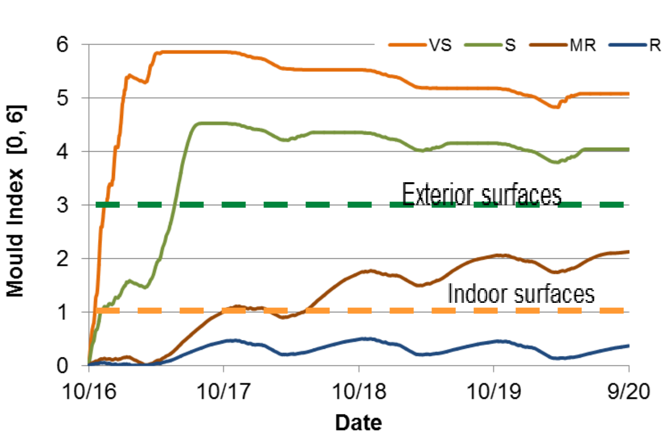


VTT mold model – Equations, parameters, performance criteria

Buildings XIII Workshop

Tuomo Ojanen & Hannu Viitanen

Contents

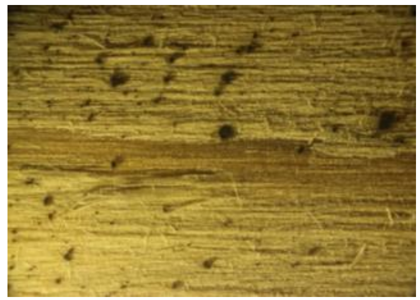
- Background and motivation
- Visual findings and mold index
- Model equations
- Mold growth conditions
- Classification of materials – Sensitivity to mold growth
- Decline of mold index
- Effect of parameter selection on simulated mold growth
- Examples
- Discussion and conclusions

Background and motivation for mold model

- Mold growth is one of the first signs of too high moisture content in (building) materials
  - It may affect the indoor air quality and the appearance of surfaces
  - Increasing moisture may lead to structural damages

- natural ageing
  - grey wood
    - mould
      - indoor air
      - structures
        - VOCs
        - aestetics
          - load exceeds tolerance
            - decay
              - damage

Service life of buildings

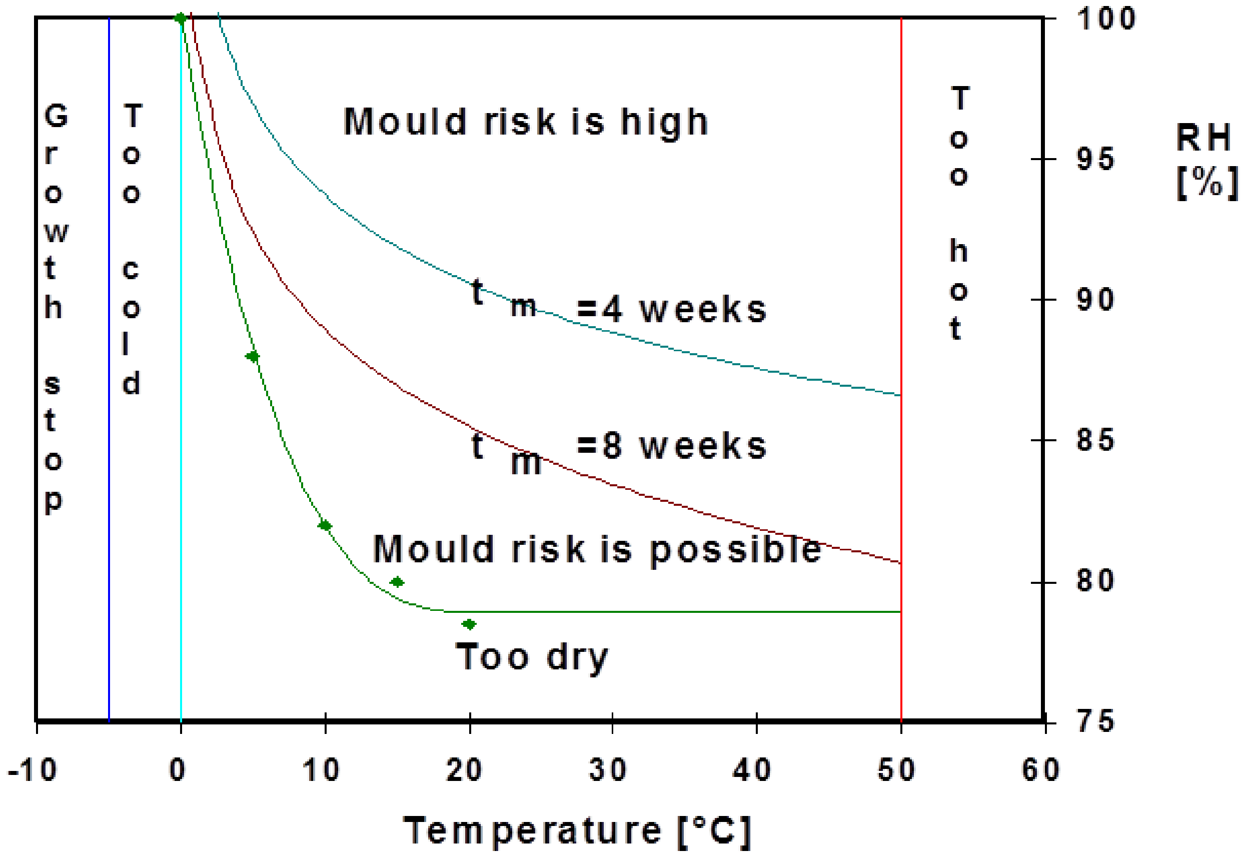


Mold Index

- Mold growth potential can be predicted by solving a numerical value, MOLD INDEX
- Values between [0, 6] depending on the growth coverage
- The model was originally based on mold growth studies on wooden material surface
- Same model can be used for other building materials – scaling coefficients for equations

Critical factors

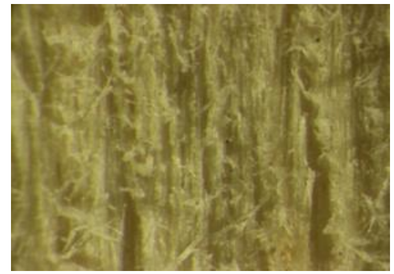
- Humidity
- Temperature
- Time
- Substrate

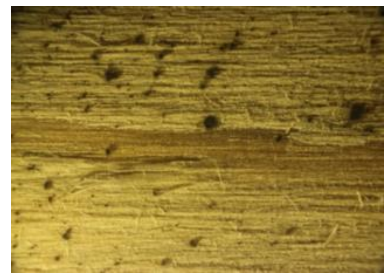


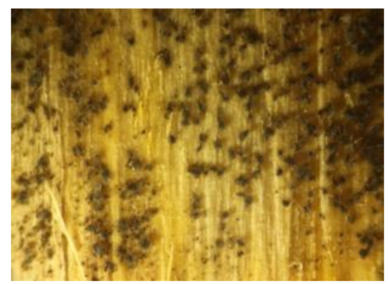
Mold Model principles – Visual findings interpreted as mold index values

- Index levels between 0 and 6

Index	Description of the growth rate
0	No growth
1	Small amounts of mould on surface (microscope), initial stages of local growth
2	Several local mould growth colonies on surface (microscope)
3	Visual findings of mould on surface, < 10 % coverage, or, < 50 % coverage of mould (microscope)
4	Visual findings of mould on surface, 10 - 50 % coverage, or, >50 % coverage of mould (microscope)
5	Plenty of growth on surface, > 50 % coverage (visual)
6	Heavy and tight growth, coverage about 100 %







Mold growth parameters used in the model

- Substrate
  - Typical building materials
- Growth conditions
  - Limit levels of RH and temperature
- Growth intensity
  - Depends on material, conditions and growth level
- Maximum growth (Mold index) level
  - Depends on material and conditions
- Decline of visible growth level during unfavorable conditions
  - Seasonal long-period conditions outside the growth area
  - Level of growth and growth intensity after decline periods

General mold growth equations – Reference material pine

$$\frac{dM}{dt} = \frac{1}{7 \cdot \exp(-0.68 \ln T - 13.9 \ln RH + 0.14W - 0.33SQ + 66.02)} k_1 k_2$$

$$k_1 = \begin{cases} \dfrac{t_{M=1,pine}}{t_{M=1}}, \text{when } M < 1 \\ 2 \cdot \dfrac{(t_{M=3,pine} - t_{M=1,pine})}{(t_{M=3} - t_{M=1})}, \text{when } M \geq 1 \end{cases}$$

$$k_2 = \max\left[1 - \exp\left[2.3 \cdot (M - M_{\max})\right], 0\right]$$

$$M_{\max} = A + B \cdot \frac{RH_{crit} - RH}{RH_{crit} - 100} - C \cdot \left(\frac{RH_{crit} - RH}{RH_{crit} - 100}\right)^2$$

Scaling factors k_1 and k_2 for different materials

Coefficient k_1 is used to scale the growth intensity

Coefficient k_2 to limit the growth to maximum possible index level

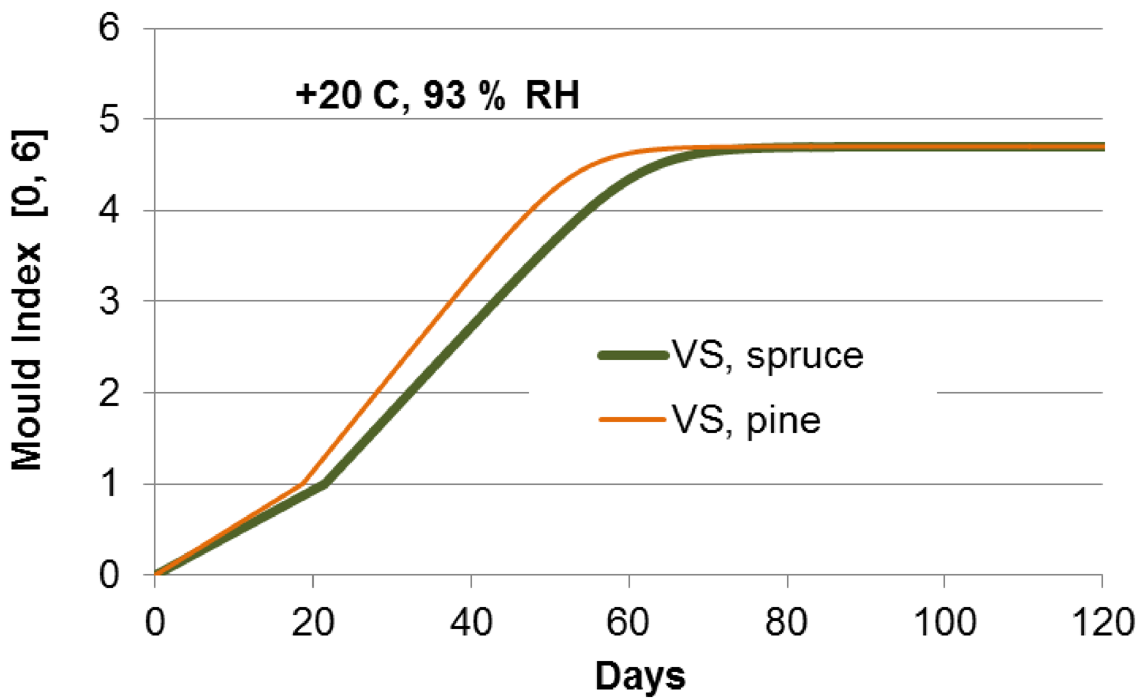
Parameters for northern timber - W

$$\frac{dM}{dt} = \frac{1}{7 \cdot \exp(-0.68 \ln T - 13.9 \ln RH + 0.14W - 0.33SQ + 66.02)} k_1 k_2$$

W for timber:
Pine W = 0,
spruce W = 1

Faster growth for pine

Timber and surface quality parameters only with spruce and pine, when known



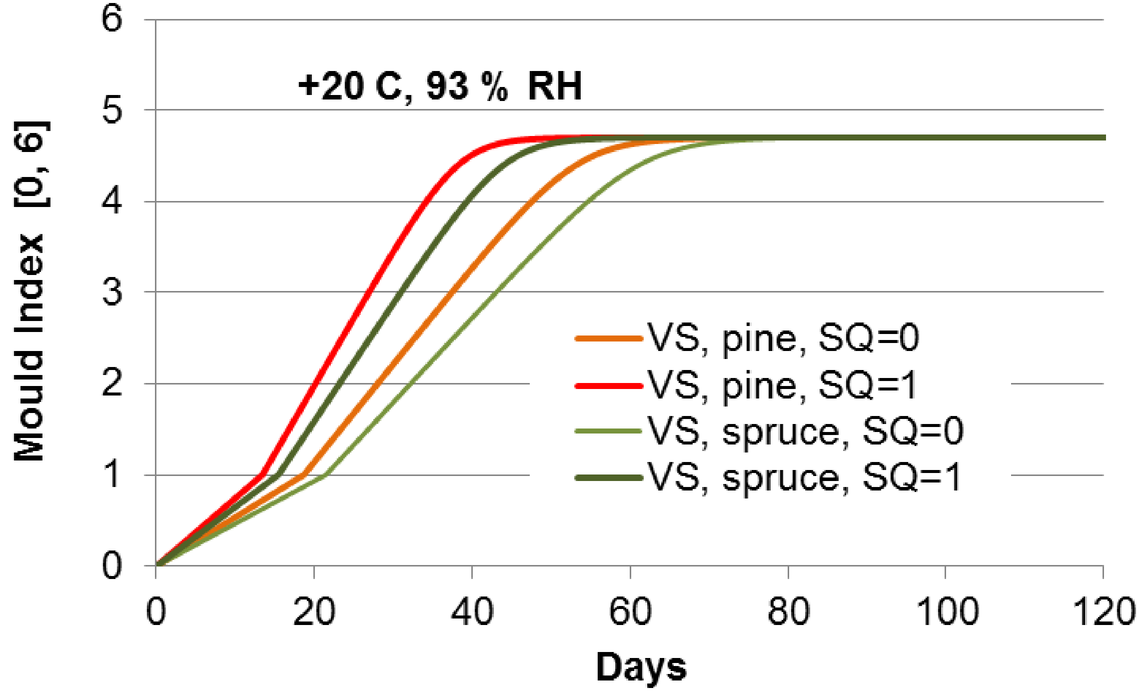
Parameters for northern timber – Surface quality

$$\frac{dM}{dt} = \frac{1}{7 \cdot \exp(-0.68 \ln T - 13.9 \ln RH + 0.14W - 0.33SQ + 66.02)} k_1 k_2$$

SQ for surface quality:
Planed, sawn SQ = 0,
Kiln dried SQ = 1

Faster growth when dried under high temp.

Timber and surface quality parameters only with spruce and pine, when known



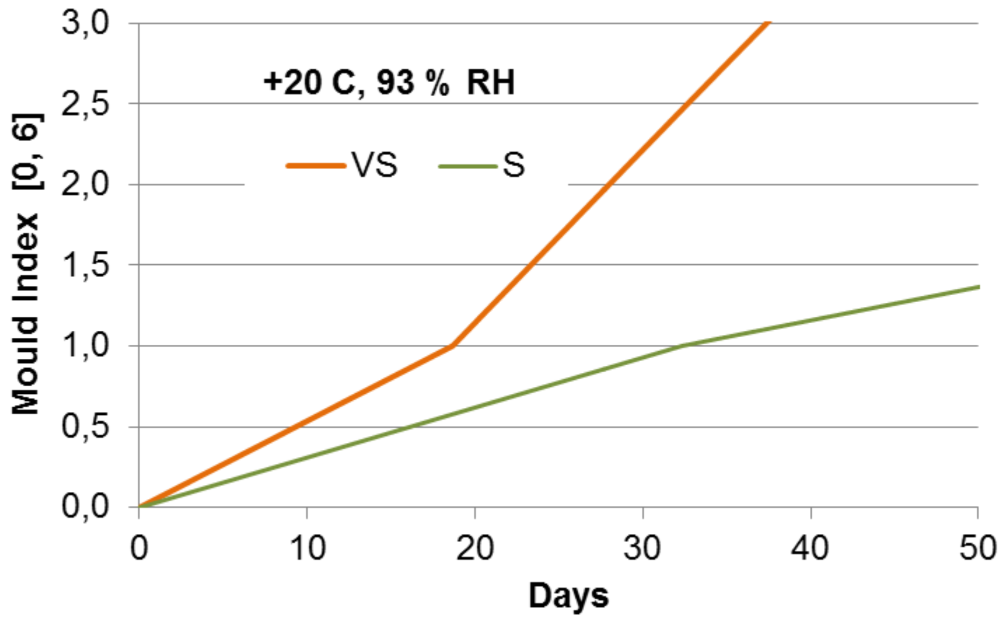
Use of different materials

- Scaling of mold growth intensity using scaling factor k_1
- Scaling of maximum mold growth level using scaling factor k_2
- Lowest critical relative humidity level allowing mold growth RH_{crit}

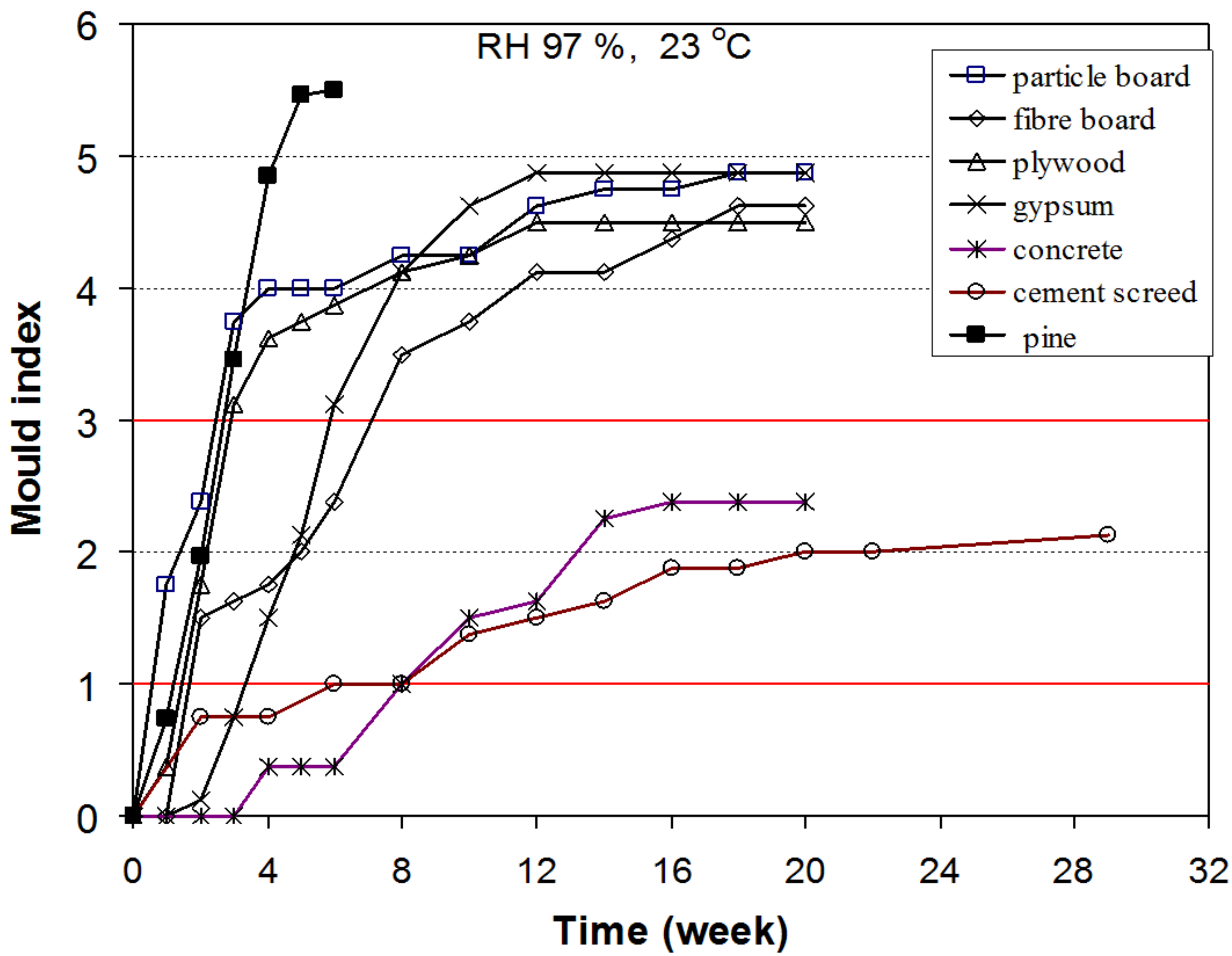
Effect of k_1 coefficient

- Growth intensity changes after the first signs of mold (MI = 1)
- Change depends on material
- Example: Sensitive and very sensitive materials under +20 ºC and 95 % RH

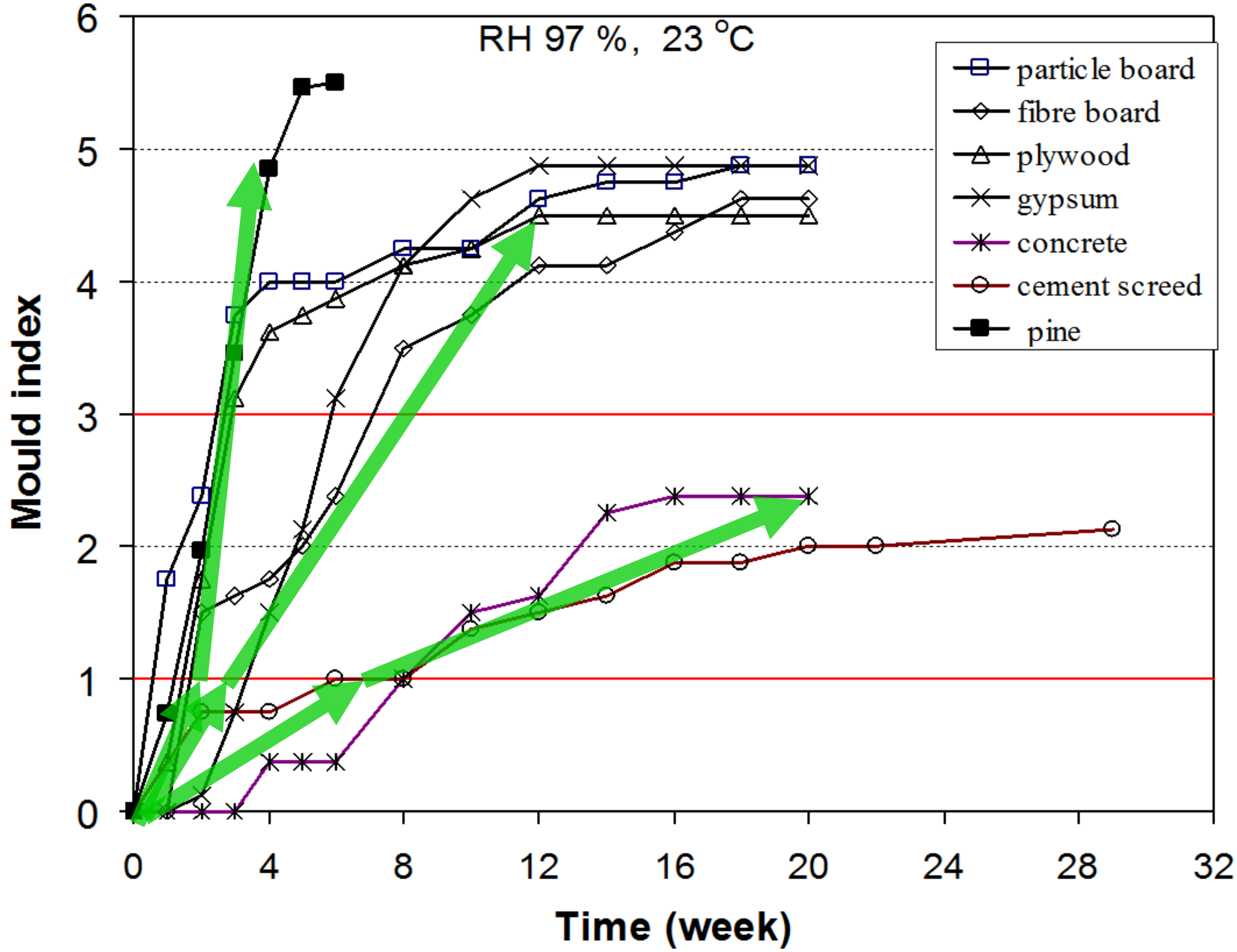
$$\frac{dM}{dt} = \frac{1}{7 \cdot \exp(-0.68 \ln T - 13.9 \ln RH + 0.14W - 0.33SQ + 66.02)} k_1 k_2$$



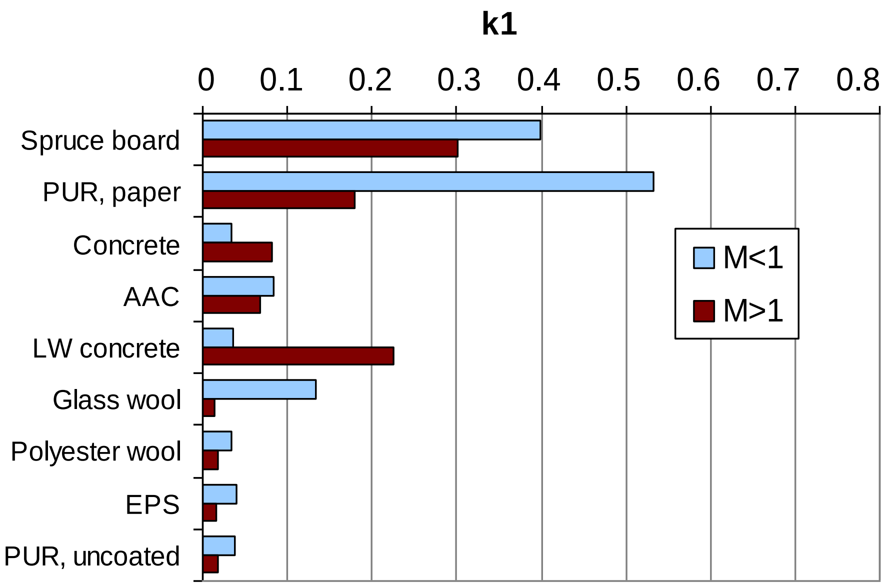
Mold growth intensities on material surfaces



Mold growth intensity classes



Mold growth intensity classes for different materials – use of k_1 coefficient

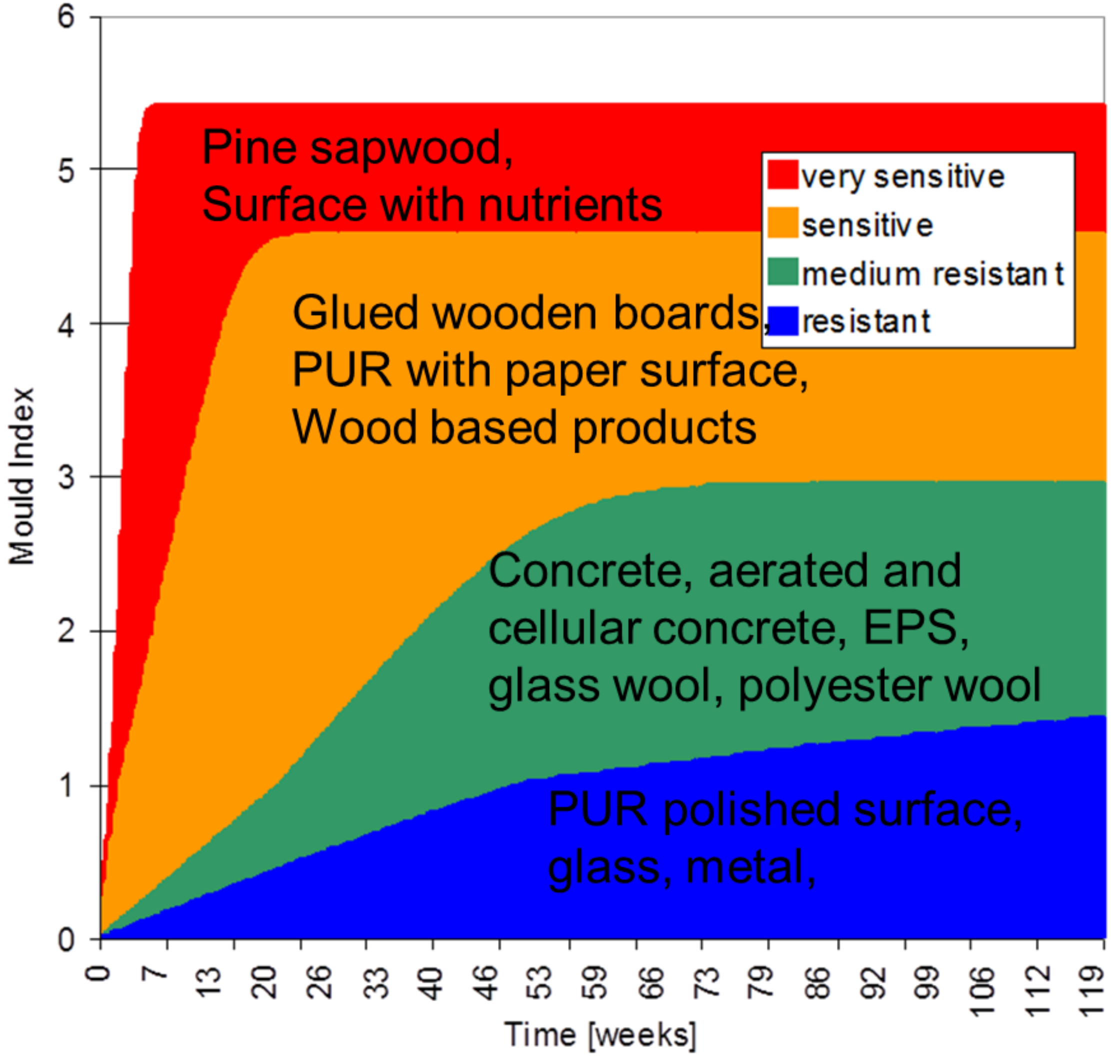


Sensitivity class	k_1 M < 1	k_1 M ≥ 1
very sensitive, vs	1	2
sensitive, s	0.578	0.386
medium resistant, mr	0.072	0.097
resistant, r	0.033	0.014

Very sensitive = pine sapwood (reference material)
Experimental findings for growth intensity of different materials
Scaling coefficients k_1 for material sensitivity classes

Ojanen, T, Peuhkuri, R, Viitanen, H, Lähdesmäki, K, Vinha, J& Salminen, K. Classification of material sensitivity. New approach for mould growth modeling. 9th Nordic Symposium on Building Physics, NSB 2011, Tampere, Finland, 2011, pp. 867-874

Mold growth sensitivity classes



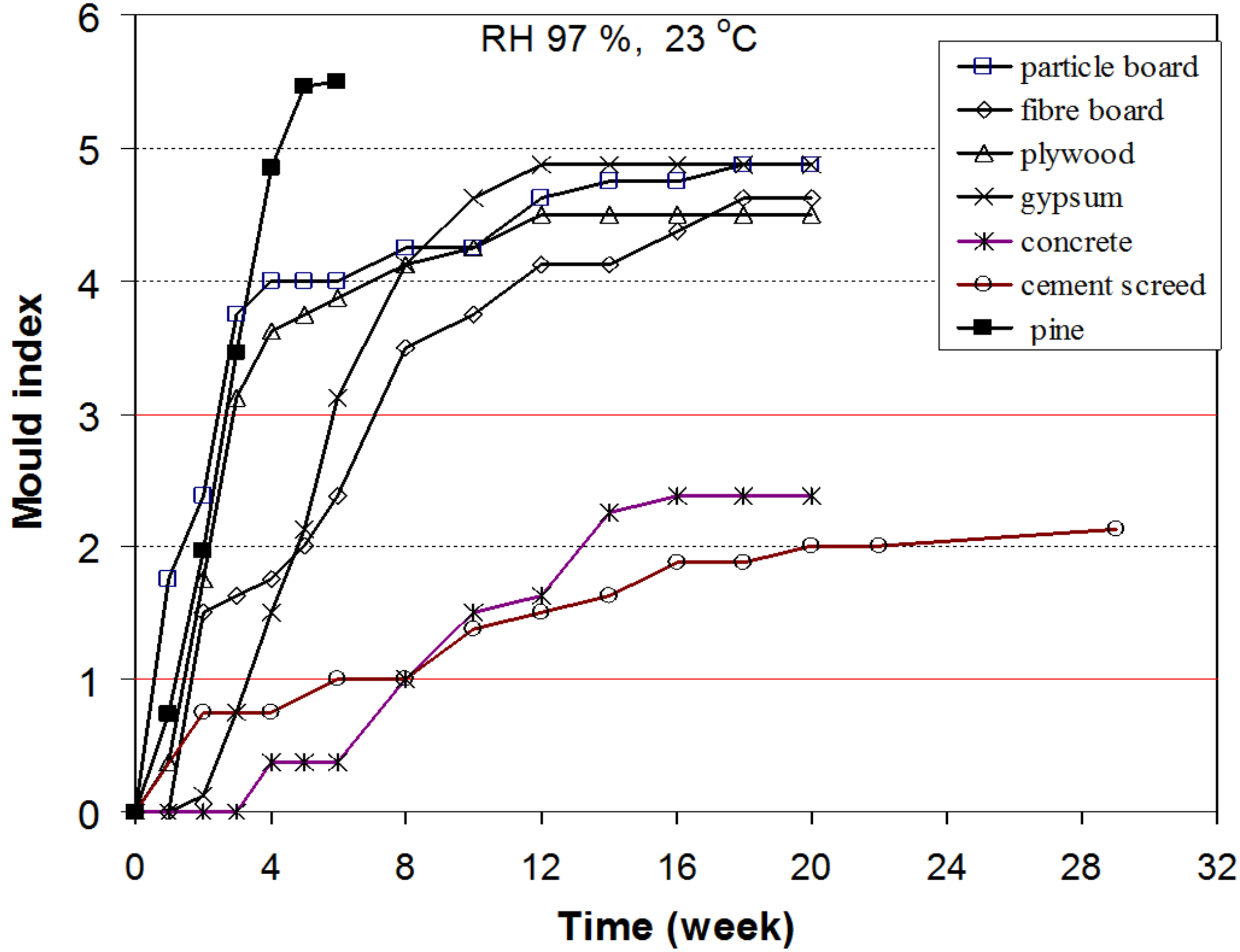
Peuhkuri, R; Viitanen, H; Ojanen, T. Modelling of mould growth in building envelopes Proceedings of the IEA ECBCS Annex 41 Closing seminar, Copenhagen, June 19, 2008

Maximum Mold Index level - coefficient k_2

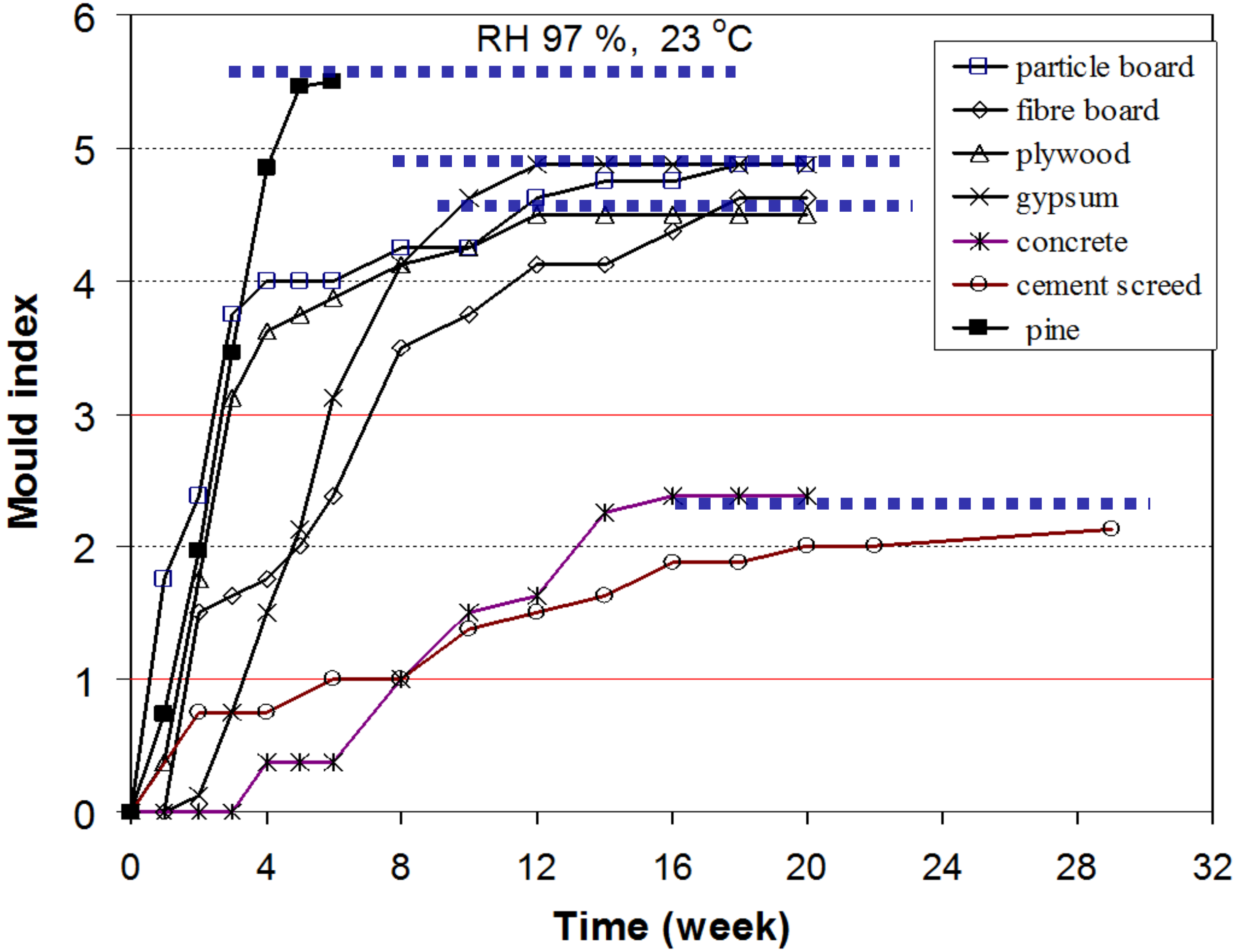
$$\frac{dM}{dt} = \frac{1}{7 \cdot \exp(-0.68 \ln T - 13.9 \ln RH + 0.14 W - 0.33 SQ + 66.02)} k_1 k_2$$

$$k_2 = \max\left[1 - \exp\left[2.3 \cdot (M - M_{\max})\right], 0\right]$$

Maximum long period mold index level under stationary conditions



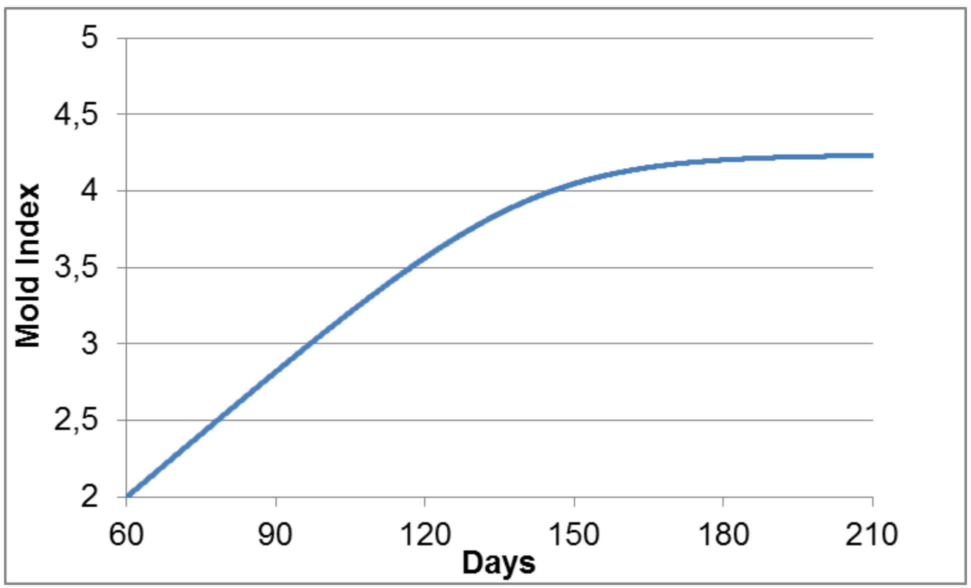
Maximum long period mold index level under stationary conditions



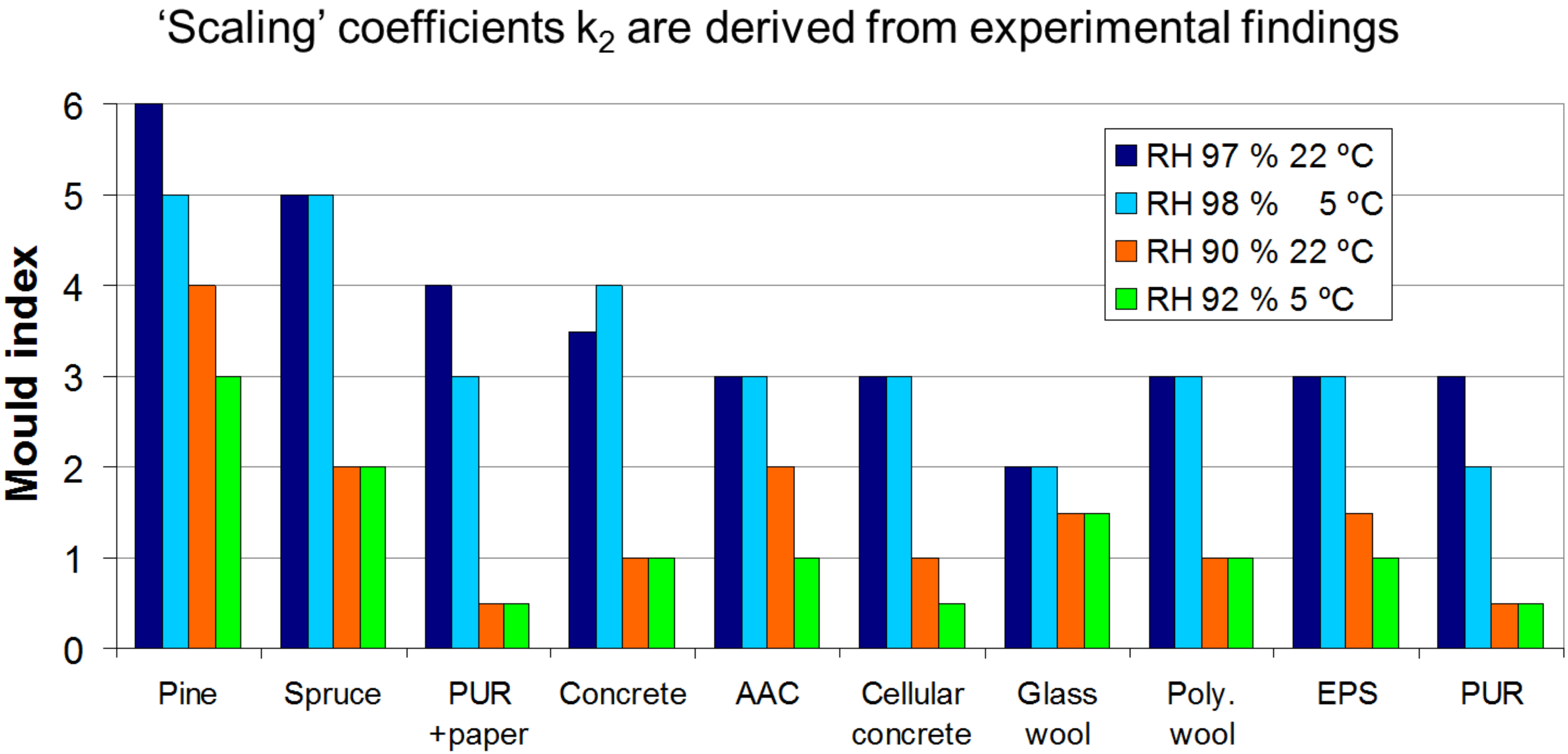
Maximum levels of growth → Classification according material types

Effect of k2 on growth close to maximum

- The growth is damped close to maximum growth index
- M_{max} =f(T, RH%)



Maximum Mold Index level - coefficient k_2



Lähdesmäki, K, Salminen, K, Vinha,J, Viitanen, H, Ojanen, T & Peuhkuri, R. Mould growth on building materials in laboratory and field experiments. 9th Nordic Symposium on Building Physics, NSB 2011, Tampere, Finland, 2011.

Maximum Mold Index level - coefficient k_2

$$k_2 = \max\left[1 - \exp\left[2.3 \cdot (M - M_{\max})\right], 0\right]$$

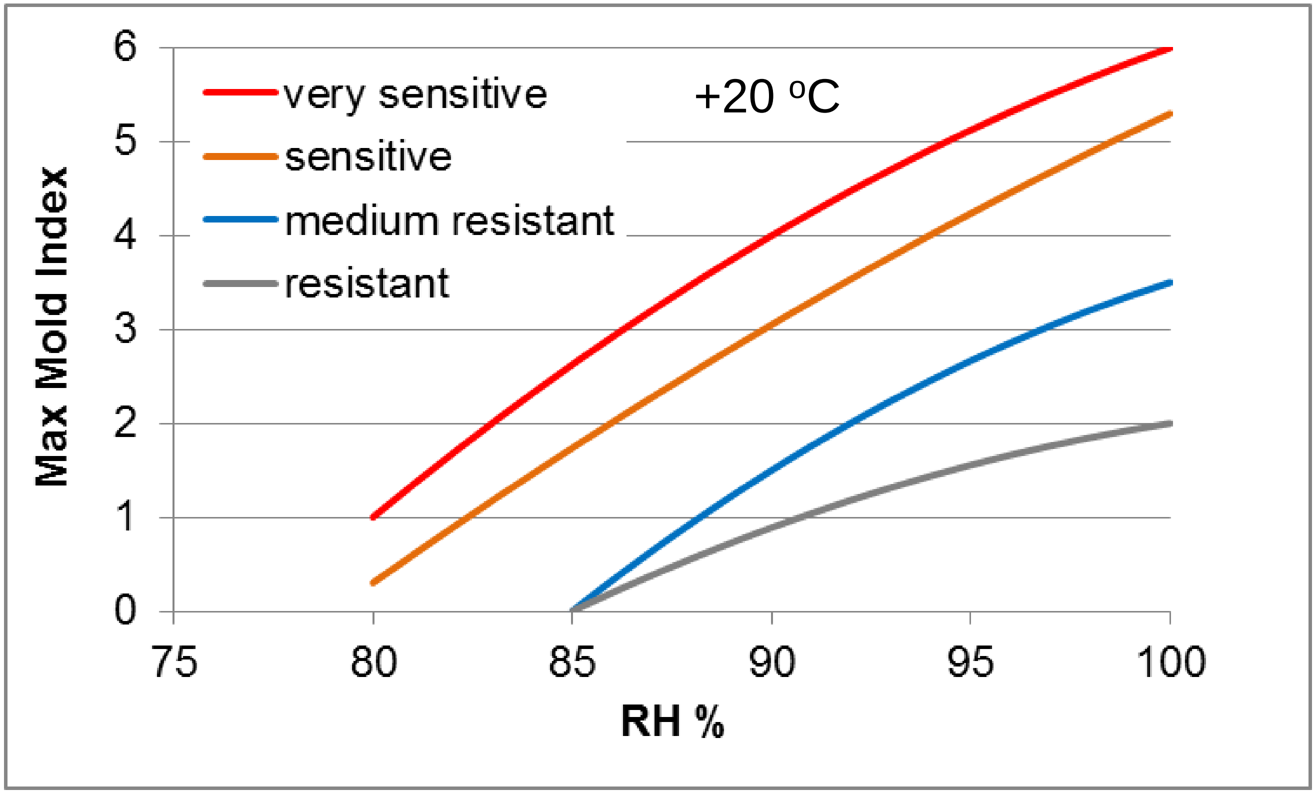
$$M_{\max} = A + B \cdot \frac{RH_{crit} - RH}{RH_{crit} - 100} - C \cdot \left(\frac{RH_{crit} - RH}{RH_{crit} - 100} \right)^2$$

Sensitivity class	k_2 A	B	C	RH_{min} %
very sensitive, vs	1	7	2	80
sensitive, s	0.3	6	1	80
medium resistant, mr	0	5	1.5	85
resistant, r	0	3	1	85

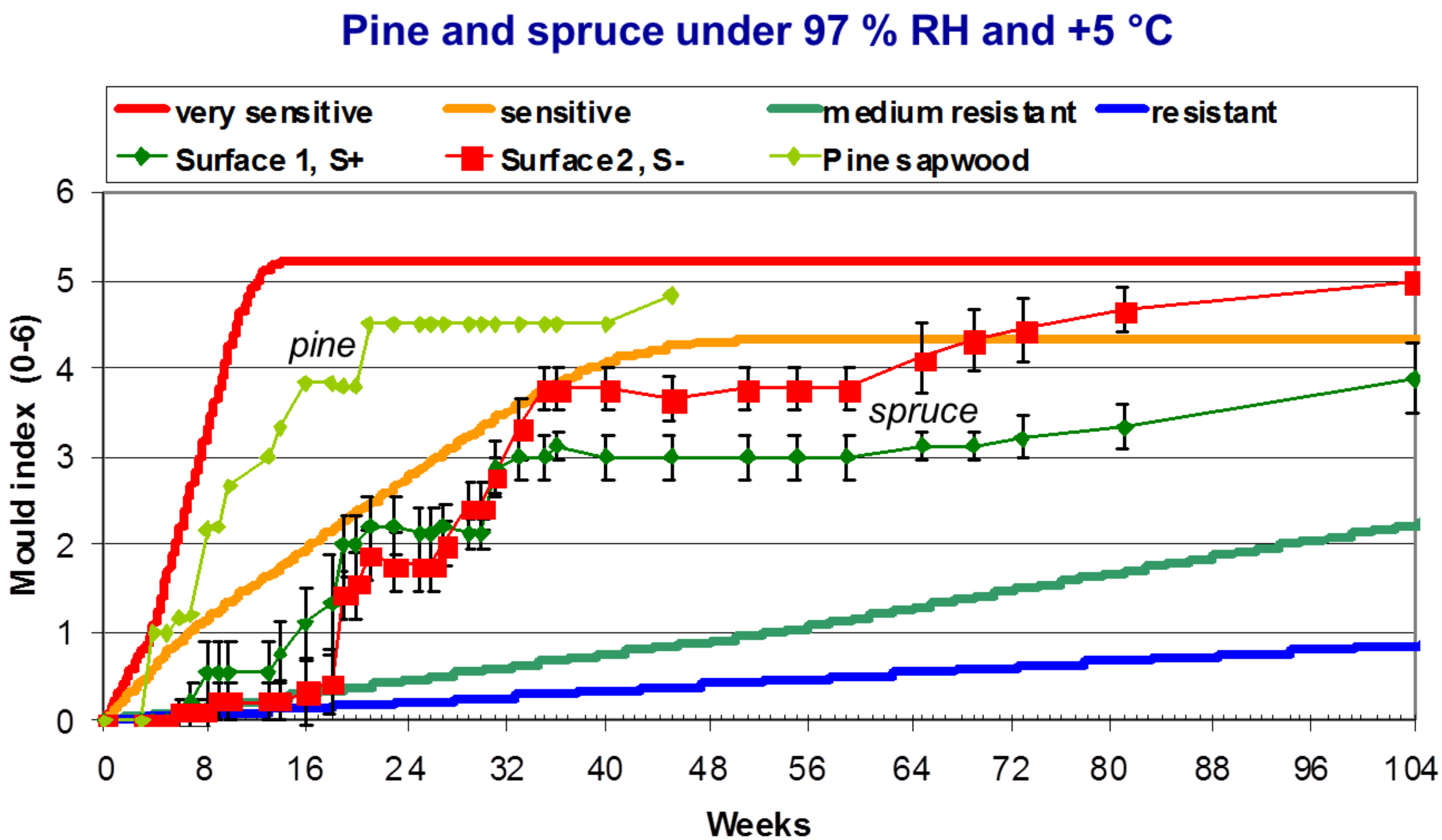
Pine, reference

Values for new sensitivity classes

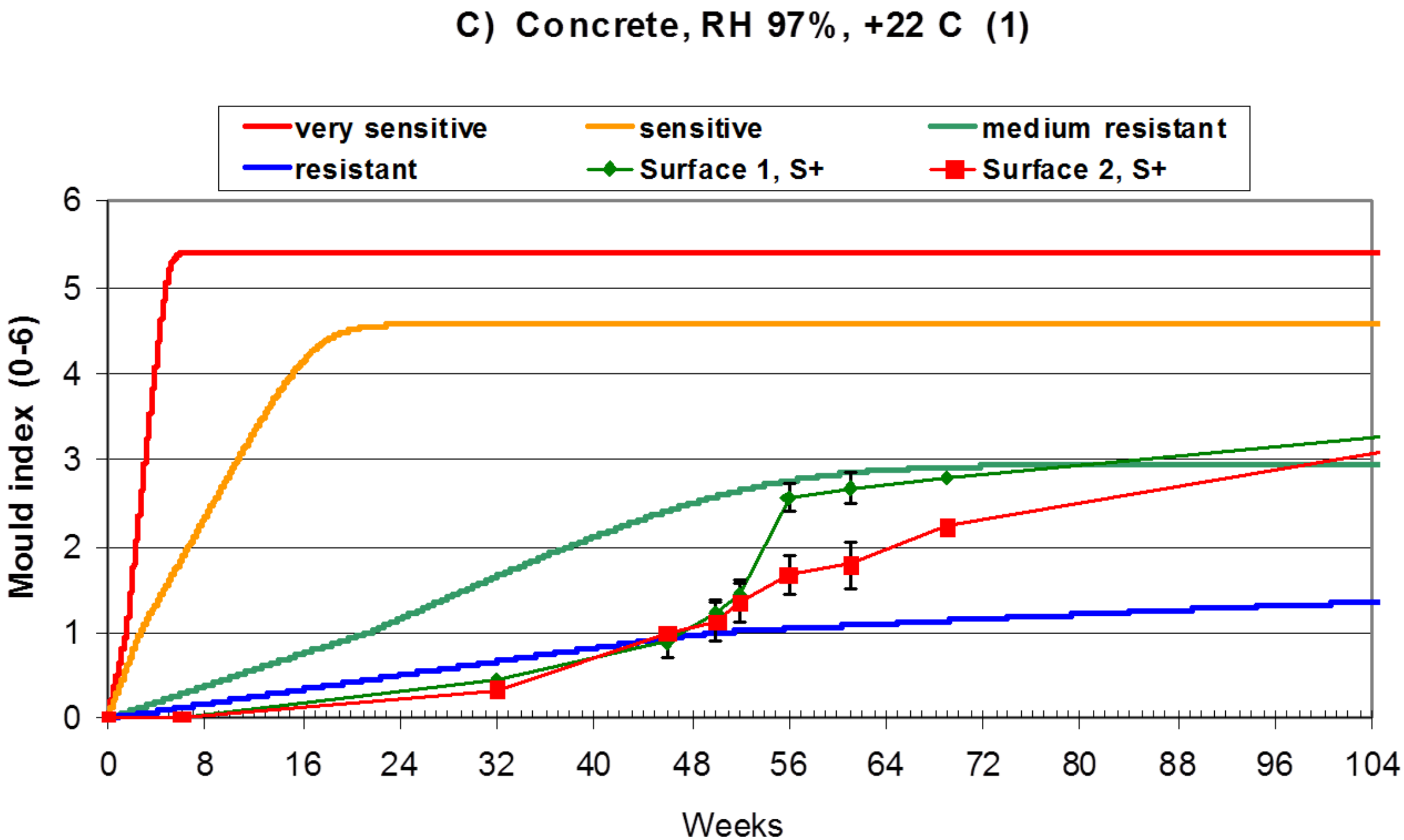
Maximum Mold Index levels at different RH % conditions



Evaluation of the model with mold sensitivity classes: Experiment vs. numerical predictions 1



Evaluation of the model with mold sensitivity classes: Experiment vs. numerical predictions 2

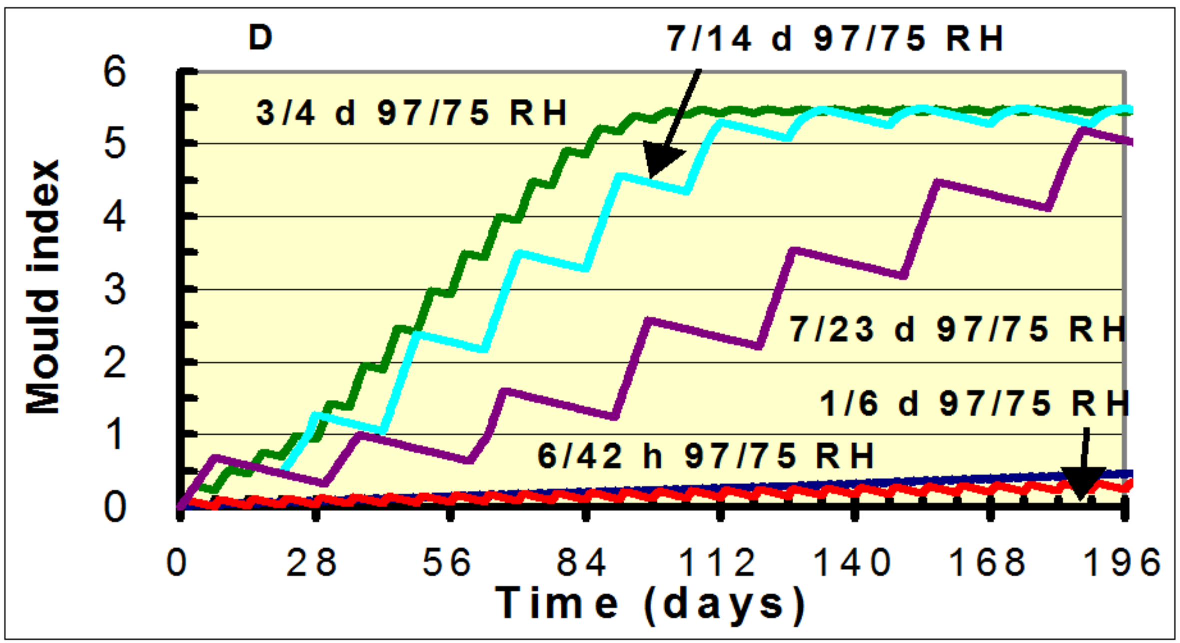


Effect of dynamic conditions on mold growth

- Dynamically changing conditions delay the growth
- Decline of visible growth level after (long) periods with unfavorable conditions

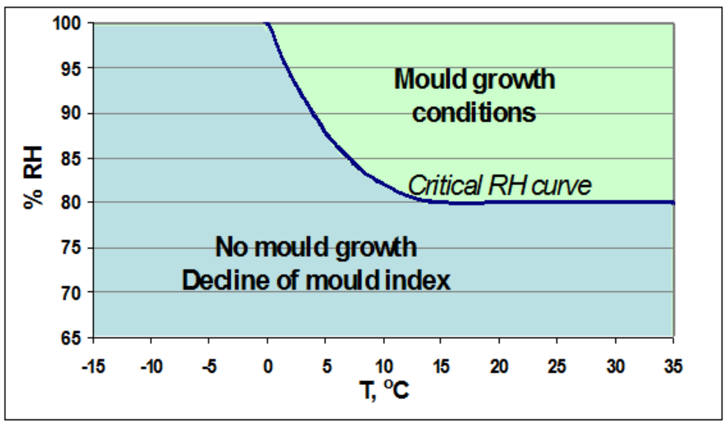
Growth delay due to dynamic conditions

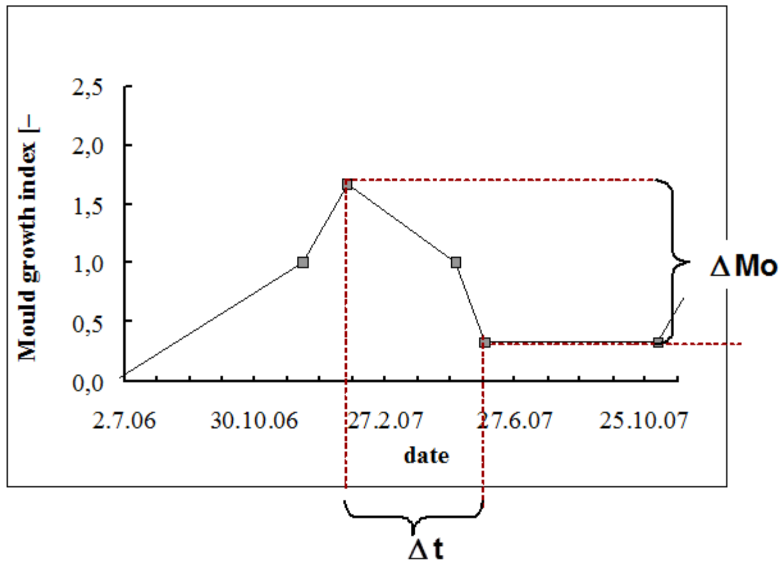
- Hourly / daily cycles can slow down the growth
- Both material capacity and mold growth dynamics have effect on this
- Predicted mold growth on pine sapwood under dynamic cyclic conditions RH 97 % / 75 % and +20 C



Decline of Mold Index

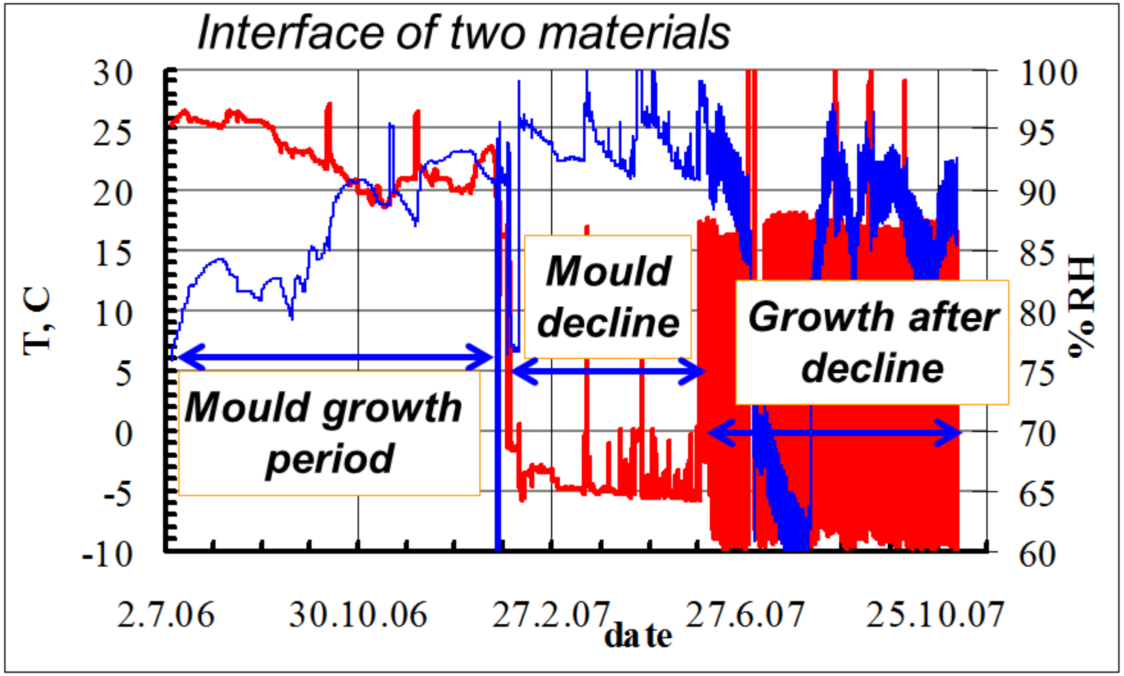
- Detected: Decrease of mold index after unfavorable growth conditions
  - Too cold, too low humidity
  - Does it really affect the level of restarting growth
  - What is the growth intensity after decline periods
- Model for wood gives high decrease





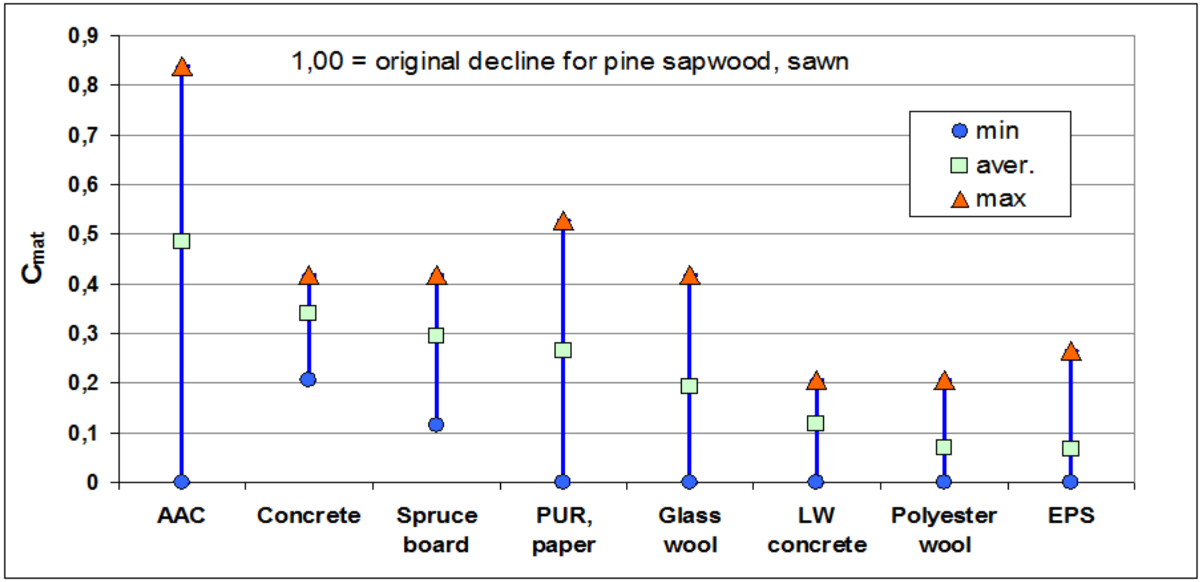
Decline of Mold Index – Seasonal effects on growth level

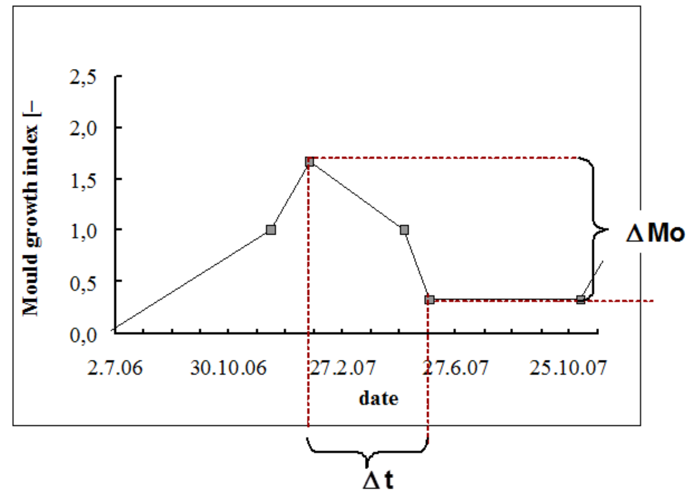
- Experiments under laboratory conditions
- Winter period with freezing temperatures at critical surface



Lähdesmäki, K, Salminen, K, Vinha,J, Viitanen, H, Ojanen, T & Peuhkuri, R. Mould growth on building materials in laboratory and field experiments. 9th Nordic Symposium on Building Physics, NSB 2011, Tampere, Finland, 2011.

Relative mold decline coefficients



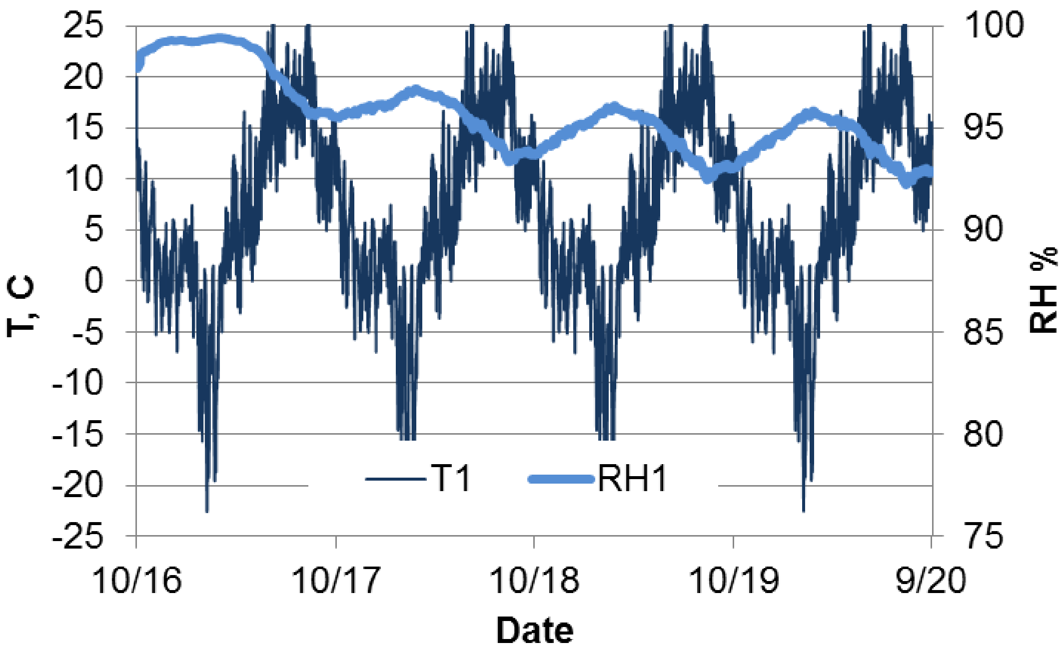


C_{mat}	Description
1,0	Significant decline, pine, short periods
0,5	Relevant decline
0,25	Relatively low decline
0,10	Almost no decline

$$\left.\frac{dM}{dt}\right|_{mat} = C_{mat} \cdot \left.\frac{dM}{dt}\right|_{Pine}$$

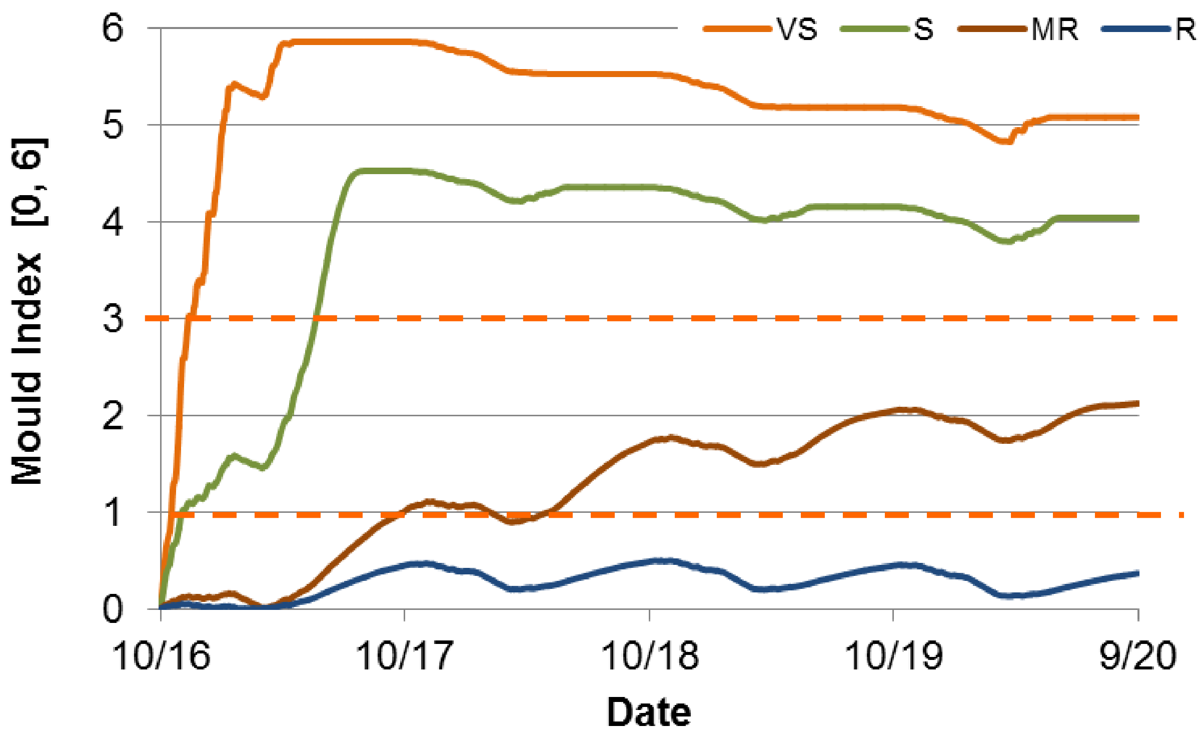
Example – Four year simulation period data – 1

- WUFI 6 – Solved temperature and RH data for critical boundary
- Test the mold model and effect of parameters on Mold index



Example – Four year simulation period data - 2

- Solved mold index levels using different sensitivity classes for growth
- Decline coefficient 0,25 – includes safety

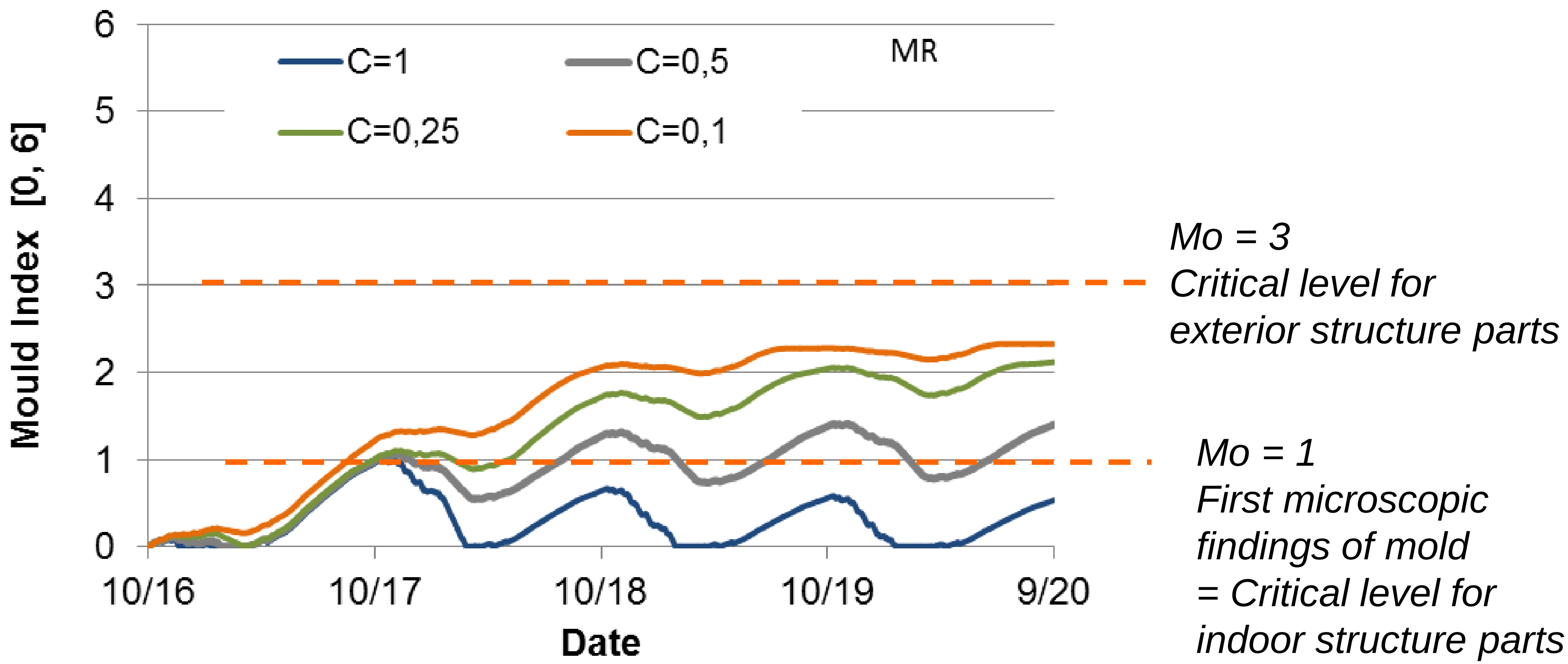


Mo = 3
Critical level for exterior structure parts

Mo = 1
First microscopic findings of mold
= Critical level for indoor structure parts

Example – Effect of decline index

- Medium resistant material – variation of decline index
- All (except C = 1) have risk at indoor surfaces
- None has risk at exterior surfaces
- Risk level about the same when decline index has some safety



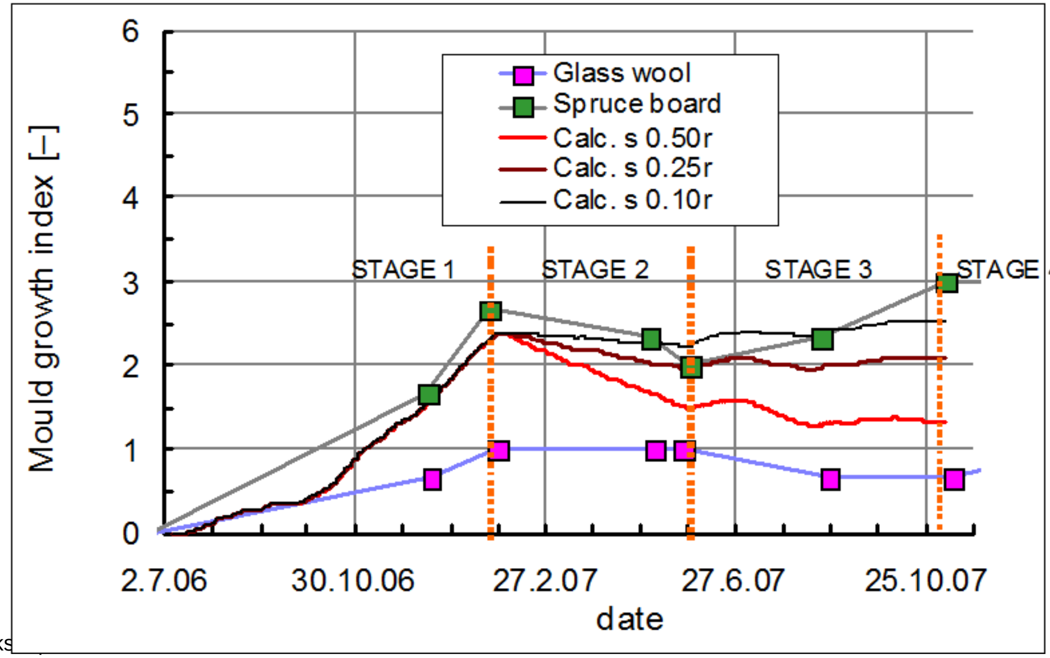
Modeling mold growth on different materials

- Model equations for wood
- Coefficients for different material groups
- Classification according to mold sensitivity classes
- Critical RH-levels for starting growth
- Maximum mold levels
- Decline coefficients for materials

Model evaluation with laboratory experiments

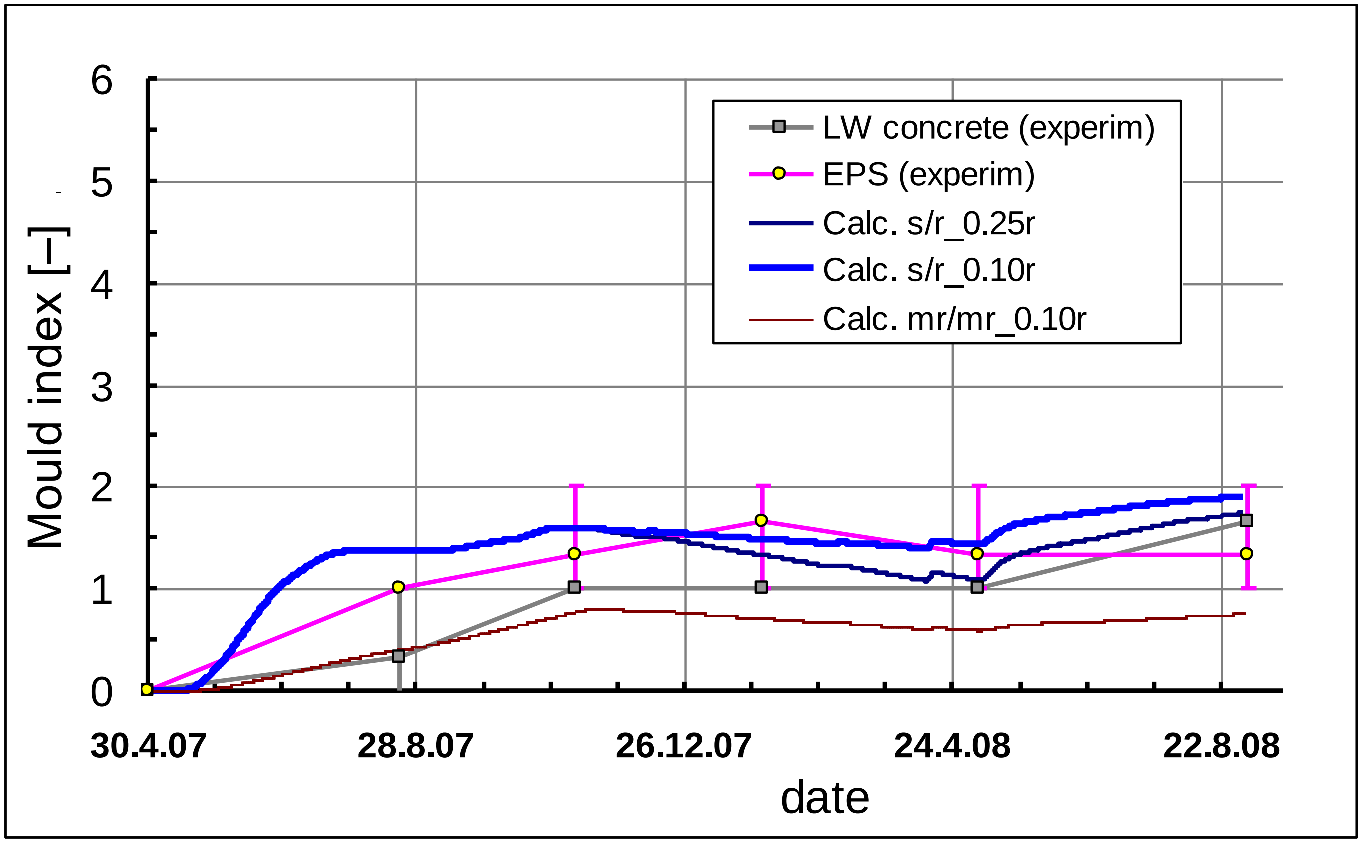
- The (RH/T) conditions and the mold index levels were monitored at the critical interface of two materials

Stage	1	2	3	4
Season	Summer/autumn	Winter	Spring	High exposure
Time, months	7	4	6	12
RH %	80 … 100	92 … 100	60 … 95	94 … 100
Temperature °C	27 … 18	-5 … +3	2 … 10	20 … 24

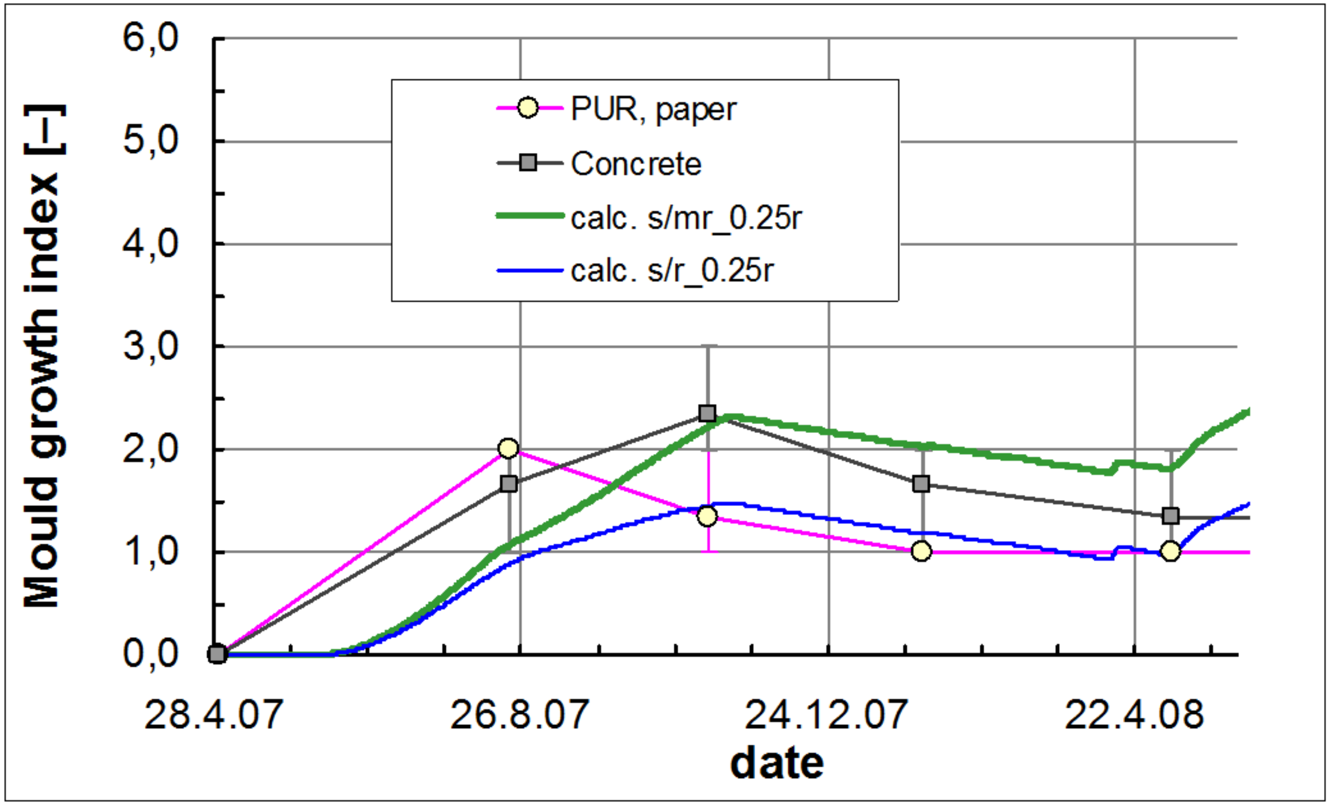


Case 1
Boundary:
Solution using the properties of the more sensitive material

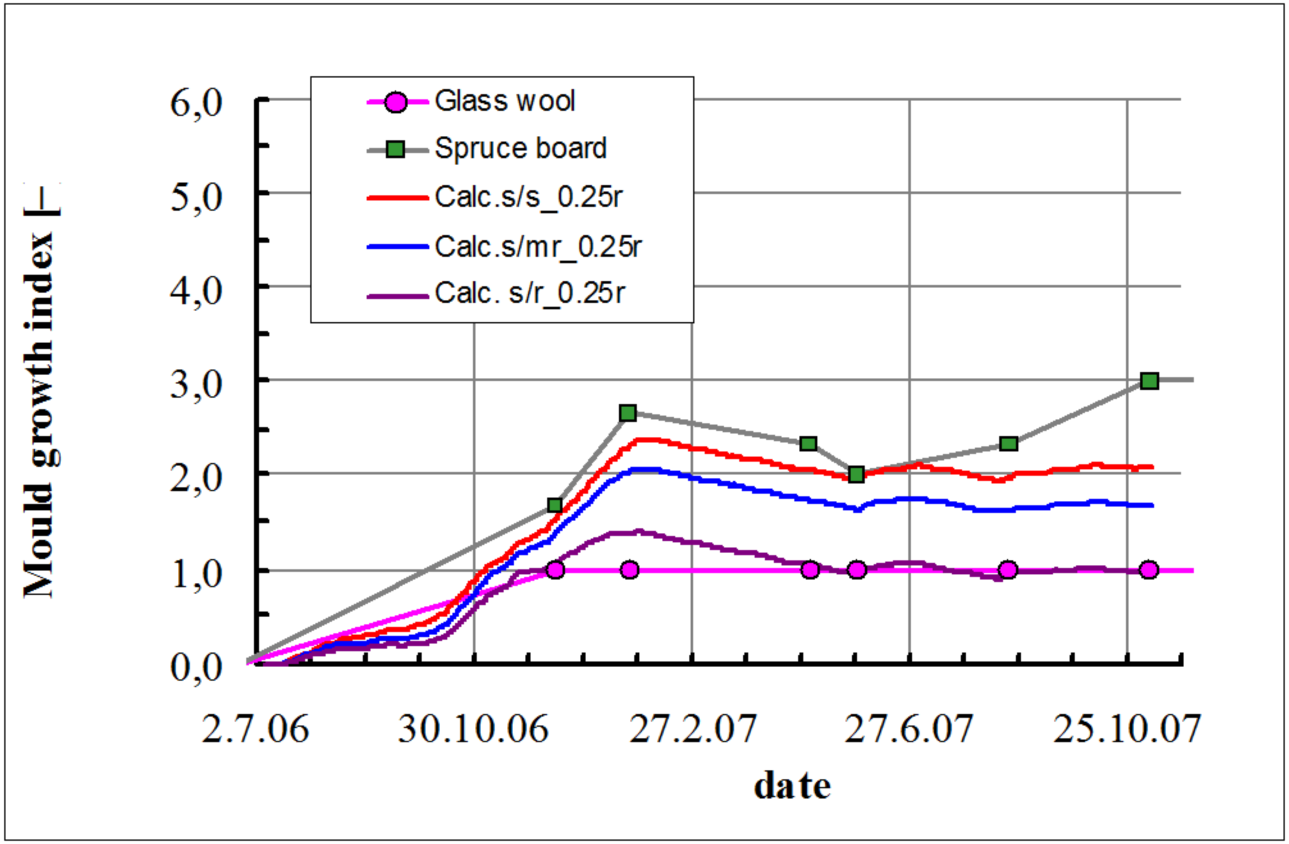
Parameters set according to material classification – Case 2



Parameters set according to material classification – Case 3



Parameters set according to material classification – Case 4



Analysis principles

- Critical parts of the structure, critical boundaries
- Typically use the more sensitive material of the boundary as critical
    - Except when there are inhibitors limiting the growth (fresh concrete, some fire resistance materials, etc.)
- Different criteria for different parts of structure
    - Inside surfaces and material layers that can be in contact with indoor air – typical criteria MI = 1 (max)
    - Exterior or closed internal parts of the structure – criteria MI = 3

Summary

- Classification of materials according to mold growth sensitivity
- Coefficients scale the VTT Mold model for different materials
- Path from experiments to mold index parameters
- **Mold Risk prediction** for different materials
- Sensitivity analysis possible

TECHNOLOGY FOR BUSINESS

Thank you for your attention!