Cost Action E55

Meeting in Trondheim, 26-27 March 2009

Working group 2 – Moisture induced stresses

MOISTURE INDUCED LOADS ON TIMBER AND COMPOSITE MEMBERS PARALLEL TO GRAIN

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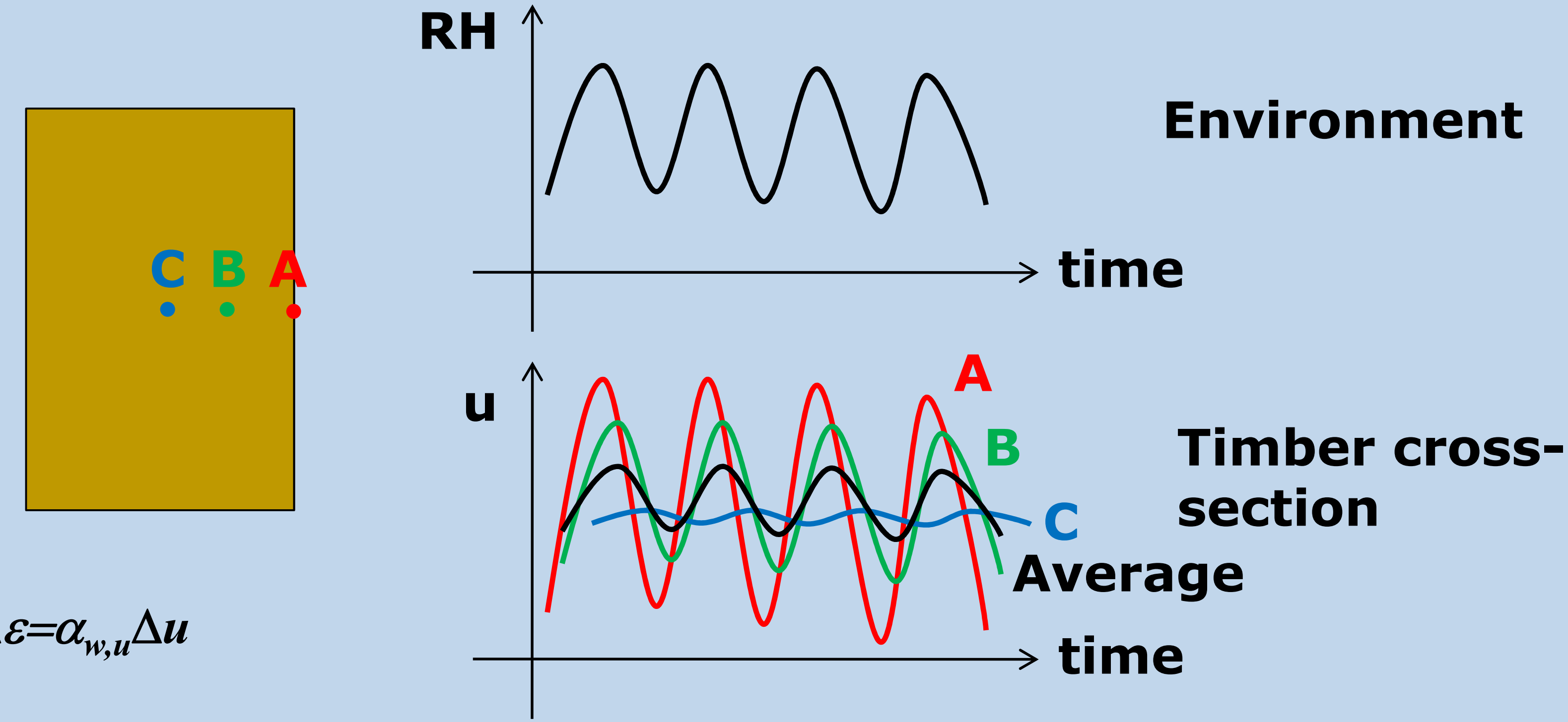
EFFECT OF MOISTURE:



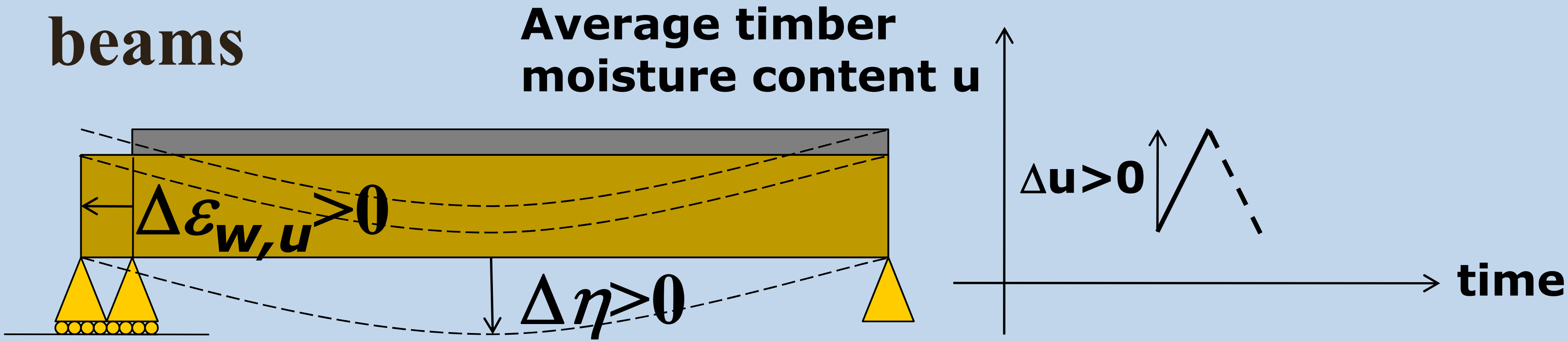
$\Delta\varepsilon = \alpha_{w,u} \Delta u$

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

EFFECT OF MOISTURE || TO GRAIN:

Statically indeterminate (composite) structures:

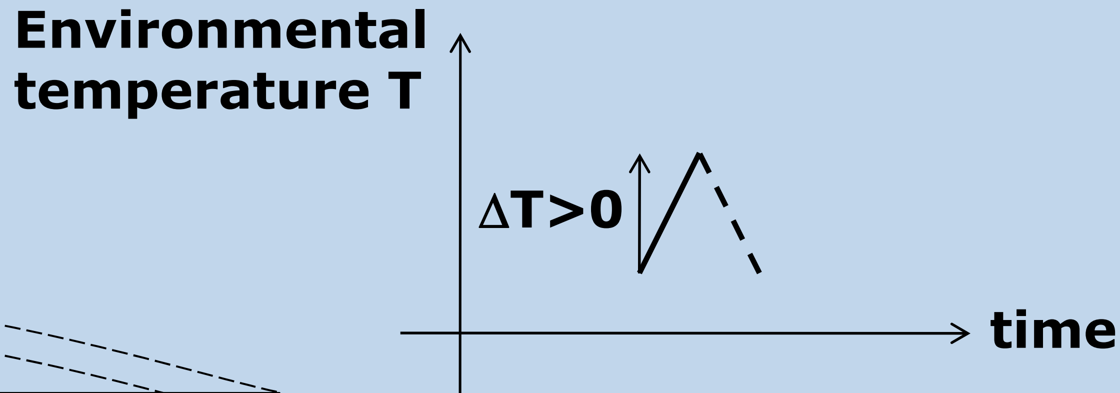
- **Moisture u and Δu increases deflection due to creep and mechano-sorption *when an external load is applied.***
- **Eigenstresses and deflections due to $\Delta\varepsilon=\alpha_{w,u}\Delta u$ *are no longer negligible,* particularly in composite beams**

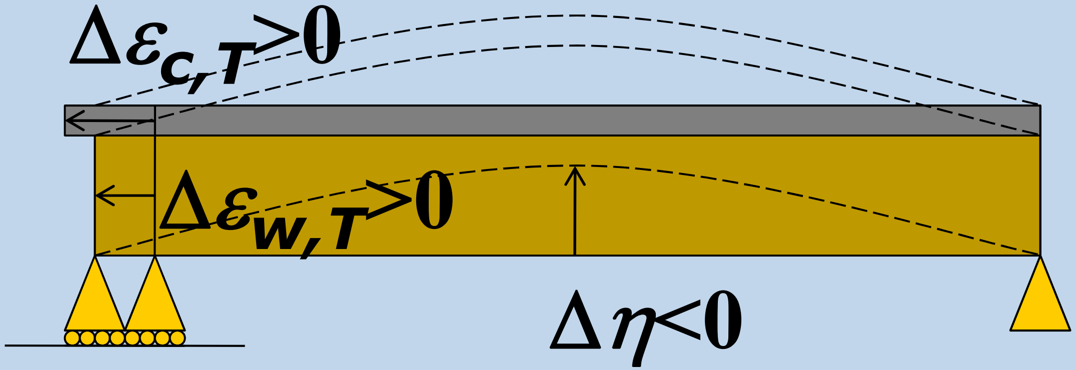


$$\Delta\varepsilon_{w,u}=\alpha_{w,u}\Delta u>0$$

EFFECT OF TEMPERATURE || TO GRAIN:

- Also temperature variations causes eigenstresses and deflections in composite beams since the thermal expansion coefficients of timber and concrete are different:





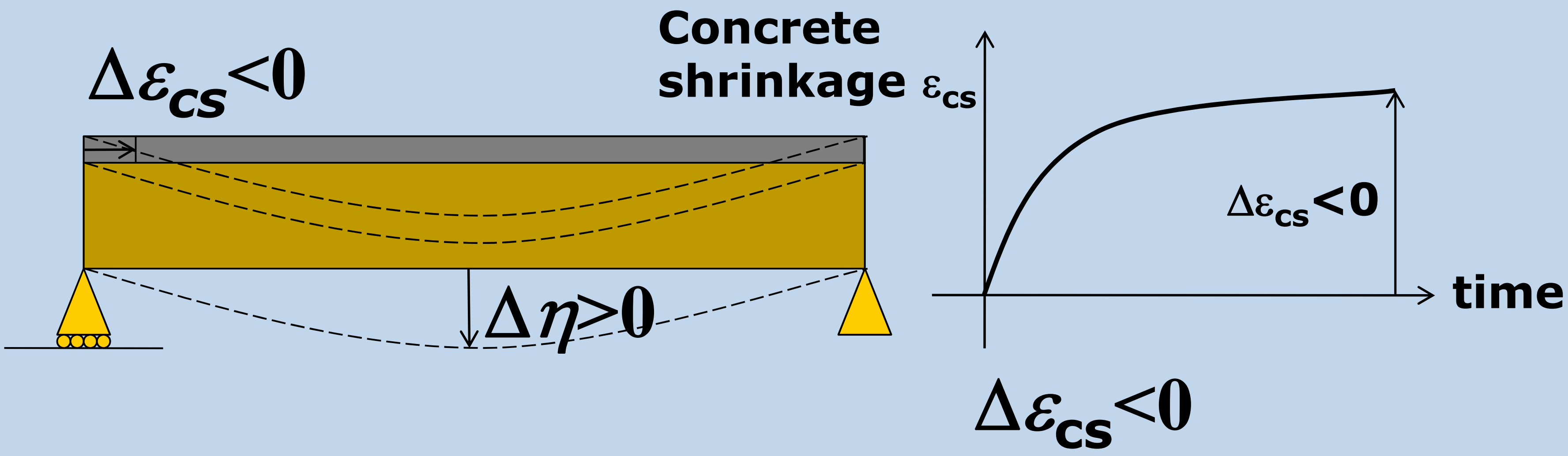
$$\Delta\varepsilon_{w,T}=\alpha_{w,T}\Delta T>0$$

$$\Delta\varepsilon_{c,T}=\alpha_{c,T}\Delta T>0$$

$$(\Delta\varepsilon_{c,T}>\Delta\varepsilon_{w,T})$$

EFFECT OF CONCRETE SHRINKAGE || GRAIN:

- **In addition, also drying shrinkage of concrete $\Delta\varepsilon_{cs}$ causes eigenstresses and deflections in composite beams:**



EFFECT OF MOISTURE || GRAIN:

- Thus *drying shrinkage of concrete, moisture and temperature variations should be considered as additional loads* ε_{cs}, Δu and ΔT in the design of statically indeterminate and composite structures:

? ? ?

$$F_U = \gamma_G G + \gamma_Q Q + \gamma_s \varepsilon_{cs} + \gamma_u \Delta u + \gamma_T \Delta T$$ **for ULS**

$$F_S = G + \psi_2 Q + \varepsilon_{cs} + \Delta u + \Delta T$$ **for SLS**

(γ_s=1 in DIN Fachbericht 104 for steel-concrete composite beams)

- **Need to provide the design values of Δu and ΔT**

CHOICE OF THE DESIGN VALUES OF Δu AND ΔT:

A proposal for **a new code of practice:**

• **select a number of yearly histories RH=RH(t) representative of different:**

- **climatic regions** (e.g. Northern Scandinavia, Southern Scandinavia, Central Europe, Alpine regions, Mediterranean regions, etc.)

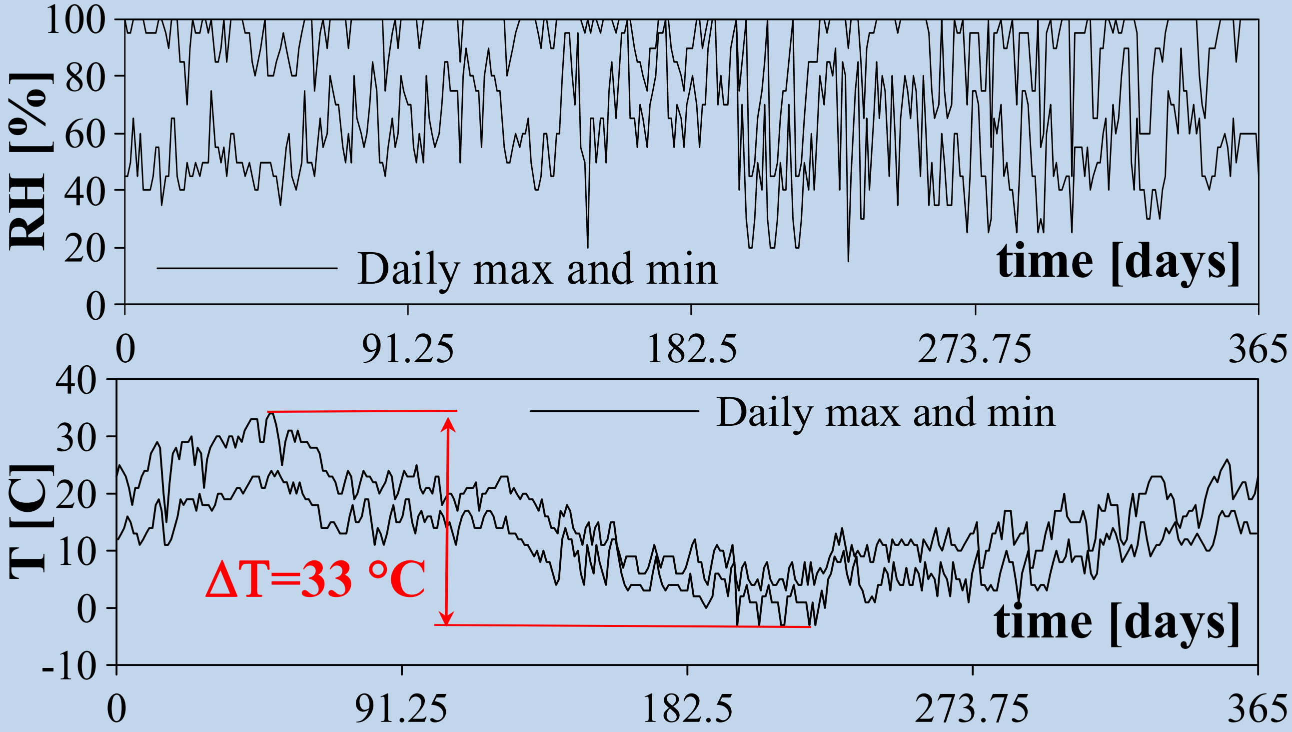
- **member exposures** (outdoor sheltered, indoor unheated, indoor heated)

(Note: this does not fully correspond with the 3 service classes of the current Eurocode 5)

CHOICE OF THE DESIGN VALUES OF Δu AND ΔT:

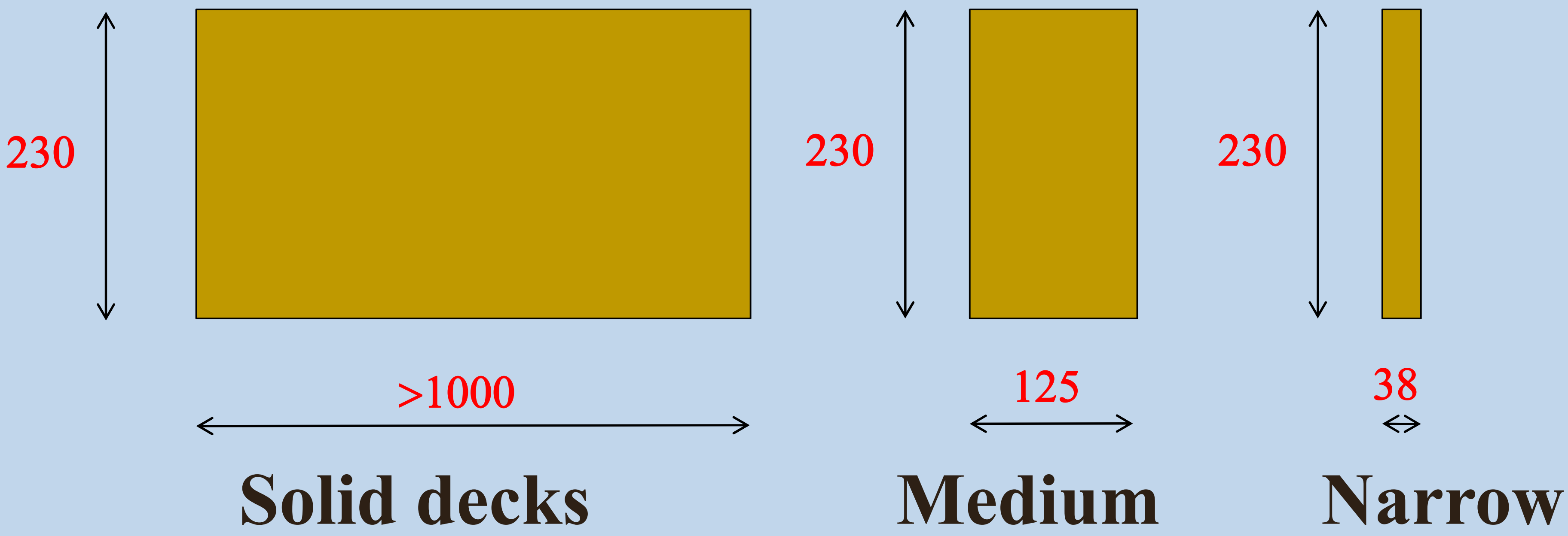
- for all those cases, **select a maximum yearly variation of temperature $\Delta T = T_{max} - T_{min}$**

For example: environmental histories in Florence



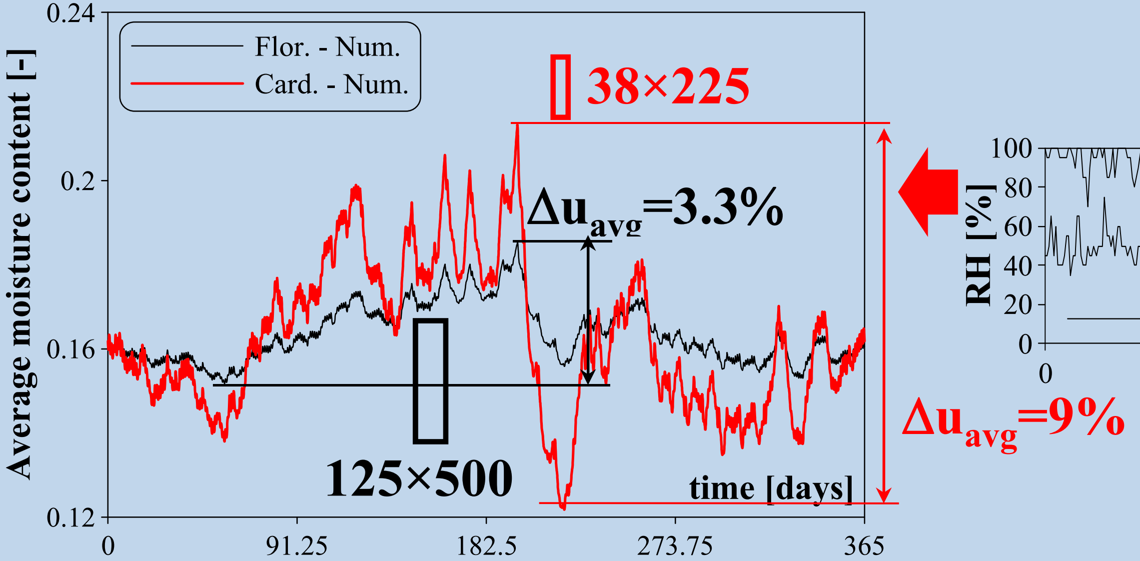
CHOICE OF THE DESIGN VALUES OF Δu AND ΔT:

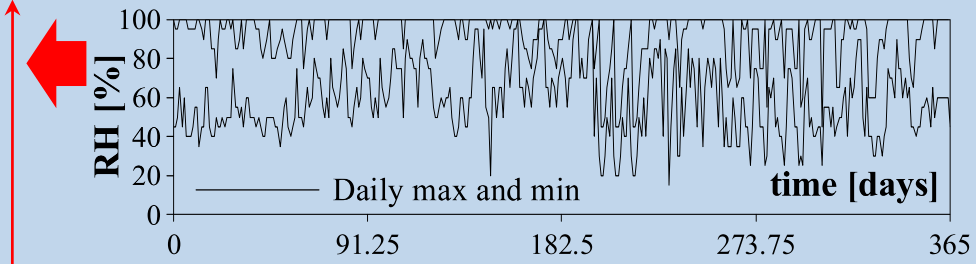
• **select a number of cross-sections characterized by different breadths:** e.g. solid (2D) decks (>1000 mm wide), medium (125×230 mm) and narrow (38×225 mm)



CHOICE OF THE DESIGN VALUES OF Δu AND ΔT:

- **calculate the history of average moisture content $u_{avg}=u_{avg}(t)$** over the section **and the max. yearly variation Δu_{avg},** by solving the diffusion problem for each cross-section and type of environment:





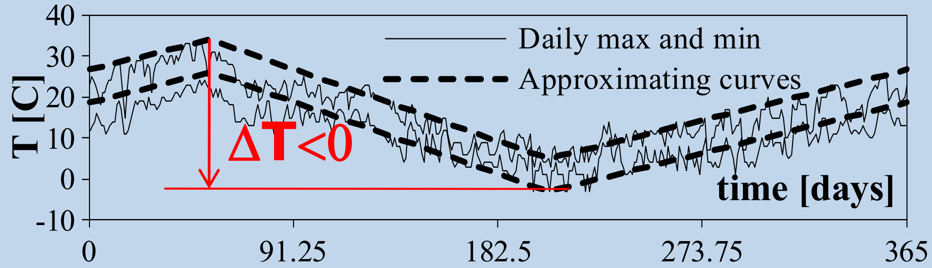
CHOICE OF THE DESIGN VALUES OF Δu AND ΔT:

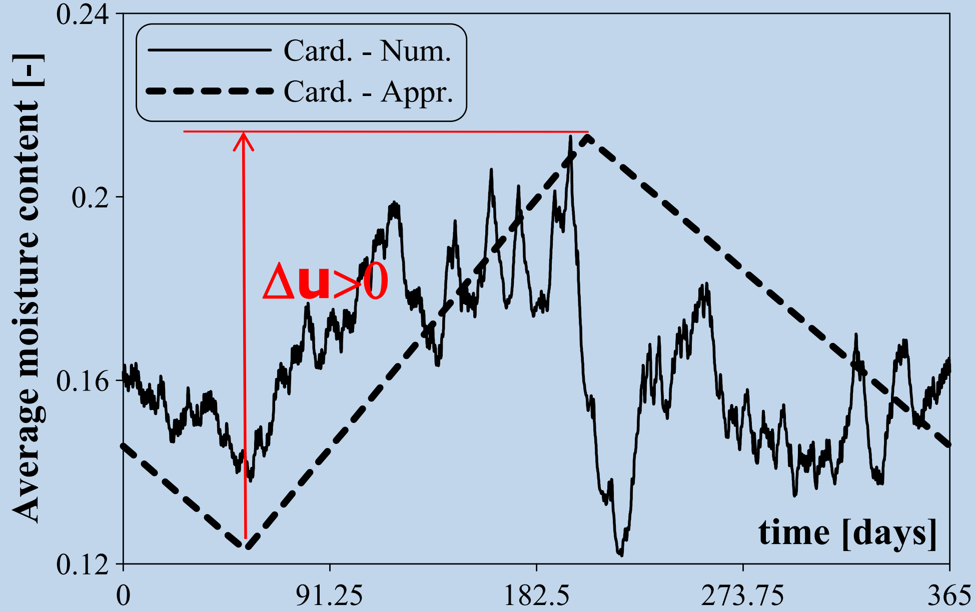
- the **max yearly moisture Δu_{avg} and temperature variations ΔT** could then be **provided in tables:**

Climatic region	**Exposure**	**ΔT [°C]**	**Δu_{avg} [%]**		
			Solid deck (continuous)	**Medium breadth section**	**Narrow section**
Mediterranean	Outdoor sheltered	-33	2	4	9
	Indoor unheated	-22	1	3	7
	Indoor heated	-11	1	2	5
Alpine	……	……	……	……	……

CHOICE OF THE DESIGN VALUES OF Δu AND ΔT:

Note that **the temperature variations have a sign which indicates whether they are opposite or not to the moisture variations**. This depends on the environmental history.





Δu>0 ➡ **ΔT**<0

LOAD EQUIVALENT TO MOISTURE AND TEMPERATURE:

- **a u.d.l. equivalent to concrete shrinkage, moisture and temperature variations, p_{SLS}, can then be calculated** for timber-concrete composite beams:

$$p_{sls} = C_{p,sls} \cdot \Delta\varepsilon$$

$$C_{p,sls} = \pi^2 \cdot \frac{E_1 \cdot A_1 \cdot E_2 \cdot A_2 \cdot z \cdot \gamma_1}{\left(E_1 \cdot A_1 + E_2 \cdot A_2\right) \cdot L^2}$$

$$\Delta\varepsilon = \Delta\varepsilon_{timber} - \Delta\varepsilon_{concrete}$$

$$\Delta\varepsilon_{timber} = \alpha_{w,u}\Delta u_{avg} + \alpha_{w,T}\Delta T$$

$$\Delta\varepsilon_{concrete} = \alpha_{c,T}\Delta T + \varepsilon_{cs}$$

γ_1 is the gamma coefficient provided by the Annex B of the Eurocode 5:

$$\gamma_1 = \frac{1}{1 + \dfrac{\pi^2 E_1 A_1 s}{k L^2}}$$

WHAT IS THE MAGNITUDE OF THE DIFFERENT EFFECTS?

$$\Delta\varepsilon = \Delta\varepsilon_{timber} - \Delta\varepsilon_{concrete} = \underbrace{\alpha_{w,u}\Delta u_{avg}}_{\Delta\varepsilon_u} - \underbrace{(\alpha_{c,T} - \alpha_{w,T})\Delta T}_{\Delta\varepsilon_T} - \varepsilon_{cs}$$

$$\alpha_{w,u} = 20 - 100 \times 10^{-6}\ [\%^{-1}] \Rightarrow \alpha_{w,u} \approx 60 \times 10^{-6}\ [\%^{-1}]$$

$$\alpha_{w,T} = 3 - 7 \times 10^{-6}\ [°C^{-1}] \Rightarrow \alpha_{w,T} \approx 5 \times 10^{-6}\ [°C^{-1}]$$

$$\alpha_{c,T} = 10 - 12 \times 10^{-6}\ [°C^{-1}] \Rightarrow \alpha_{c,T} - \alpha_{w,T} \approx 5 \times 10^{-6}\ [°C^{-1}]$$

$RH_{aver}=90\%$ $RH_{aver}=50\%$ $RH_{aver}=75\%$

$$\varepsilon_{cs} = 191 - 615 \times 10^{-6}\ [-] \Rightarrow \varepsilon_{cs} = 406 \times 10^{-6}\ [-]$$

WHAT IS THE MAGNITUDE OF THE DIFFERENT EFFECTS?

Climatic region	Exposure	$\Delta\varepsilon_T$ [x10^{-6}]	$\Delta\varepsilon_u$ [x10^{-6}]			ε_{cs} [x10^{-6}] (2Ac/u=10cm fcm=30MPa)
			Solid deck	**Medium section**	**Narrow section**	
Mediterranean (RH_{aver}=75%)	Outdoor sheltered	-165	120	240	540	406
	Indoor unheated	-110	60	180	420	
	Indoor heated	-55	60	120	300	
Alpine (RH_{aver}=50%)	....	....	....	....	....	615

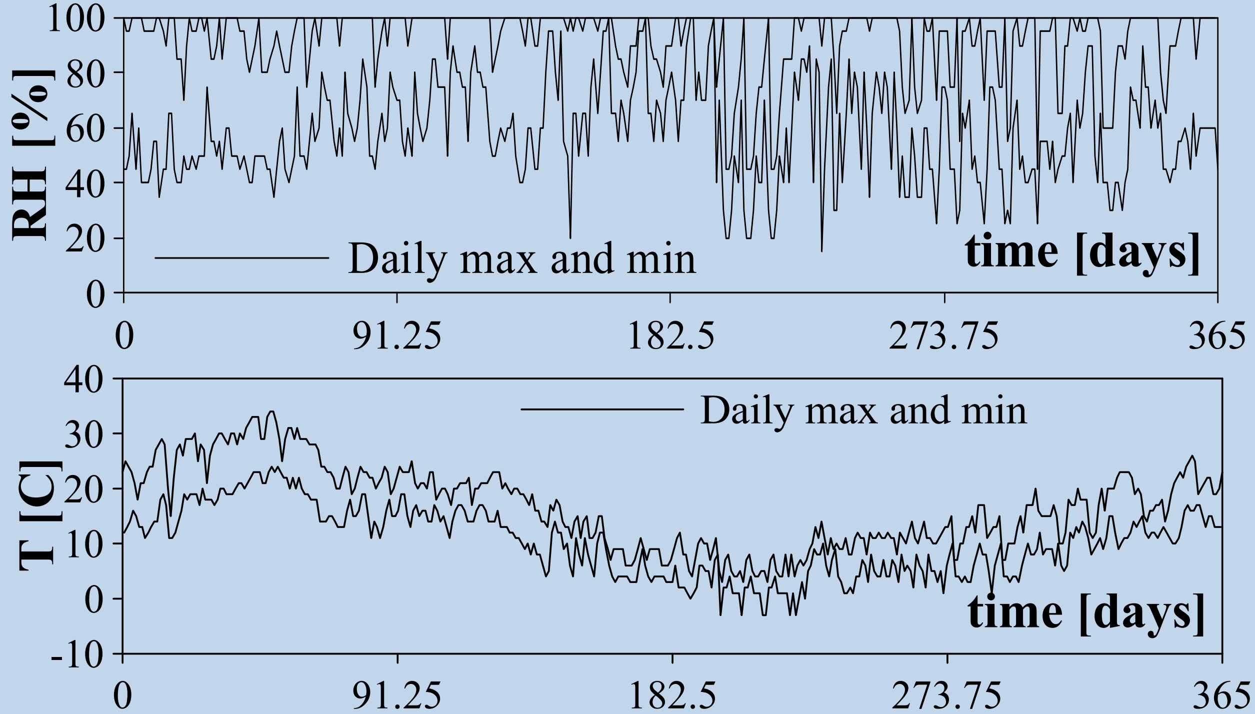
Thermal and moisture inelastic **strains** have **similar magnitude**

COMMENTS, PLEASE

Thank you!

WORK TO DO:

- **Divide Europe into a number of climatic regions**
- **Identify histories of temperature and relative humidity** for each region and exposure



WORK TO DO:

- **Solve diffusion problem for different cross-sections** (decks, medium breadth and narrow)
- **Provide Δu and ΔT in tabular format** for every climatic region, exposure and size of cross-section

Remark: *the case of* ***timber members in outdoor conditions directly exposed to the rain*** *has been* ***ignored.*** *This very severe condition will lead to durability issues and must be treated separately. Note that this case is currently classified Service Class 3 by Eurocode 5.*

WORK TO DO:

Question: how to estimate the histories of relative humidity in indoor conditions based on the environmental histories?

Häglund and Thelandersson (2005) suggests that **in heated, indoor conditions, the same timber moisture content variation** as in outdoor, unheated conditions should be considered.

The book Limträhandbook (2001), however, suggests **half the value** in outdoor conditions: $\Delta u/2$.

WORK TO DO:

More work is needed to clarify this issue. It is suggested that **the climate in indoor conditions is monitored in** a number of **different buildings and climatic regions**.