Moisture induced stresses
Discussion, part II

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Business from technology

Moisture induced mechanical effects: Classes 1, 2, 3, 4

Classification

1. Restrained shrinkage - joint design and detailing (Perp to grain)
2. Fast drying (Perp to grain)
3. Long wetting (Perp to grain)
4. Load in the Grain direction

⇒Proper detailing, dry wood

⇒Moisture stresses cause cracks on surface

⇒ Moisture stresses cause cracks on centre

⇒ Creep, Creep rupture = reduced long term strength

1. Restrained shrinkage is a problem in joint design and detailing

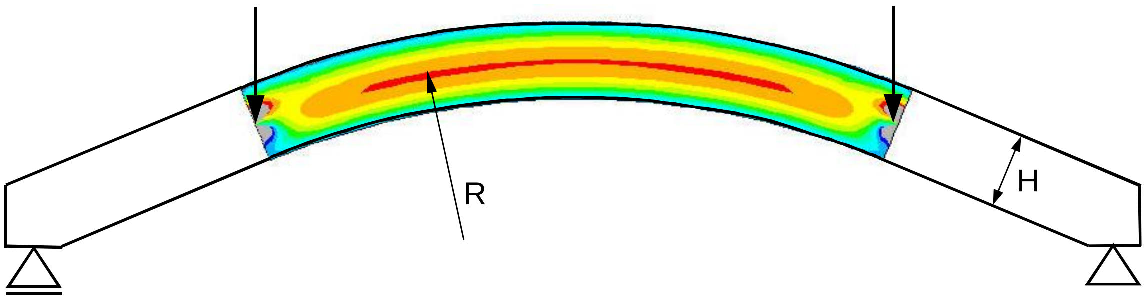
Figure 115-1. Arched column with steel parts (in white).

Figure 115-2. Crack at column fitting to the steel part.

2. Fast drying is a problem in areas

Fig. 9. Longitudinal through crack in glulam roof girder due to shrinkage effects. Hot water piping in the vicinity of the girder contributed to fast drying. Source: Ref. [7].

3. Long wetting is a problem where wood is under tension perp load (tapered beams)



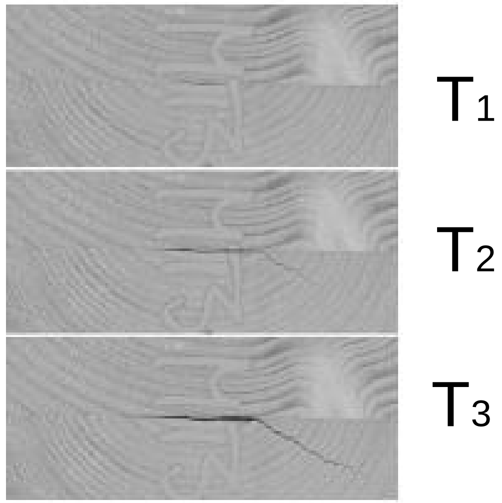


Fig. 8. Crack propagation in gradient specimens, RH 40 to 80%, tested at day 5

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Conclusions from previous research

- **Moisture induced stresses is primary reason of failure**
- **Number of cycles or duration of load not important**
- **Stress analysis shows similar stress fields in successive cycles**

4. Load in the Grain direction, continuous humidity cycles more important than single moisture changes.

- **Strength is reduced in high humidities and still more reduced in cyclic humidities, duration of load is important**

How to deal with moisture stresses

Moisture induced mechanical effects Classes 1, 2, 3, 4

Perpendicular stress

1. Restrained shrinkage
2. Fast drying
3. Long wetting

Longitudinal stress

4. Continuous humidity cycles important on reduction of strength

Proposal on how to treat in Codes

For cases 1,2,3,4

Specific instructions on:

a) Fixed points max spacing perp to grain,
b) Permissible wood moisture contents: initial, during building and in-service
c) Development of coatings
d) 'Trumpet' curve

For cases 2,3

Additional moisture load:

Ranta-Maunus proposed adding a moisture stress of σ_Q = 0,25 MPa for uncoated and 0,1 MPa for coated wood members.

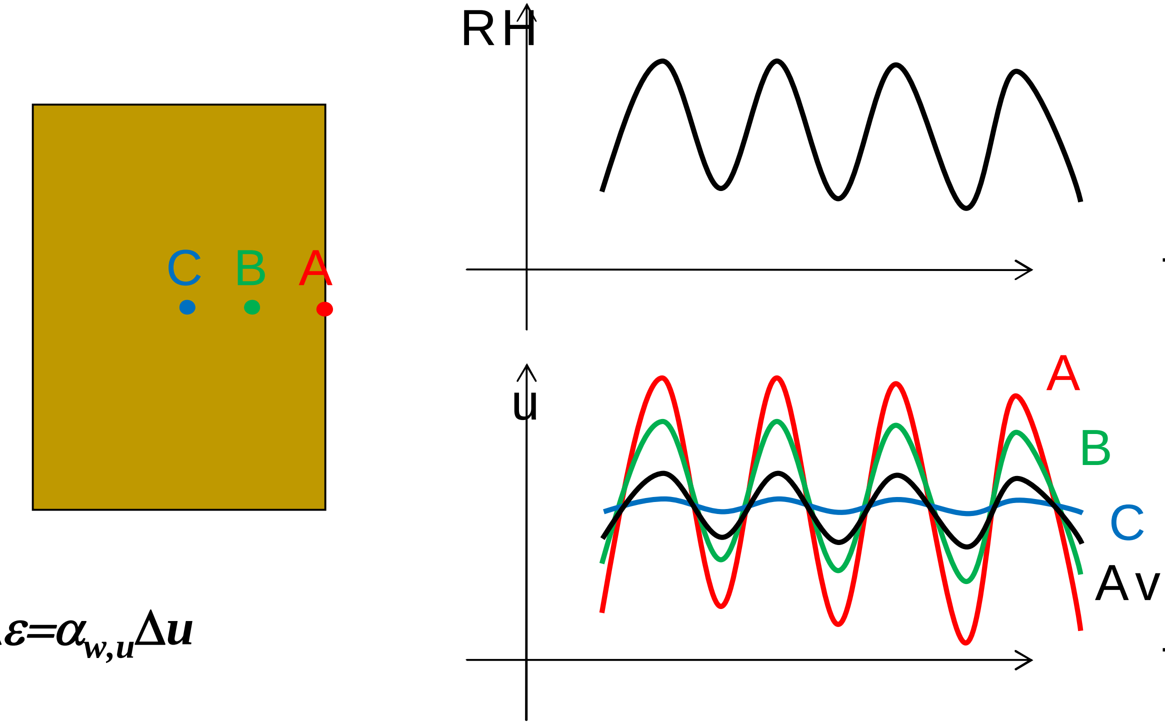
For case 4

Apply the k_{mod} factor

$$\gamma_G \sigma_G + \gamma_Q (\sigma_{Q1} + \psi \sigma_{Q2}) \leq k_{\text{mod}} \frac{f}{\gamma_M}$$

From Massimo's presentation in Zagreb 2008

EFFECT OF MOISTURE:



Environment

Timber cross-section

Average

$\Delta\varepsilon = \alpha_{w,u} \Delta u$

The different moisture content variations over the cross-section cause inelastic strains and, therefore, eigenstresses and deflections, both parallel and perpendicular to grain.

From Massimo's presentation in Zagreb 2008

LOAD EQUIVALENT TO MOISTURE AND TEMPERATURE:

A proposal for a new code of practice:

- **select a number of yearly history RH=RH(t) for:**

- different countries (e.g. Sweden, Germany, Italy)

- different member exposure (outdoor unprotected by the rain, outdoor protected, indoor unheated, indoor heated)

- **for all those cases, select a maximum yearly variation of temperature $\Delta T=T_{max}-T_{min}$**

- **select a number of cross-sections: e.g. large (160×230), medium (90×230) and small (38×225)**

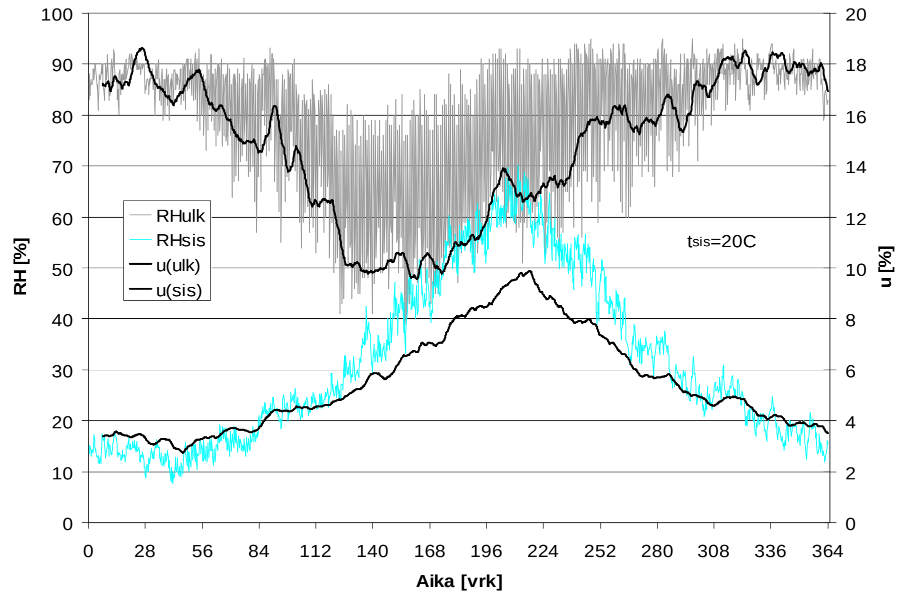
From Staffan's presentation in Zagreb 2008

From model to code

A reliable code must be founded on accurate and precise models for moisture transport, sorption and shrinkage

Ever varying climate

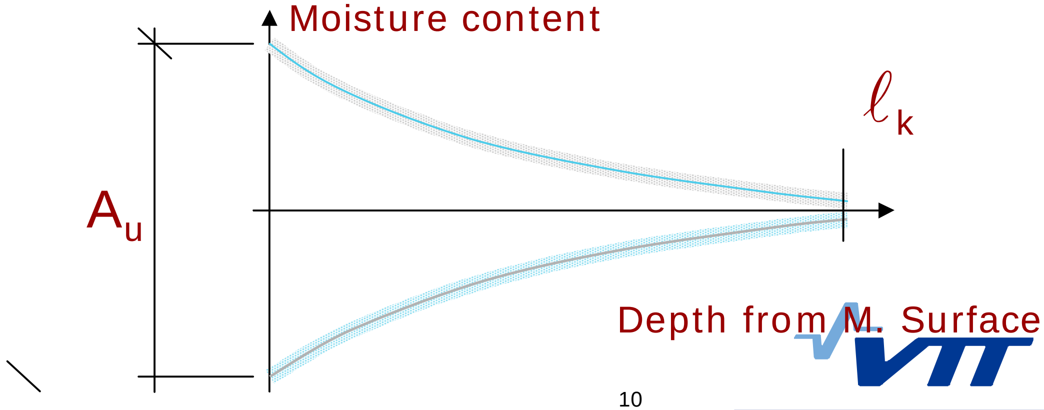
Depth and amplitude, daily annual variations



'Trumpet' curve

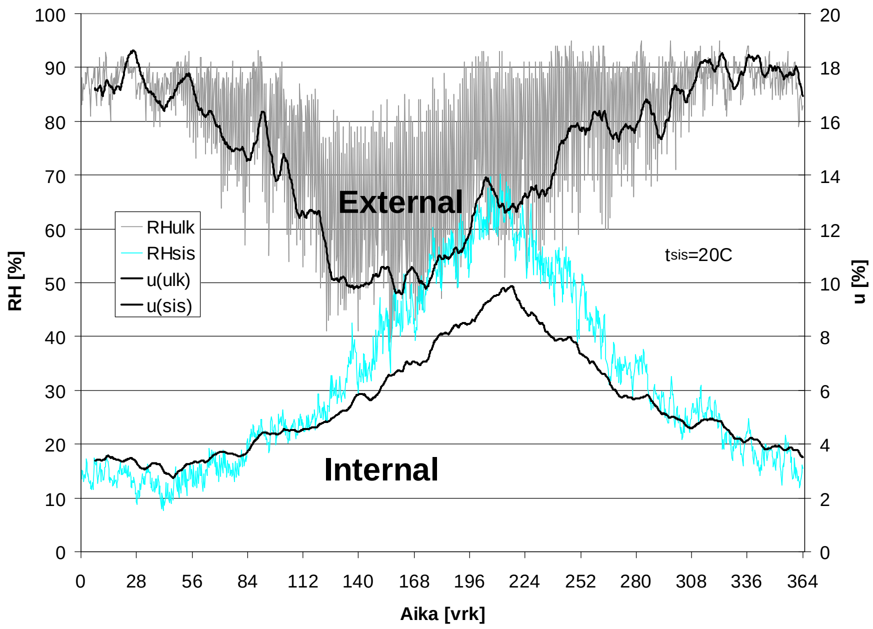
$$A_u = \Im(\overline{RH},\ A_{RH},\ f_{RH},\ T)$$

$$\ell_k = \mathcal{F}(\overline{RH},\ A_{RH},\ f_{RH},\ T)$$



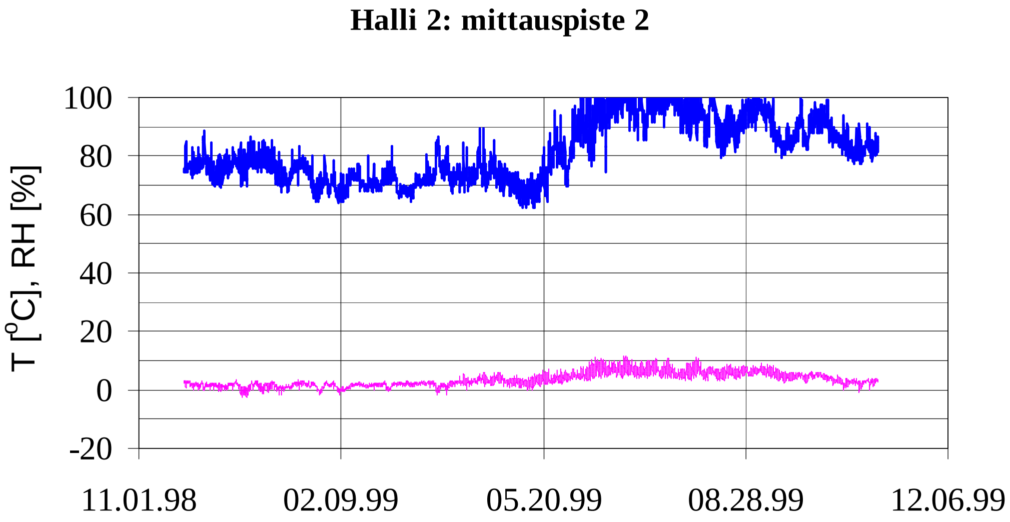
Humidity environments

Sibelius hall

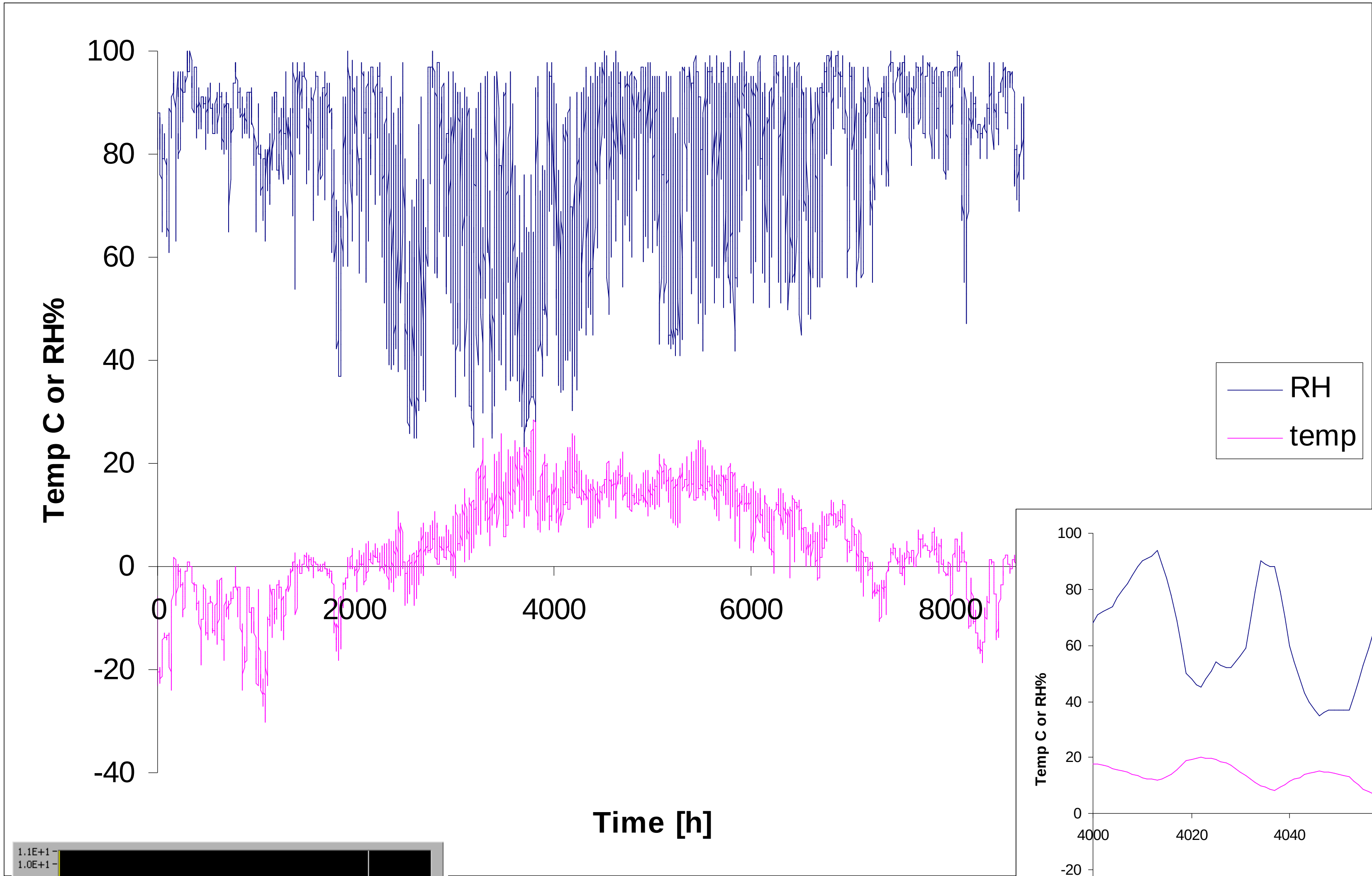


Ref: Koponen, 2002

Ice skating hall



Ref: Kevarinmäki et al., 2000


Temp C or RH%
100
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Time [h]
RH
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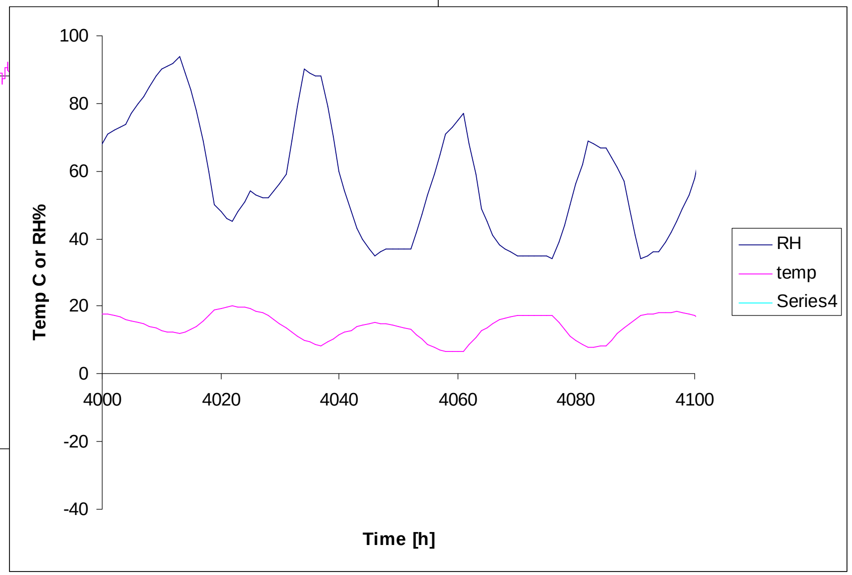
Temp C or RH%
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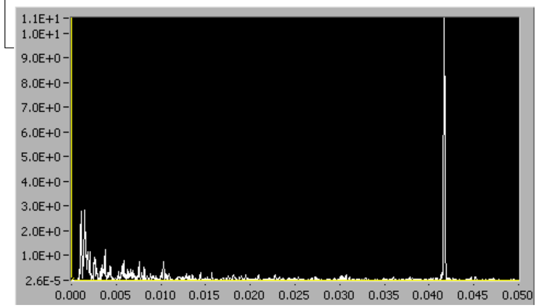

1.1E+1
1.0E+1
9.0E+0
8.0E+0
7.0E+0
6.0E+0
5.0E+0
4.0E+0
3.0E+0
2.0E+0
1.0E+0
2.6E-5
0.000
0.005
0.010
0.015
0.020
0.025
0.030
0.035
0.040
0.045
0.050

Idealised RH exposure

Yearly cycle

Outdoor sheltered

- 95 – 50 %RH Sinusoidal

Indoor heated

- Heated spaces
  15 – 60 %RH Sinusoidal
- Swim/skate/agricultural
  75 – 99 %RH Sinusoidal

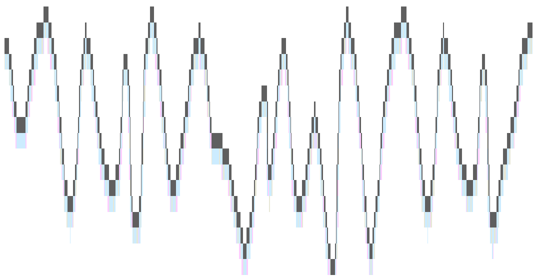
Daily cycle

Amplitude 20 %RH

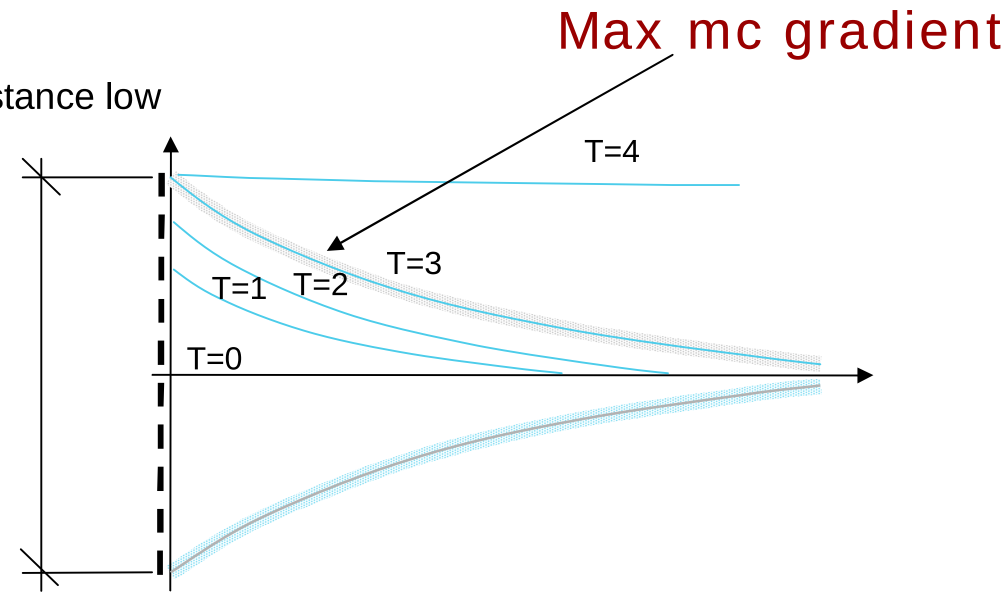
Notes:
Sinusoidal is not realistic, depends on length of summer period

‘Trumpet’ curve

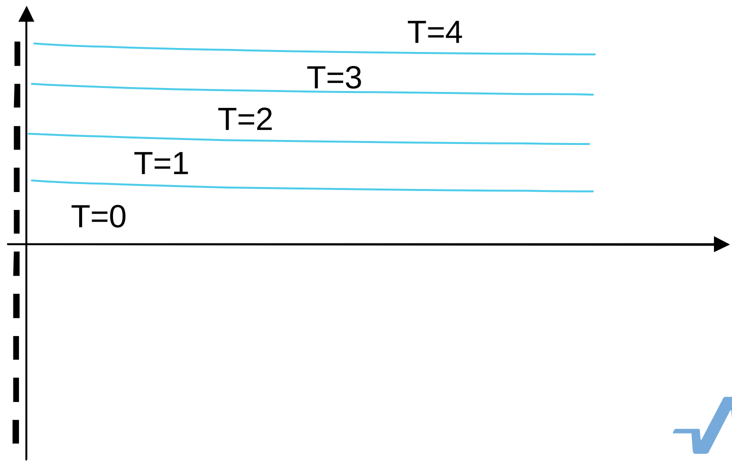
RH (amp, frequency)



Coating moisture resistance low



Coating moisture resistance high



Concluding remarks

- What RH frequency is important, can daily frequencies be neglected
- What is the critical MC gradient ?
- The stress induced by MC gradient
- What coating permeability is needed to solve the problem ?

- The moisture stress can be given as a load, but we need information on:
  - Relative humidity exposure
  - Coating moisture resistances
- A multi-Fickian and a Fickian approach could be used