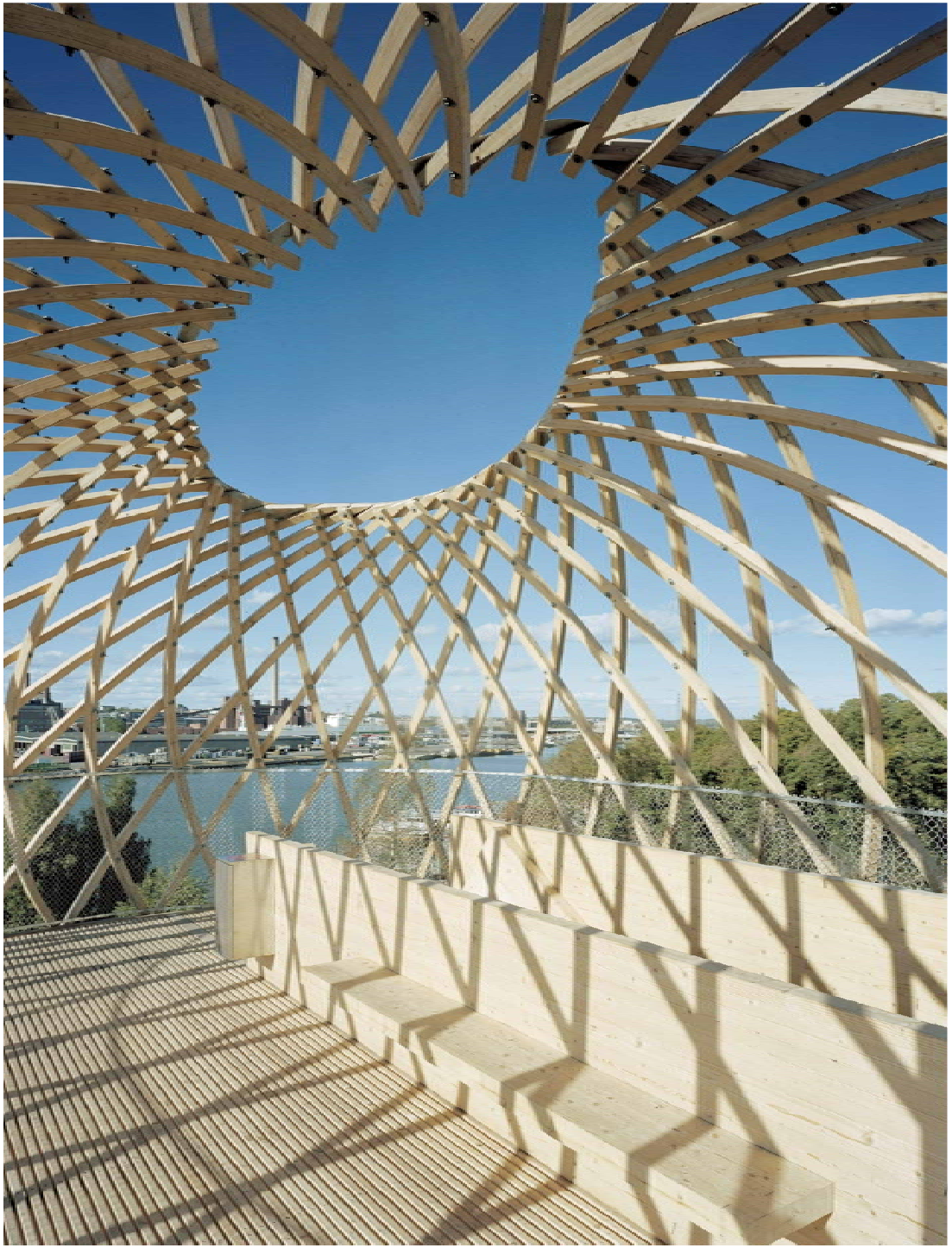


# COST Action E55

# Timber Structures exposed to Moisture

Jochen Köhler, Gerhard Fink
Swiss Federal Institute of Technology

# Problem overview

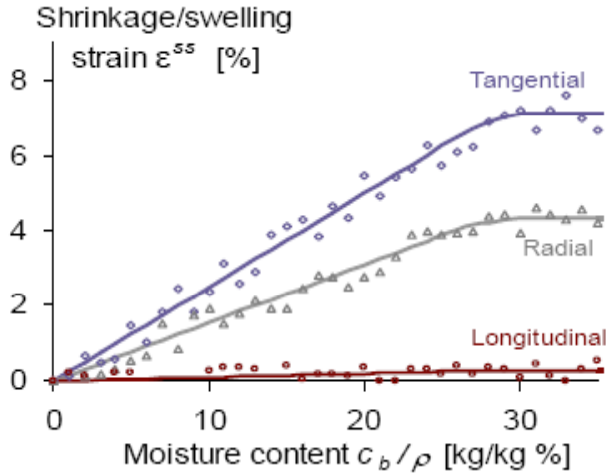
- The load bearing capacity of timber structural elements is affected by moisture and moisture variations,
  and,
  time history of applied loading (duration of load effect)

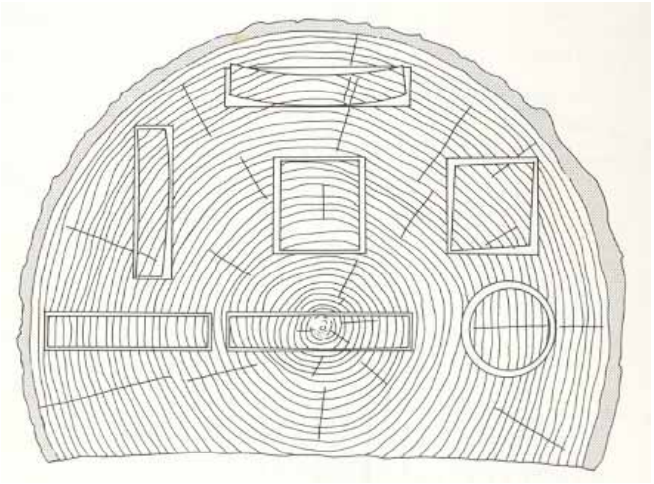
- In design codes, as e.g. the EC, these effects are accounted for by a factorization of strength with a modification factor ( $k_{\mathrm{mod}}$)

| Material | Standard | Service class | Load-duration class | | | | |
|---|---|---|---|---|---|---|---|
| | | | Permanent action | Long term action | Medium term action | Short term action | Instanta-neous action |
| Solid timber | EN 14081-1 | 1 | 0,60 | 0,70 | 0,80 | 0,90 | 1,10 |
| | | 2 | 0,60 | 0,70 | 0,80 | 0,90 | 1,10 |
| | | 3 | 0,50 | 0,55 | 0,65 | 0,70 | 0,90 |
| Glued laminated timber | EN 14080 | 1 | 0,60 | 0,70 | 0,80 | 0,90 | 1,10 |
| | | 2 | 0,60 | 0,70 | 0,80 | 0,90 | 1,10 |
| | | 3 | 0,50 | 0,55 | 0,65 | 0,70 | 0,90 |

# Problem overview (cont.)

- The effect of moisture on the load bearing behaviour might be differentiated:
  - Stresses due to restrained shrinkage and swelling of the timber



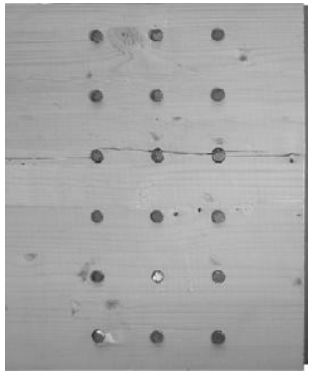
  - Accelerated aging (+DOL) as a result of moisture state and history

# Problem overview (cont.)

- The effect of moisture on the load bearing behaviour might be differentiated:

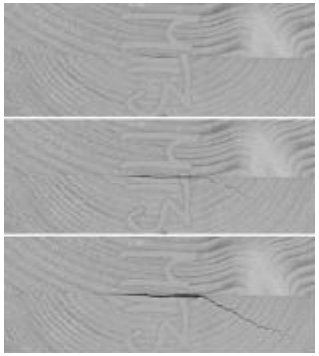
  – Stresses due to restrained shrinkage and swelling of the timber

Connections



Drying

Wetting



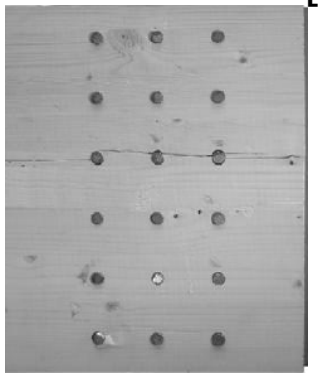
  – Accelerated aging (+DOL) as a result of moisture state and history

# Problem overview (cont.)

- The effect of moisture on the load bearing behaviour might be differentiated:

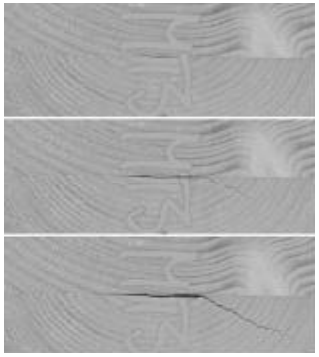
  – Stresses due to restrained shrinkage and swelling of the timber [Type I]

Connections [Ia]



Drying [Ib]

Wetting [Ib]



  – Accelerated aging (+DOL) as a result of moisture state and history [Type II]

# Problem overview (cont.)

- Moisture effects as a problem when structures had failed:

| Failure Mode | % of cases analysed | Moisture Influece |
|---|---|---|
| Instability | 30 | Likely (deformations) |
| Bending failure | 15 | Possible (aging) |
| Tension failure perp. | 11 | Yes, MIS |
| Shear failure | 9 | Likely (cracks) |
| Drying cracks | 9 | Yes |
| Excessive deflection | 7 | Yes (creep) |
| Tension failure | 5 | Possible (aging) |
| Corrosion of fasteners / decay | 4 | Yes |
| Withdrawal of fasteners | 3 | Possible |
| Compression | 2 | Possible |
| Other / unknown | 21 | - |

# Problem overview (cont.)

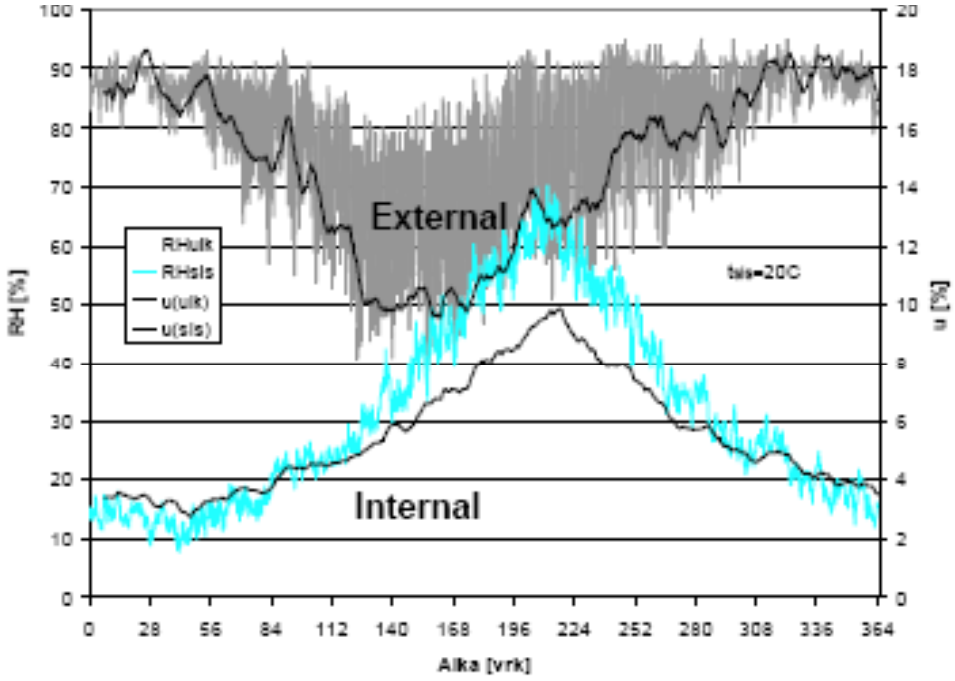
- Problem character and possible measures:

| **Effect** | **Characteristics** | **Design measures** |
|---|---|---|
| I a – rest. shrink. connections<br><br>I b - rest. shrink. cross sections | -Moisture induced stresses.<br>-Stress dependent on peak to peak amplitude, period of RH and comp. cross section.<br>-RH history not of interest – time independent. | -Specific regulations on:<br>+ Dowel arrangement perp. grain<br>+ initial moisture contents<br>+ in-service moisture contents<br>- Moisture stress design for key components. |
| II - aging | - reduced strength<br>- Combined effect of load and RH history – time dependent. | -$k_{mod}$ principle seems o.k.<br>- further development of model basis necessary.<br>-Refinement of load duration and climate classification in codes. |

# Indoor and outdoor climate

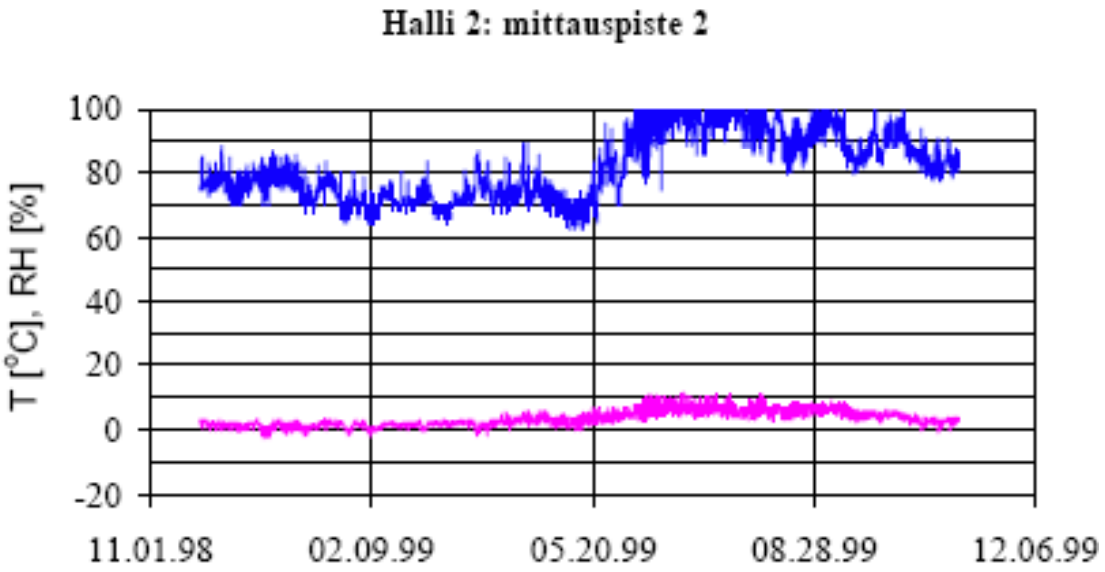
- Example:

## Sibelius hall




Ref: Koponen, 2002

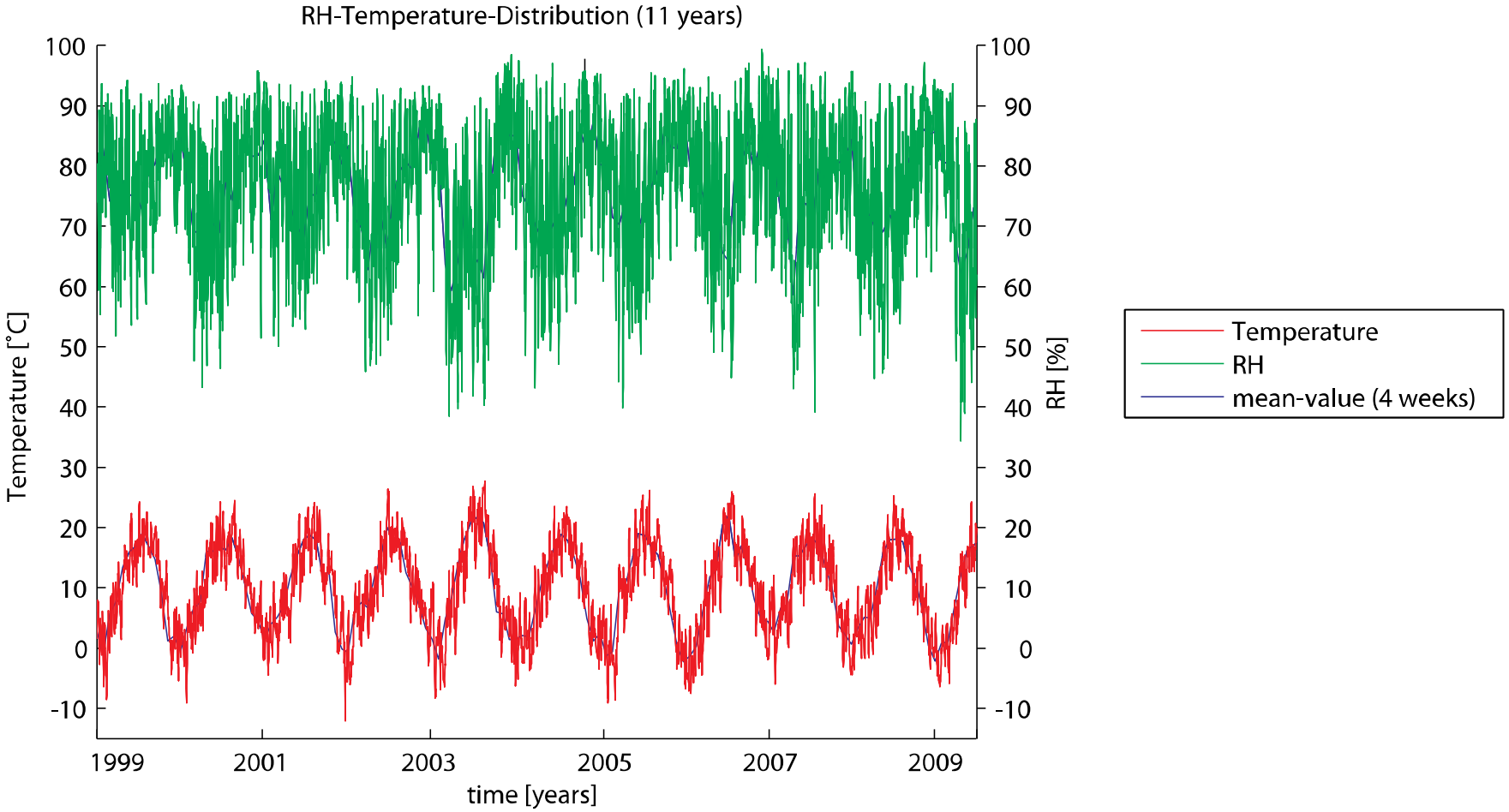
## Ice skating hall




Ref: Kevarinmäki et al., 2000

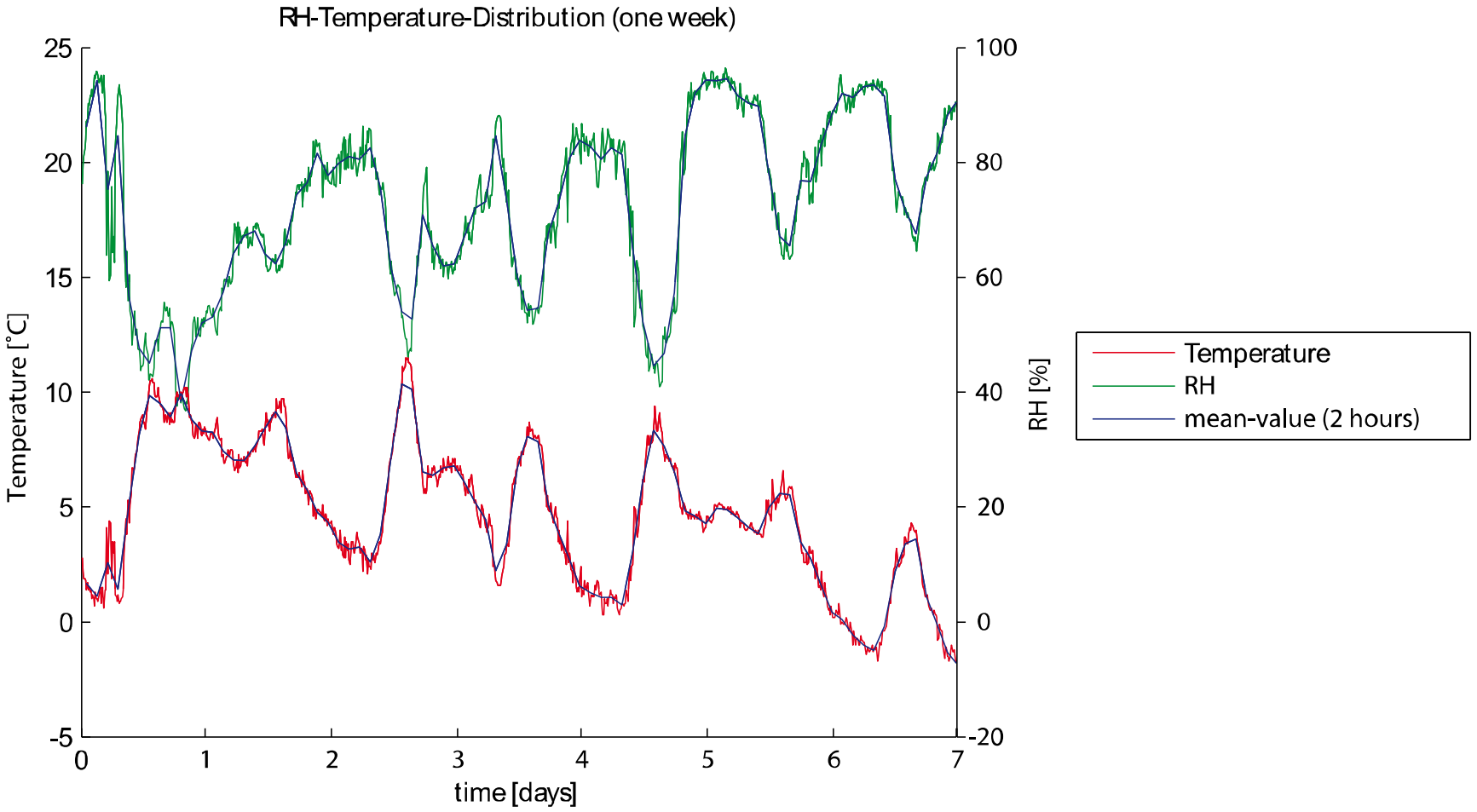
# Indoor and outdoor climate

- Example:



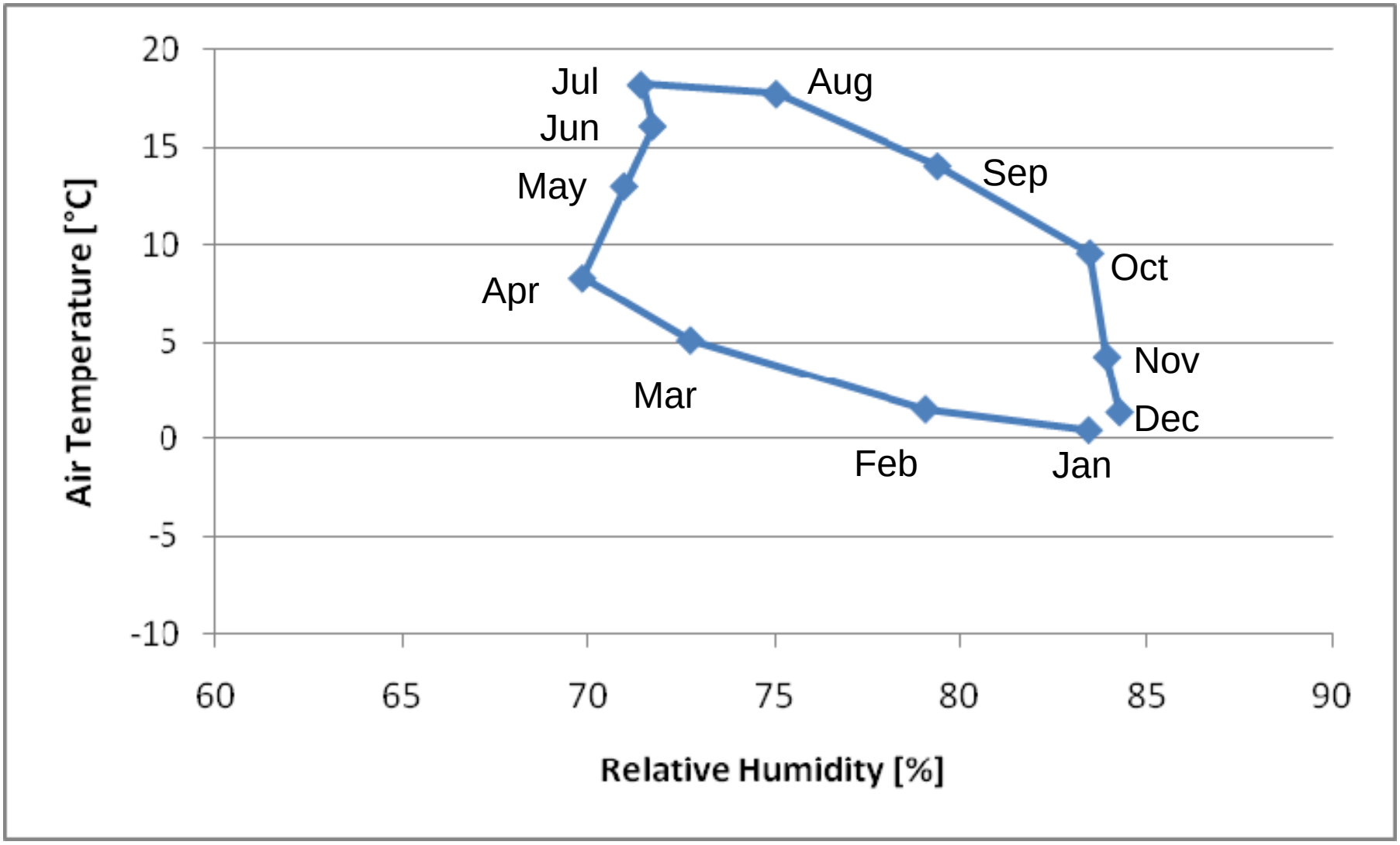
# Indoor and outdoor climate

- Example:



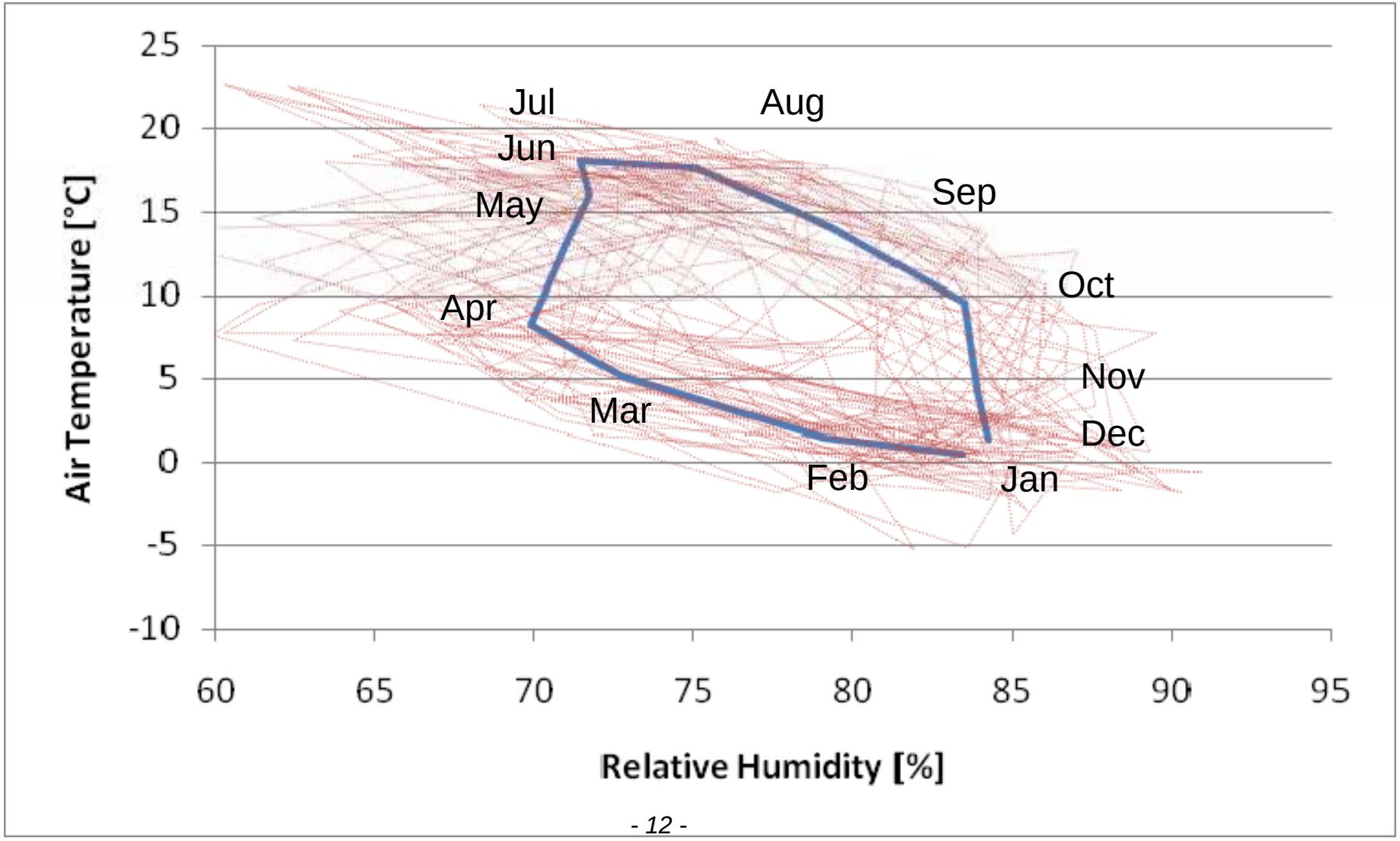
# Indoor and outdoor climate

- Example:



# Indoor and outdoor climate

- Example:



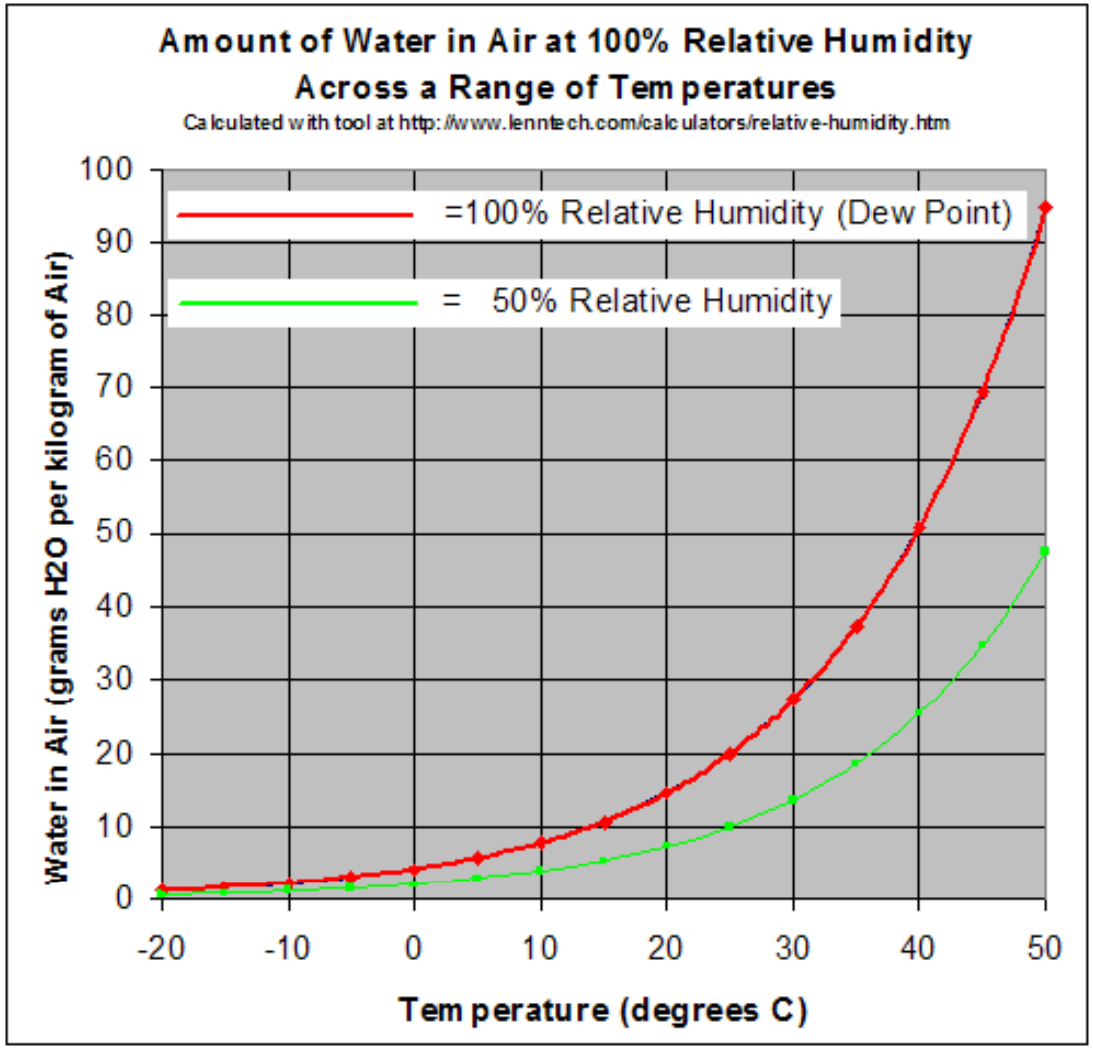
# Indoor and outdoor climate

- Good empirical basis for outside climates.
- Approach: Modelling the indoor climate as a function of:
  - The outdoor climate
  - Indoor moisture and heat production
  - Ventilation.

# Building climate relations

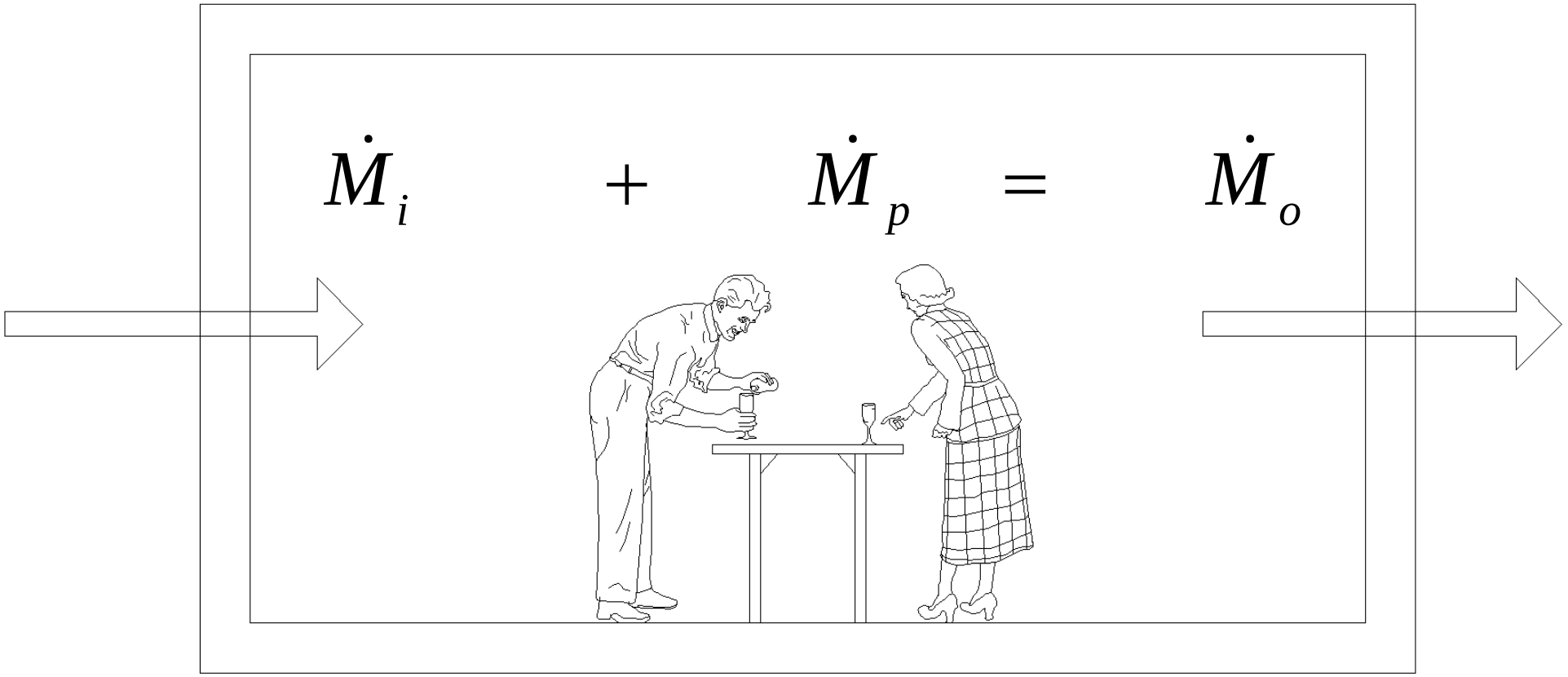
- Satiation level depends on the temperature
- Relative Humidity:

$$\varphi = \frac{c}{c_s} = \frac{\text{vapor content}}{\text{max vapor content}}$$



# Building climate relations

- Humidity equilibrium



# Building climate relations

- Humidity equilibrium

$$\dot{M}_i + \dot{M}_p = \dot{M}_o$$

$$L \cdot V \cdot \varphi_o \cdot c_{so} \cdot \frac{T_o}{T_i} + \dot{M}_p = L \cdot V \cdot \varphi_i \cdot c_{si}$$

$L$ Air alteration rate [$h^{-1}$]

$V$ Volume [$m^3$]

$\varphi_{o,i}$ Relative Humidity (outside/inside)

$c_{so,si}$ Satiation vapor content

$T_{o,i}$ Temperature

# Building climate relations

- Humidity equilibrium

$$\varphi_i = \varphi_o \frac{c_{so}}{c_{si}} \cdot \frac{T_o}{T_i} + \frac{M_p}{L \cdot V \cdot c_{si}}$$

$L$ Air alteration rate [$h^{-1}$]

$V$ Volume [$m^3$]

$\varphi_{o,i}$ Relative Humidity (outside/inside)

$c_{so,si}$ Satiation vapor content

$T_{o,i}$ Temperature

# Building climate relations

- Humidity equilibrium

$$L = \infty \rightarrow \varphi_i \cdot c_{si} \cdot T_i = \varphi_o \cdot c_{so} \cdot T_o$$

Vapor content inside = Vapor content outside

$L$ Air alteration rate [$h^{-1}$]

$V$ Volume [$m^3$]

$\varphi_{o,i}$ Relative Humidity (outside/inside)

$c_{so,si}$ Satiation vapor content

$T_{o,i}$ Temperature

# Building climate relations

- Reference Values:

  – Produced Humidity $M_P\ [g/h]$

| | |
|---|---|
| Office working person | 50 |
| handcrafter | 150 |
| Professional athlete | 1000 |
| cooking | 500 – 1000 |

  - Air alteration rate $L\ [h^{-1}]$

| | |
|---|---|
| Tilted window + down shutters | 0.3 – 1.5 |
| Tilted window | 0.8 – 2.5 |
| Tilted window + cross-ventilation | 2.0 – 4.0 |
| Half-open window | 5.0 – 10.0 |
| Open window | 9.0 – 15.0 |
| Open window + cross-ventilation | 20.0 – 40.0 |

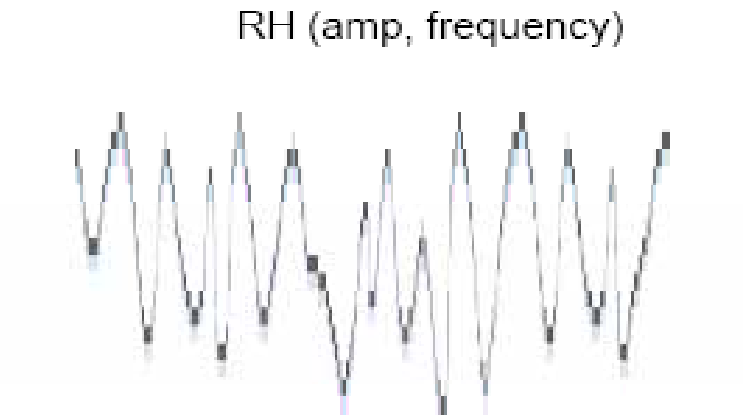
# Building climate relations

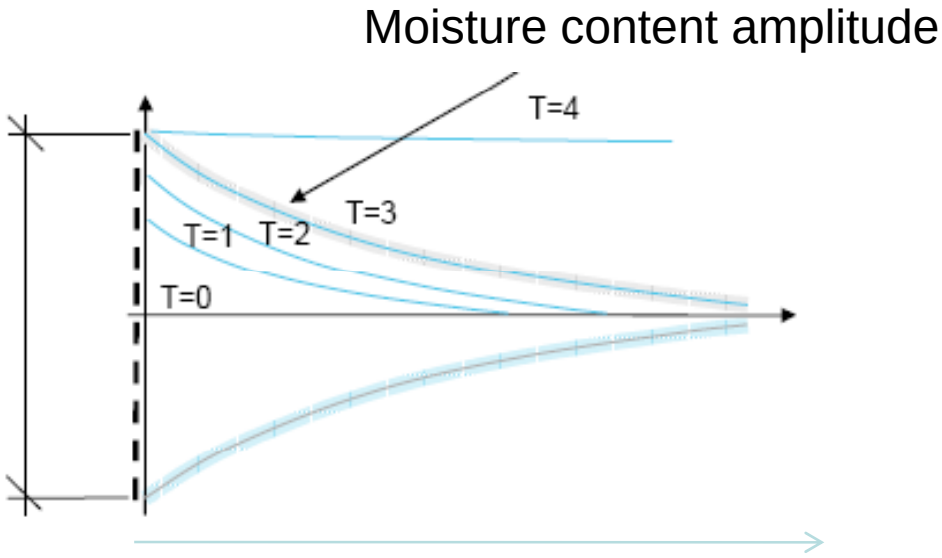
- Reference Values:

| – Building Types | $\varphi_i$ [%] (yearly cycle) |
|---|---|
| Outdoor sheltered | 100 - 55 |
| Indoor heated | 15 - 60 |
| Swimming, Ice skating | 75 - 99 |
| Hospitals | 40 – 60 |
| Theater, Sports | 50 – 80 |
| Stair case | 50 – 70 |
| Industry | 40 - 50 |

# Summary and Outlook

- Highly resulted outdoor climate data available
- Indoor climate as a function of outdoor climate and building characteristics
- Proper time resolution of the data?

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