λ = 0,039)

Z = 0,53 (d = 0,19)

Brick (108 mm):

R = 0,14 (λ = 0,78)

Z = 5,40 (d = 0,020)

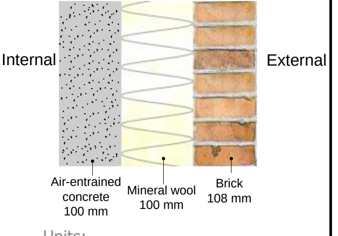
External surface, Rse = 0,04

Internal condition:

20 °C, 60% RF

External condition:

0 °C, 90% RF



Units:

λ: W/(mK), R: m²K/W

d: kg/(GPa·m·s), Z: GPa·m²·s/kg

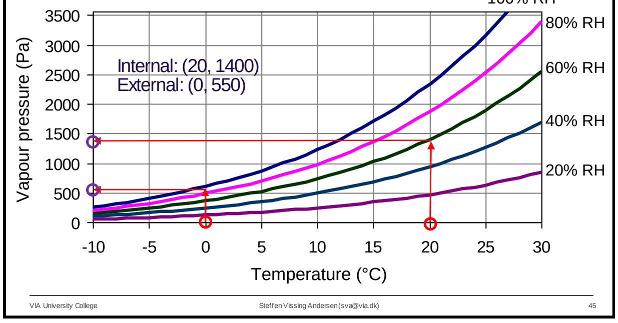
Example: External wall (Conditions)

External condition:

0 °C, 90% RF

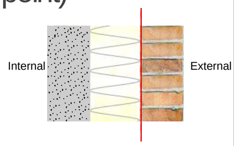
Internal condition:

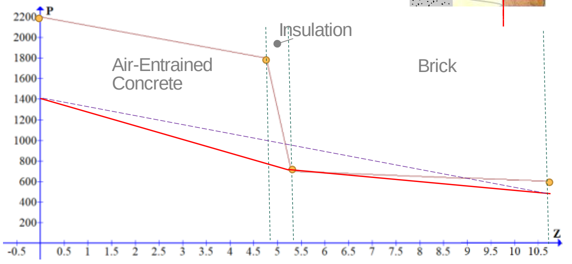
20 °C, 60% RF



Example: External wall (Dew point)

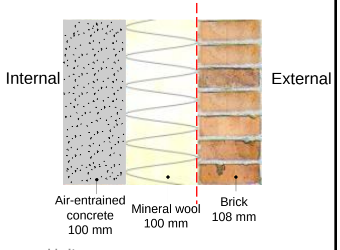
- Internal: (20, 1400)
- External: (0, 550)





Example: External wall (Dew point)

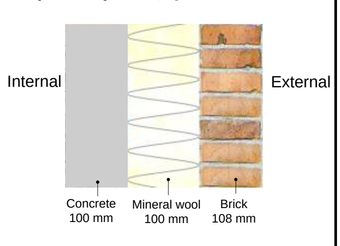
Internal surface, Rsi = 0,25
Air-entrained concrete (100 mm):
R = 0,45 (λ = 0,22)
Z = 4,76 (d = 0,021)
Mineral wool (100 mm):
R = 2,56 (λ = 0,039)
Z = 0,53 (d = 0,19)
Brick (108 mm):
R = 0,14 (λ = 0,78)
Z = 5,40 (d = 0,020)
External surface, Rse = 0,04
Internal condition:
20 °C, 60% RF
External condition:
0 °C, 90% RF



Units:
λ: W/(mK), R: m²K/W
d: kg/(GPa·m·s), Z: GPa·m²·s/kg

Exercise: External wall (Dew point?)

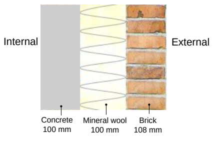
Internal surface, Rsi = 0,25
Concrete (100 mm):
R = 0,1 (λ = 1,0)
Z = 12,5 (d = 0,008)
Mineral wool (100 mm):
R = 2,56 (λ = 0,039)
Z = 0,53 (d = 0,19)
Brick (108 mm):
R = 0,14 (λ = 0,78)
Z = 5,40 (d = 0,020)
External surface, Rse = 0,04
Internal condition:
20 °C, 60% RF
External condition:
0 °C, 90% RF

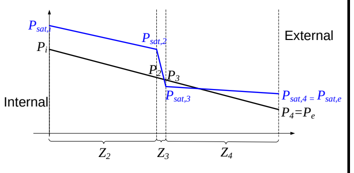


Units:
λ: W/(mK), R: m²K/W
d: kg/(GPa·m·s), Z: GPa·m²·s/kg

4. Graphical dew point identification

- Describe by example, sketches and explanations how a graphical determination of condensation can be performed





How to perform a moisture analysis?

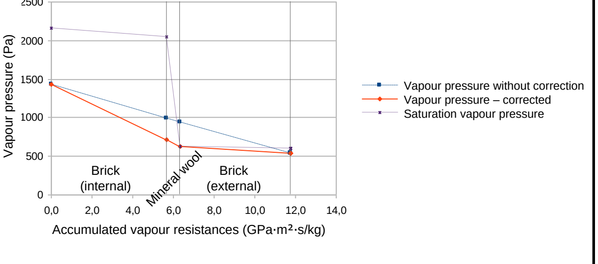
DS/EN ISO 13788

a) 12 consecutive calculations (with monthly average for temperature and RH)
   - Exterior data as monthly average for temperature and RH
   - Start month as the first month with accumulated moisture
   - Following months with a constraint that RH = 100% in the dew point area from previous calculation/month
   - Negative accumulation represents evaporation

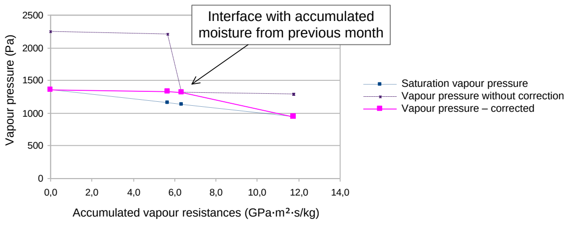
b) Additionally, check for RH on internal surfaces < 80% (< 75%)

Use "Moisture Analysis" http://sva.ict-engineering.dk/MoistureAnalysis/

Vapour pressure through a building component

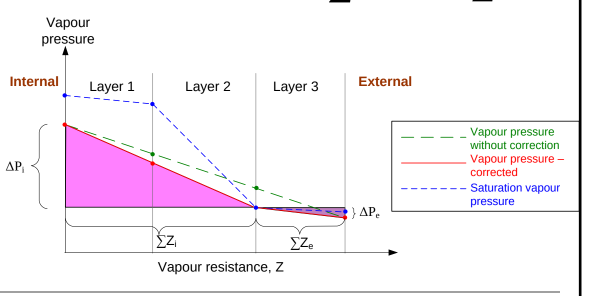


Evaporation

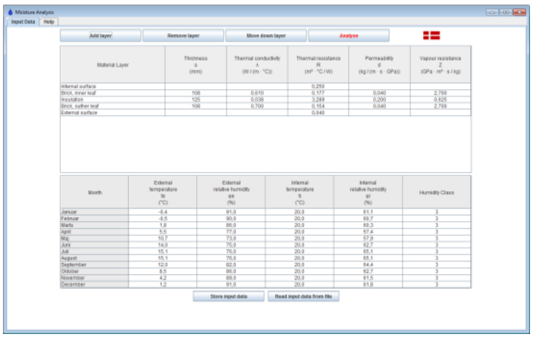


Moisture accumulation

$$c_{accumulated} = c_{in} - c_{out} \qquad c_{in} = \frac{\Delta P_i}{\sum Z_i} \qquad c_{out} = \frac{\Delta P_e}{\sum Z_e}$$



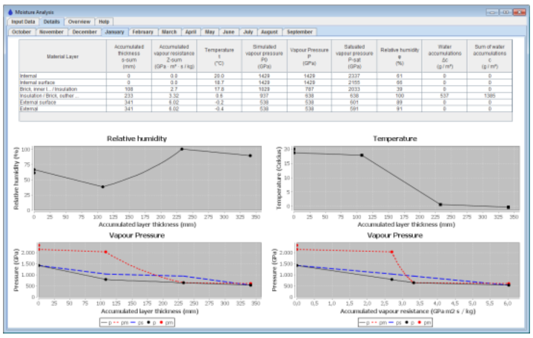
Moisture Analysis – Input



Material Layer	Thickness s (mm)	Thermal conductivity λ (W / (m · °C))	Thermal resistance R (m² · °C / W)	Permeability d (kg / (m · s · GPa))	Vapour resistance Z (GPa · m² · s / kg)
Internal surface			0,250		
Brick, inner leaf	108	0,610	0,177	0,040	2,700
Insulation	125	0,038	3,289	0,200	0,625
Brick, outher leaf	108	0,700	0,154	0,040	2,700
External surface			0,040		

Month	External temperature te (°C)	External relative humidity φe (%)	Internal temperature ti (°C)	Internal relative humidity φi (%)	Humidity Class
Januar	-0,4	91,0	20,0	61,1	3
Februar	-0,5	90,0	20,0	60,7	3
Marts	1,8	86,0	20,0	60,3	3
April	5,5	77,0	20,0	57,4	3
Maj	10,7	73,0	20,0	57,9	3
Juni	14,0	75,0	20,0	62,7	3
Juli	15,1	76,0	20,0	65,1	3
August	15,1	76,0	20,0	65,1	3
September	12,0	82,0	20,0	64,4	3
Oktober	8,5	86,0	20,0	62,7	3
November	4,2	89,0	20,0	61,5	3
December	1,2	91,0	20,0	61,8	3

Moisture Analysis – Details



Moisture Analysis – Overview