Classification of material sensitivity – New approach for mould growth modeling

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Outline

- Background – Existing mould growth model for wood
- Model parameters and their adjustment for different materials
- Formulation of material sensitivity classes
- Evaluation of the improved model
- Discussion and conclusions

Acknowledgement
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Existing model for pine sapwood

- The model is based on visual findings of mould
- The rate of mould growth is presented as **MOULD INDEX** [0, 6]
- Mould index can be solved numerically
  - **parallel with HAM simulations or as a post processing tool**

Critical factors:

- **Moisture**
- **Temperature**
- **Time**
- **Substrate**

Mould Index – Values for visual observations of the growth level

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 %

Objectives for model development

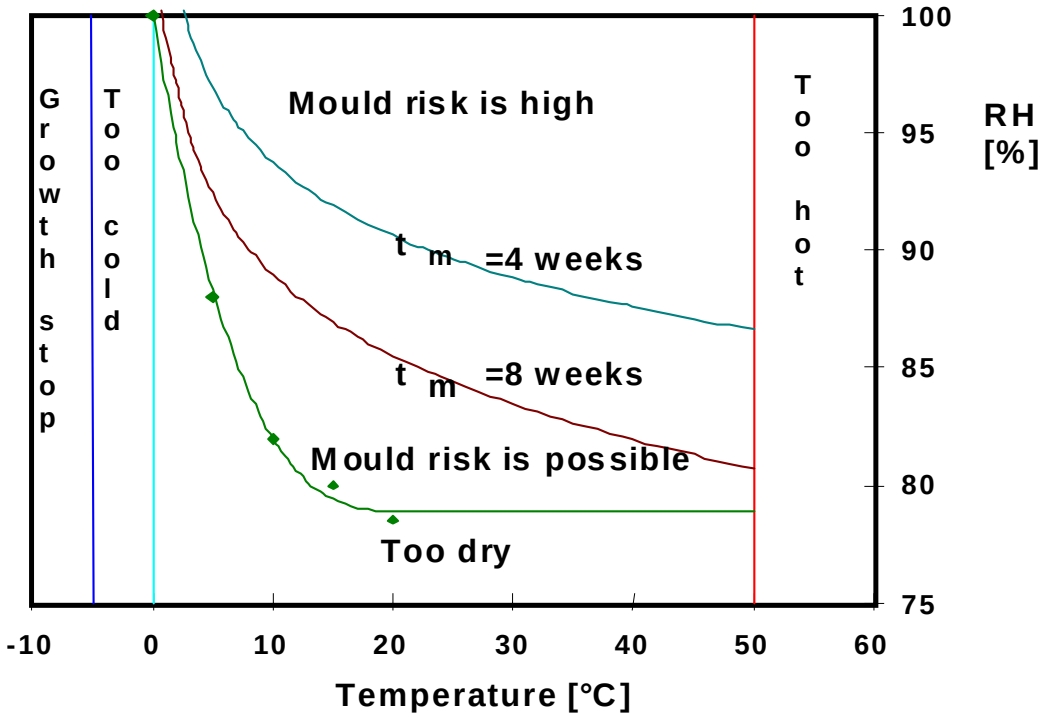
- Improved tool for prediction of mould growth on typical building materials
- The same mould growth parameters are used for all materials
- Scaling factors for material sensitivity classes

Mould growth parameters used in the numerical model

- Substrate, typical building materials
- Growth conditions (RH and temperature)
- Growth intensity
- Maximum growth (Mould index) level
- Decline of visible growth level during unfavorable conditions
- Restarting of growth

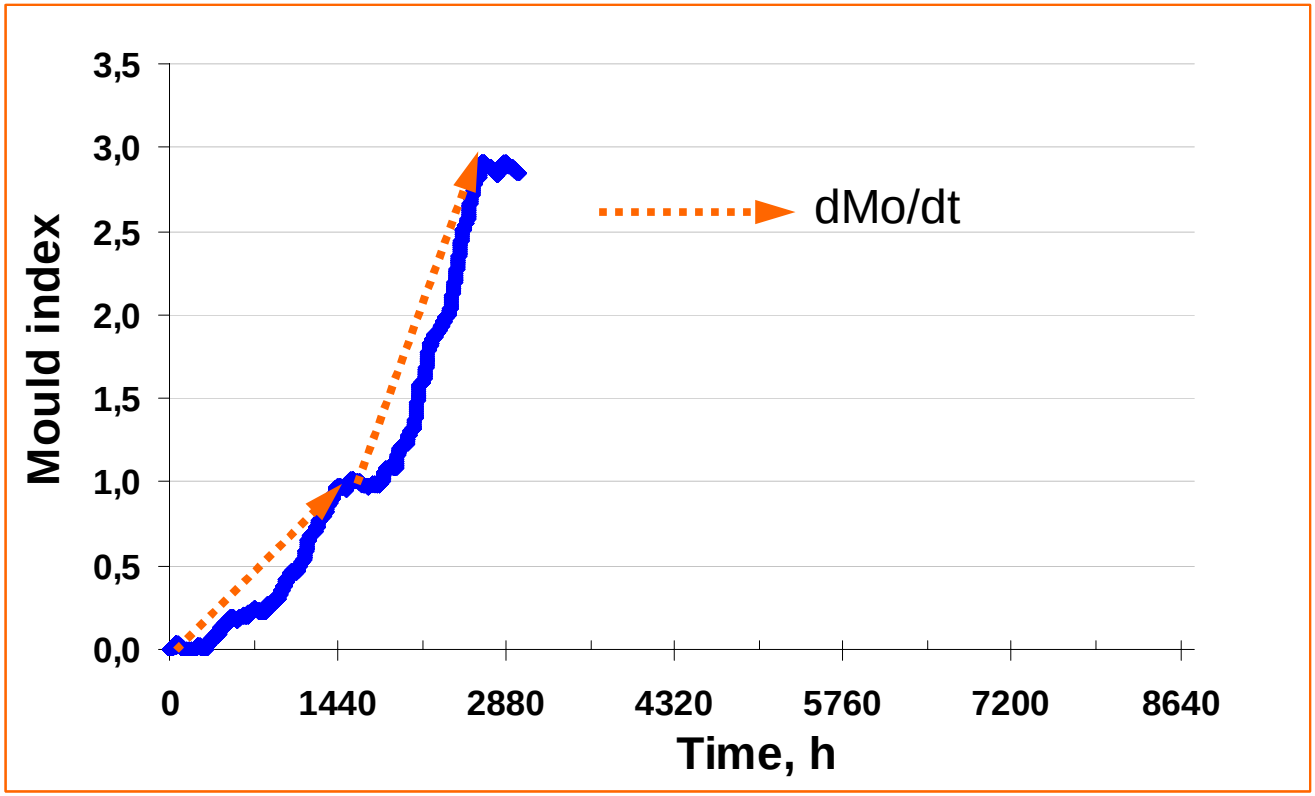
Mould growth conditions

- Pine sapwood



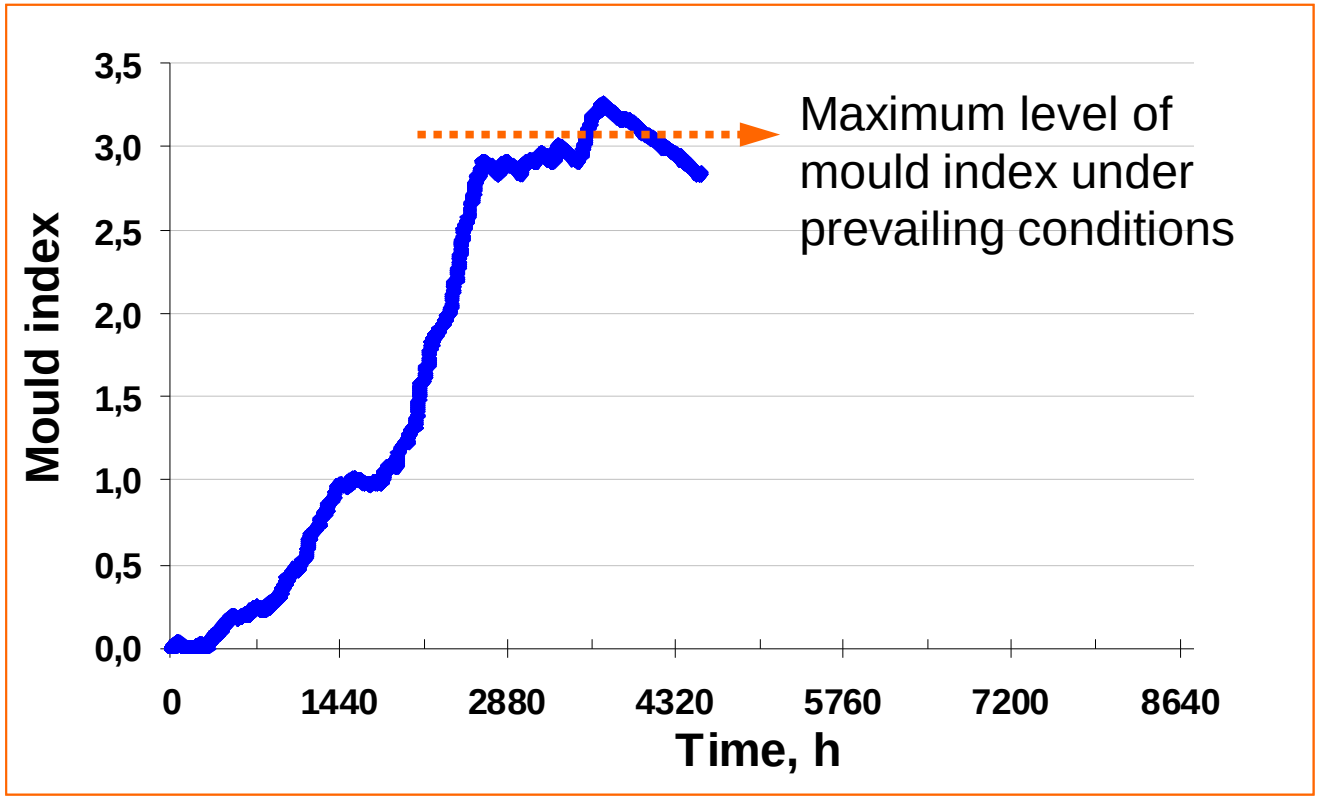
Mould growth intensity

Growth intensity at different stages



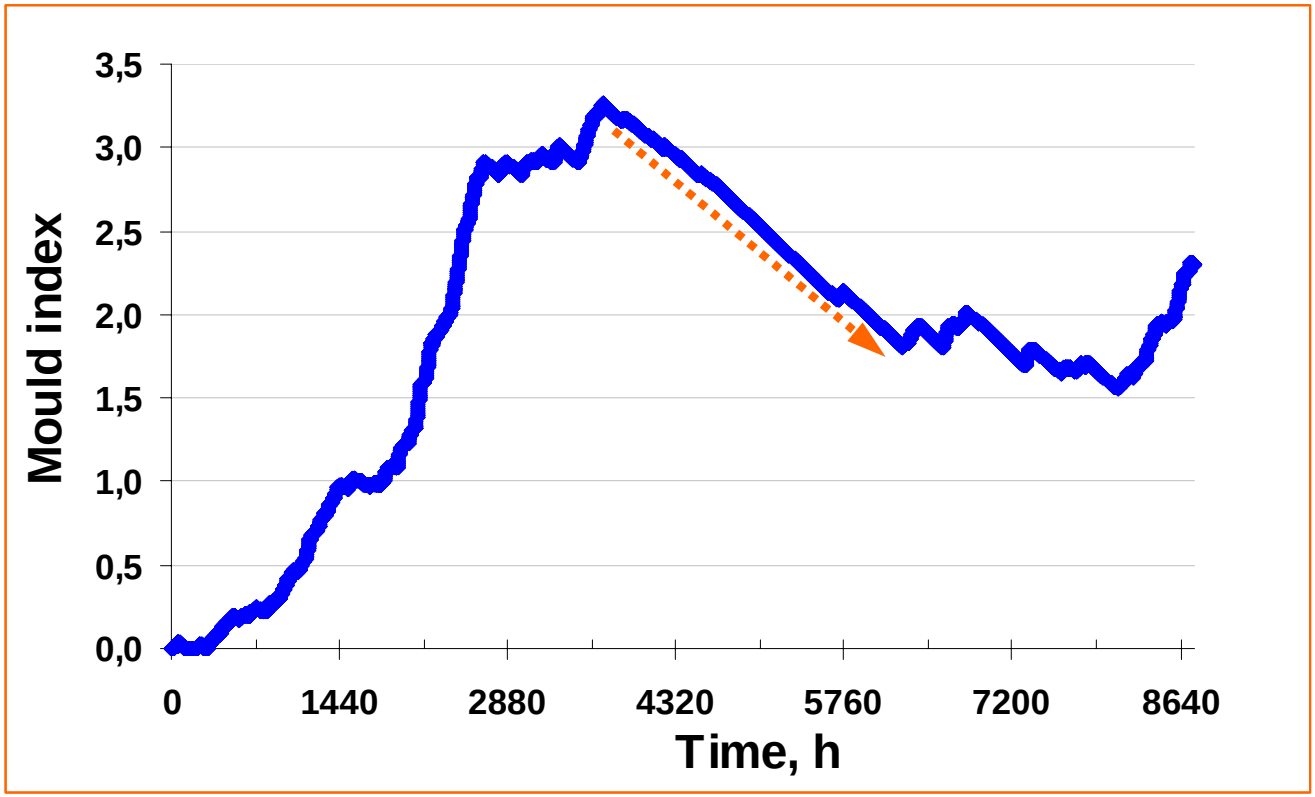
Mould growth level

Temperature, relative humidity and material



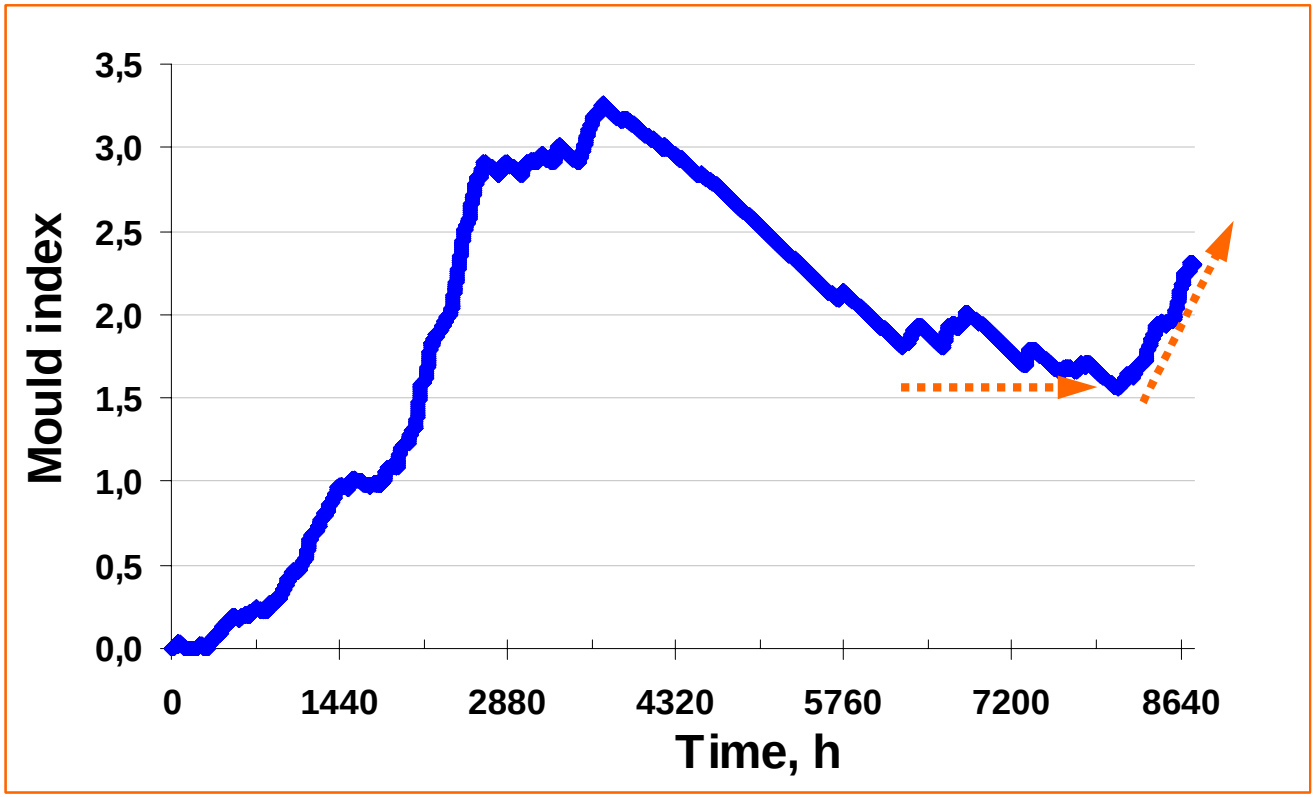
Mould index decline

Unfavourable conditions for growth – cold or dry season

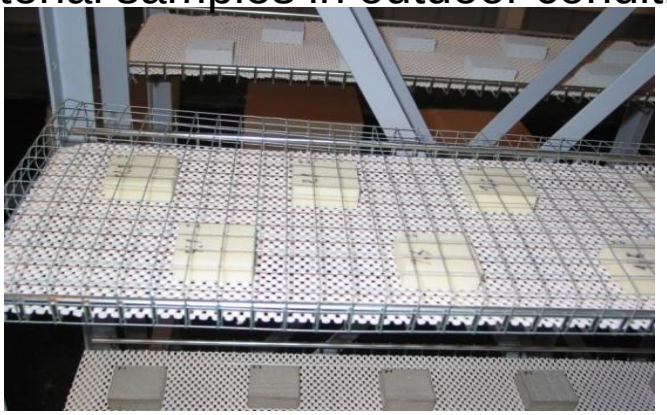


Restart of mould growth

Delays and intensity of restarting growth

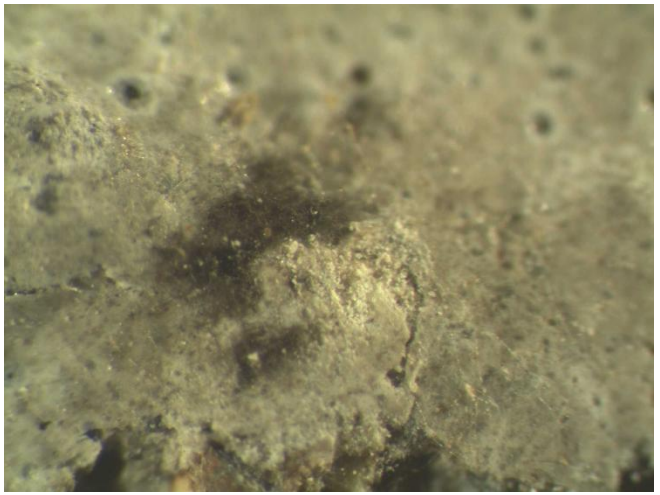


Experimental research for determination of material parameters and evaluation of the model

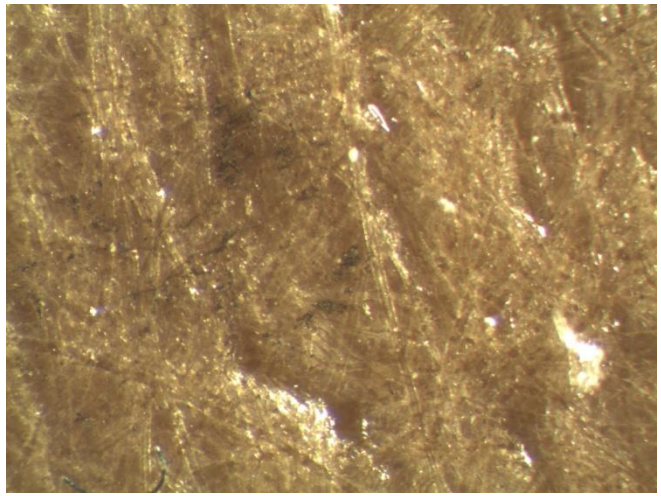
Samples under constant /cyclic conditions 	Material samples in outdoor conditions 
Material interfaces - structures in lab. 	Structures in outdoor conditions 

Mould index [0, 6] detected in different materials

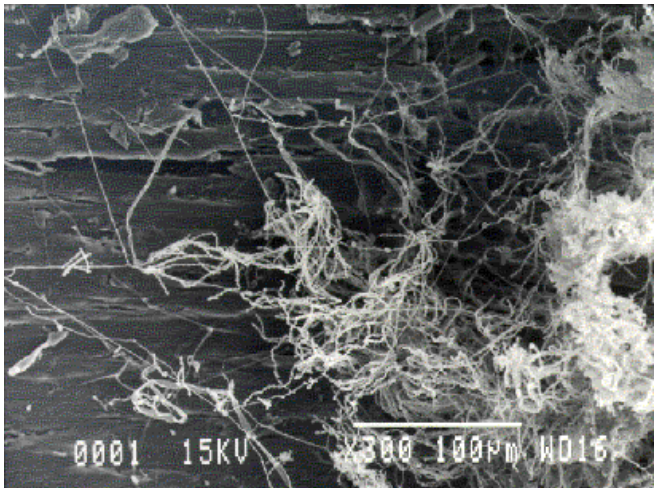
M = 1
Aerated cellular concrete



M = 3 - 4
Concrete

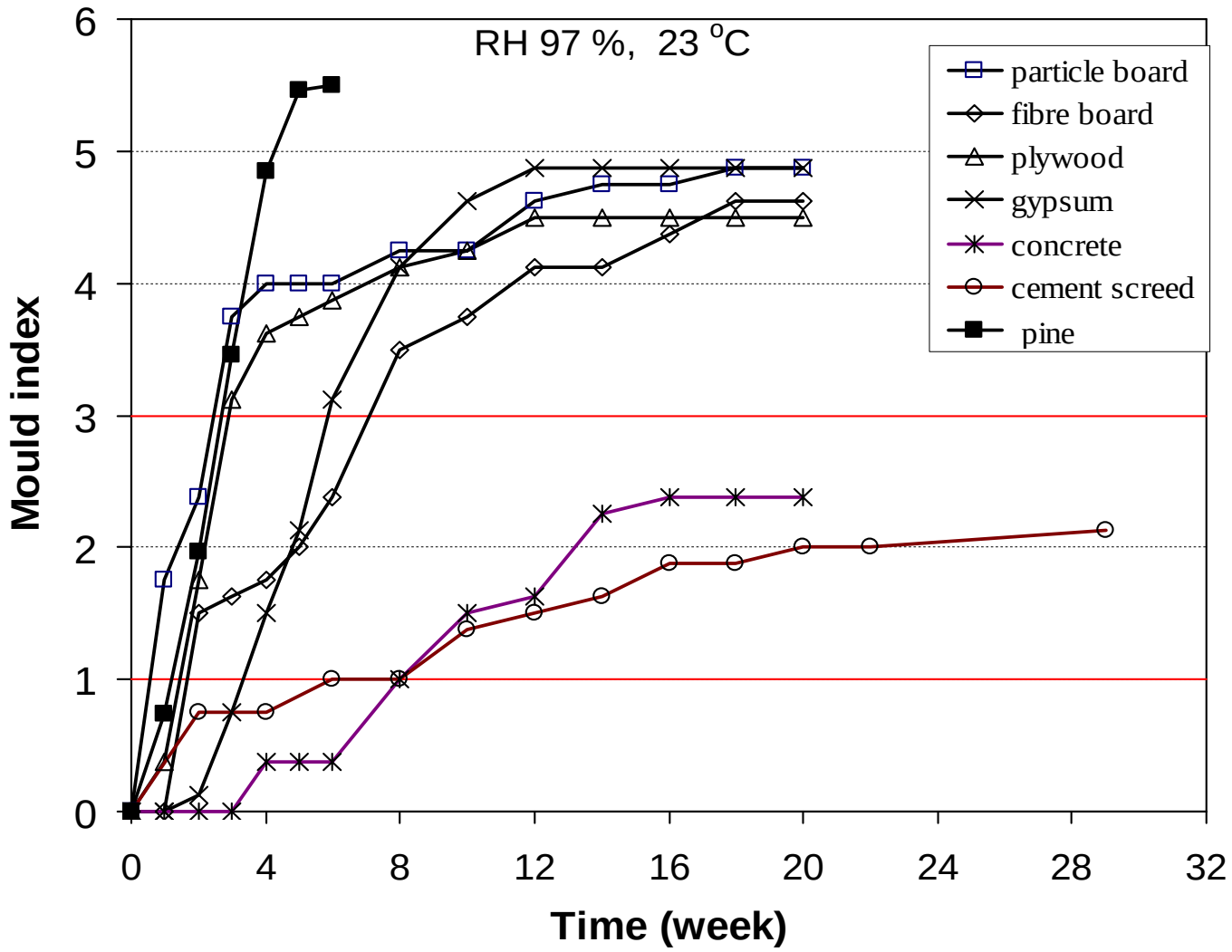


M = 3
PUR + paper surface

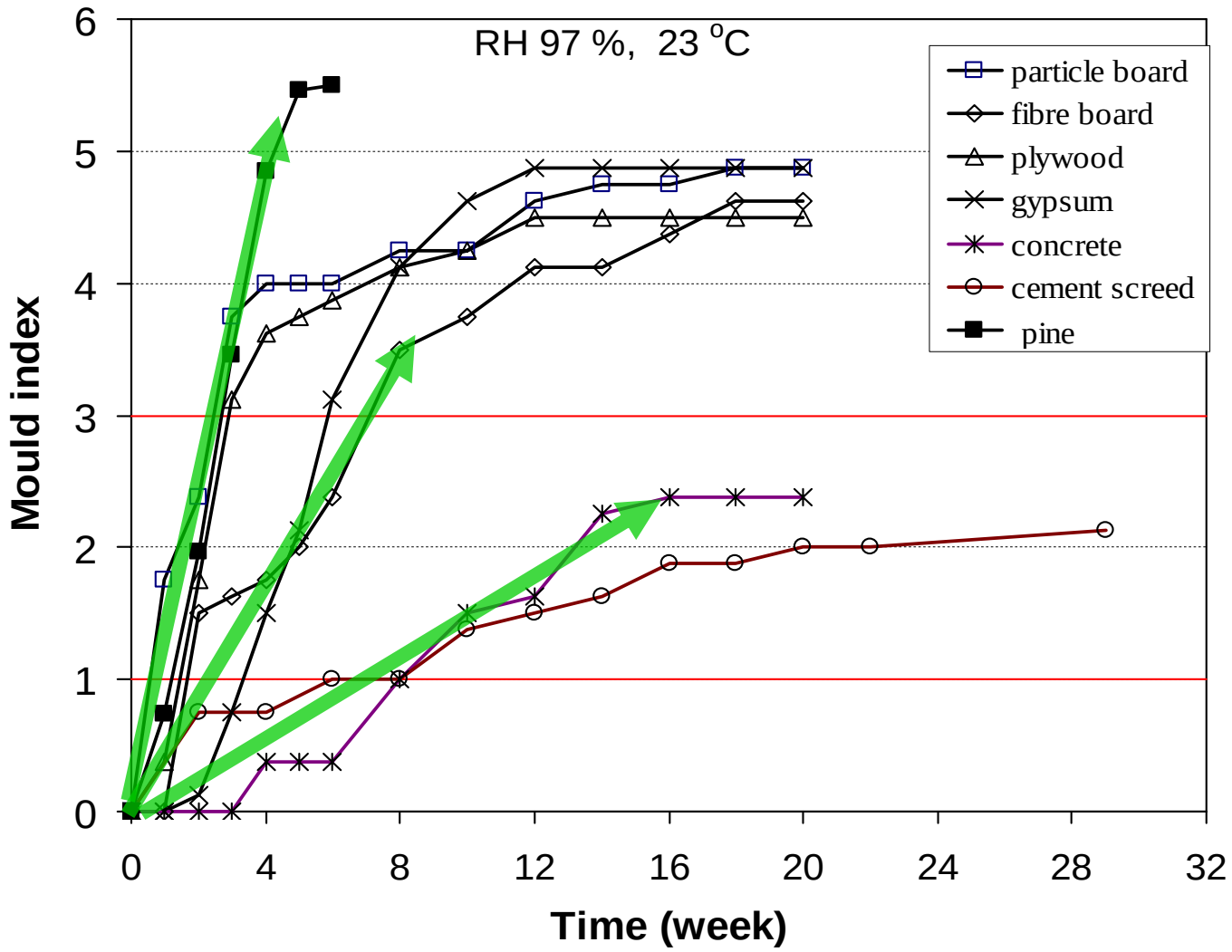


M = 5 - 6
Wooden board

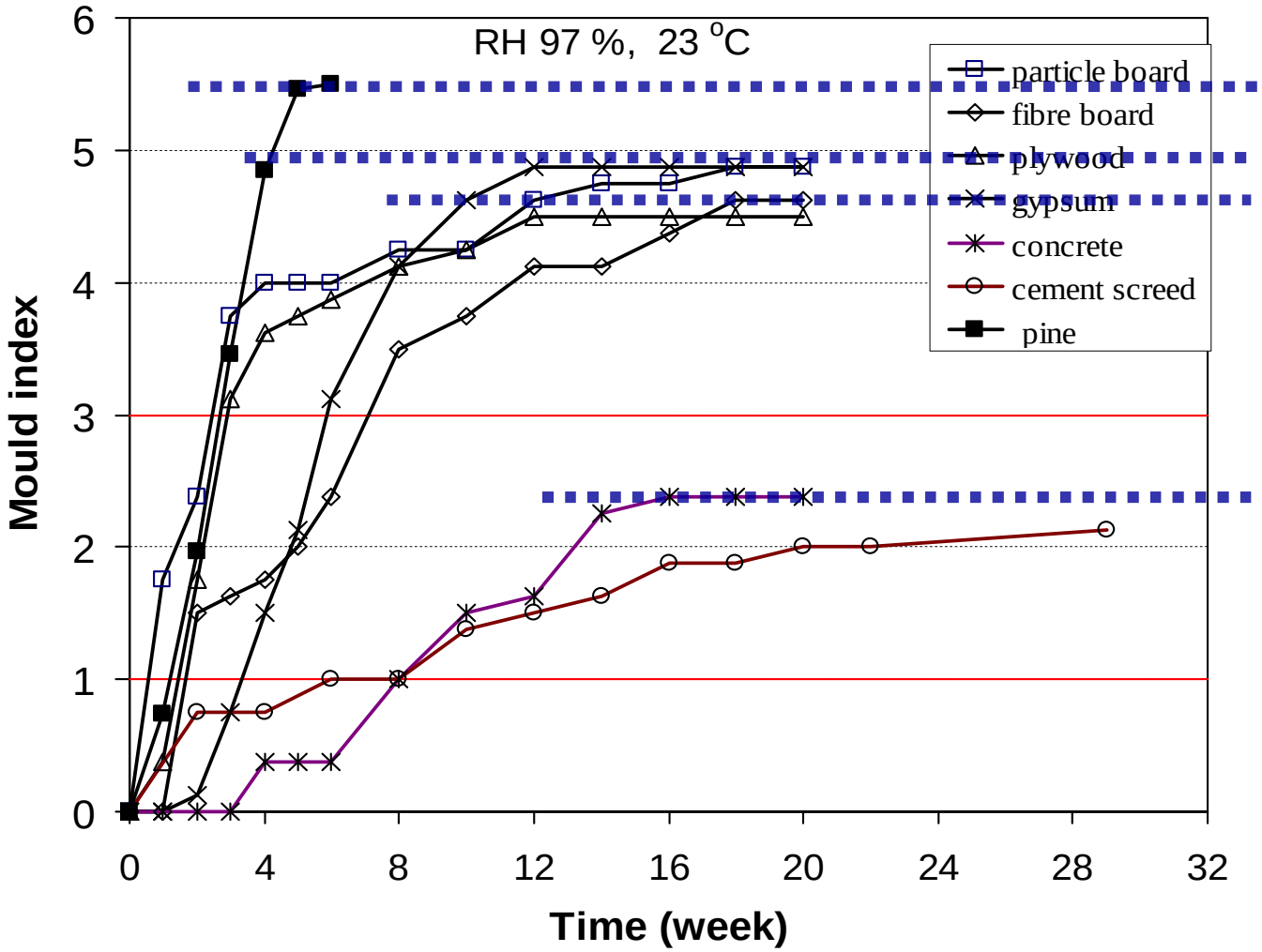
Experimental findings - Mould growth intensities on materials



Mould growth intensity classes



Maximum mould index levels under constant conditions



Maximum levels of growth → Classification

General mould growth equations – Reference material pine

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

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

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

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

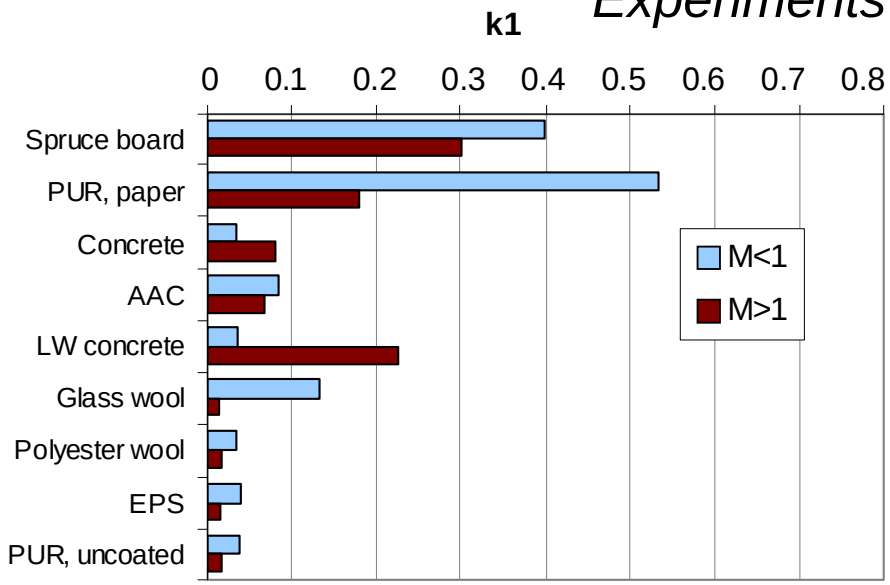
'Scaling factors'

Coefficient k_1 is used to scale the growth intensity

Coefficient k_2 to limit the growth to maximum index level

Four mould growth intensity classes

Experiments → *Material classes*



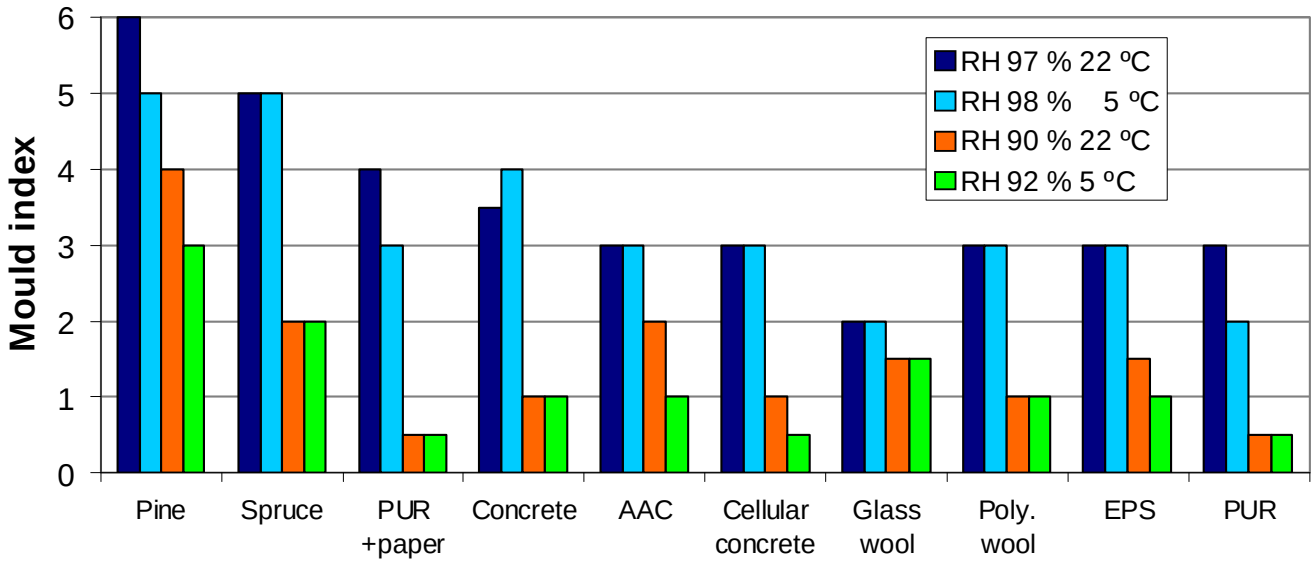
Sensitivity class	k_1	
	M < 1	M ≥ 1
very sensitive	1	2
sensitive	0.578	0.386
medium resistant	0.072	0.097
resistant	0.033	0.014

Very sensitive = pine sapwood

Experimental findings are interpreted with ‘scaling’ coefficients k_1

k_1 values are determined for material sensitivity classes

Maximum growth level – Classification using coefficient k_2



'Scaling' coefficients k_2 are derived from experimental findings

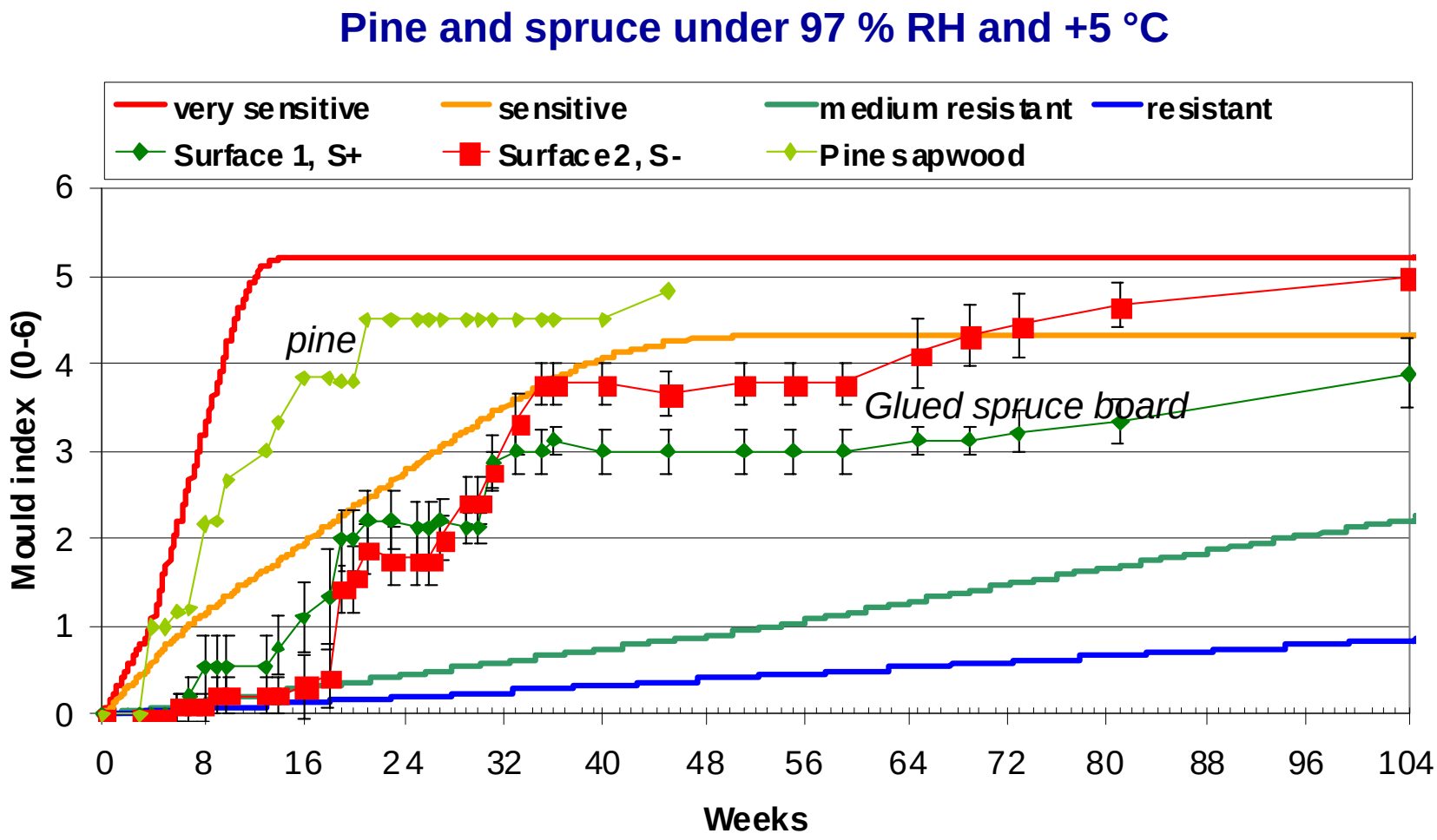
Sensitivity class	k_2 A	k_2 B	k_2 C	RH_{min} %
very sensitive, vs	1	7	2	80
sensitive, s	0.3	6	1	80
medium resistant, mr	0	5	1.5	85
resistant, r	0	3	1	85

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

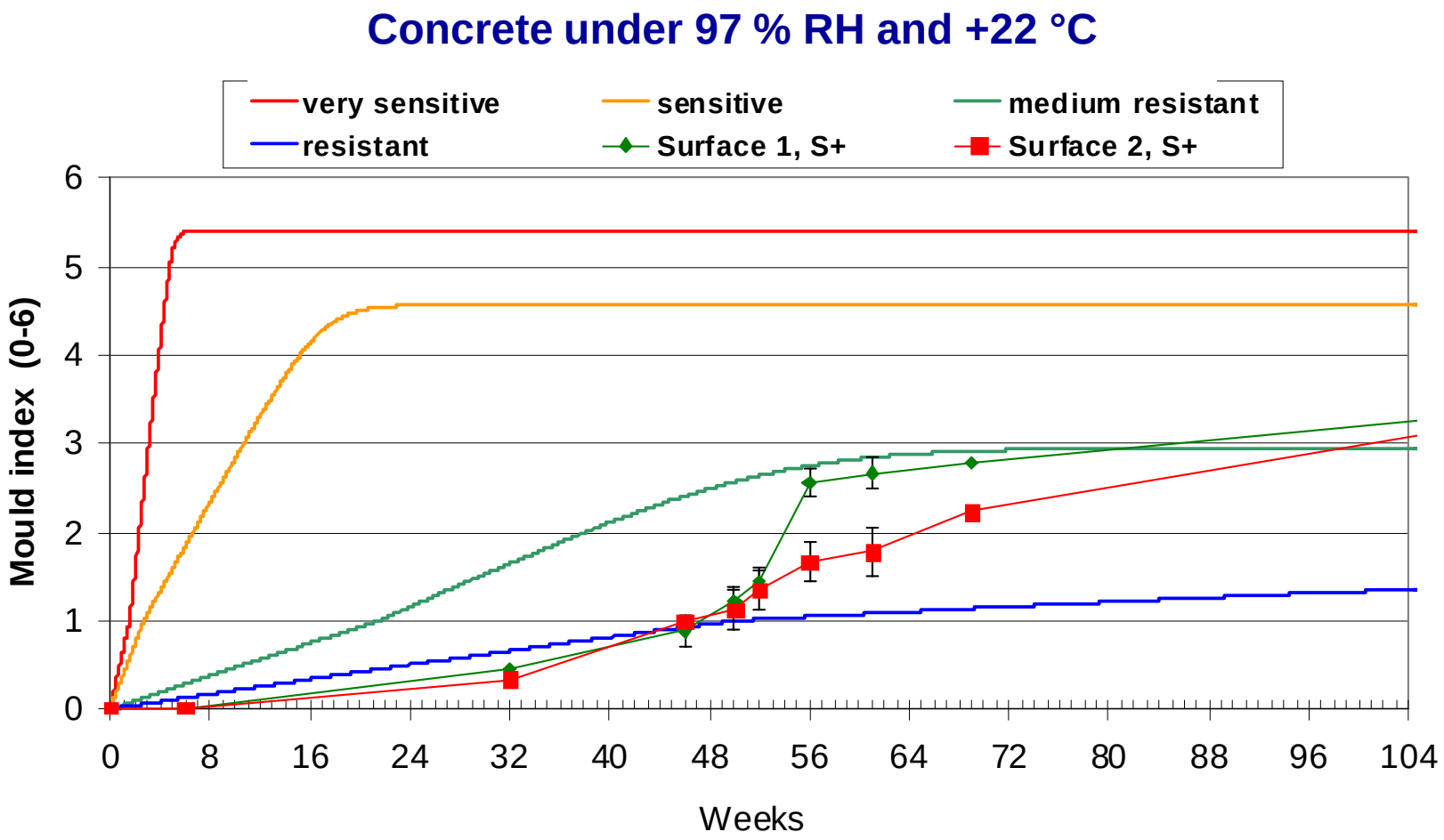
Pine, reference

Values for new sensitivity classes

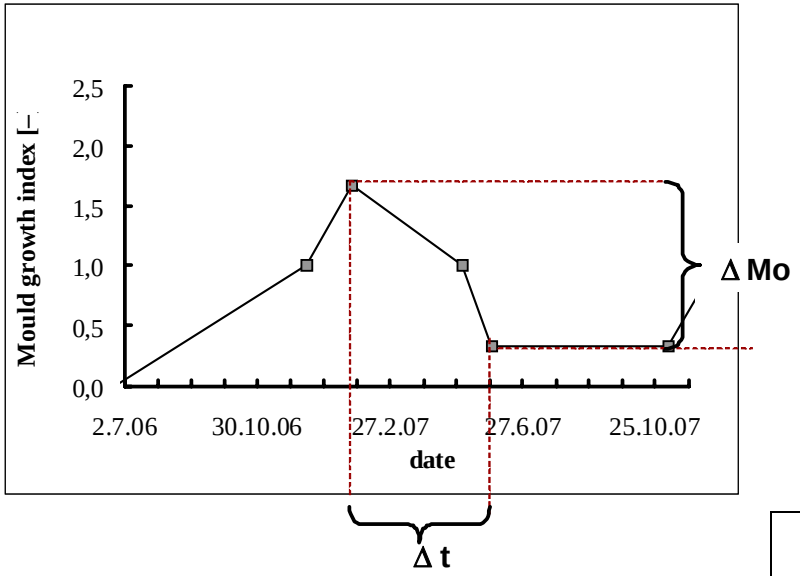
Sensitivity classes and experimental findings under constant conditions



Experiments vs. sensitivity classes



Decline of Mould Index – Seasonal effects on growth level



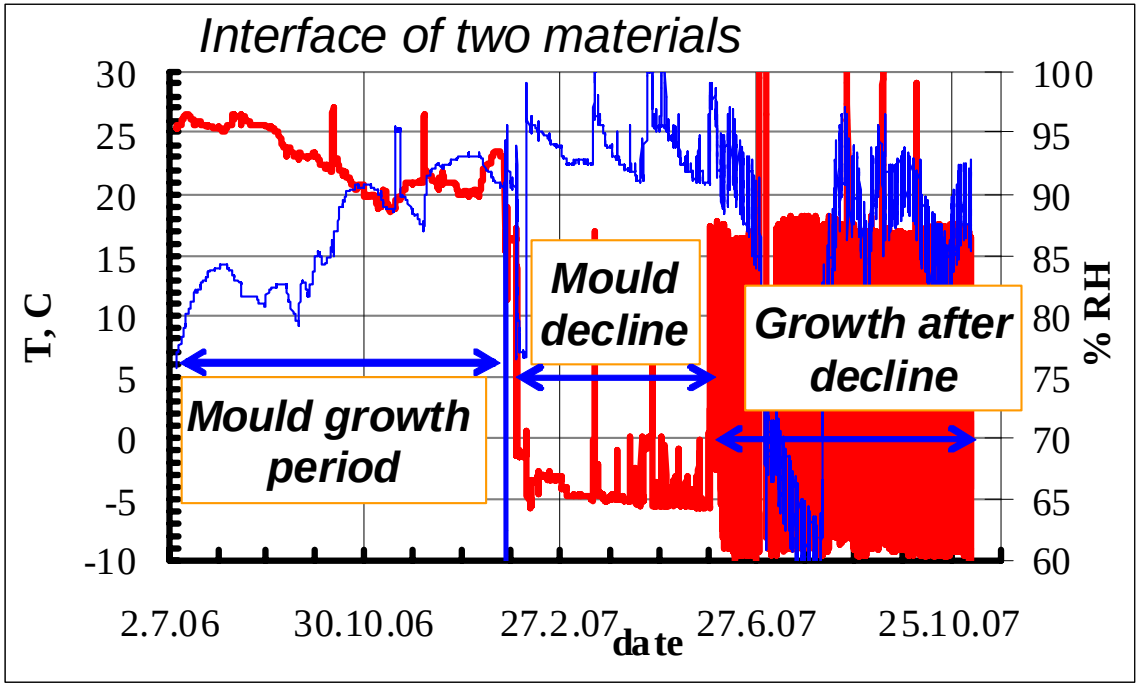
$$\left(\frac{dM}{dt}\right)_{mat} = C_{mat} \cdot \left(\frac{dM}{dt}\right)_{Pine}$$

Correlations factors for mould index decline

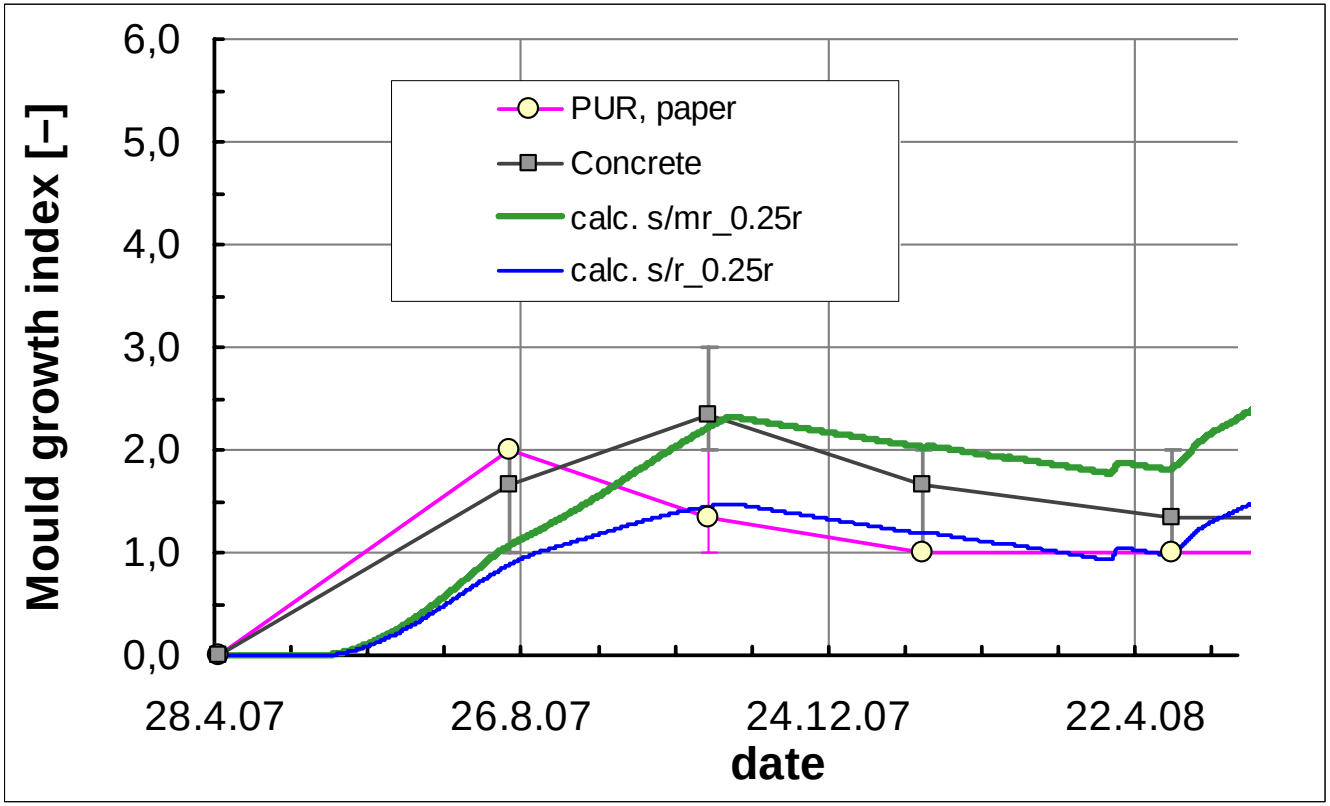
C_{mat}	Description
1.0	Pine in original model, short periods, significant decline
0.5	Relevant decline
0.25	Relatively low decline
0.1	Almost no decline

Model evaluation – Simulation of experiments

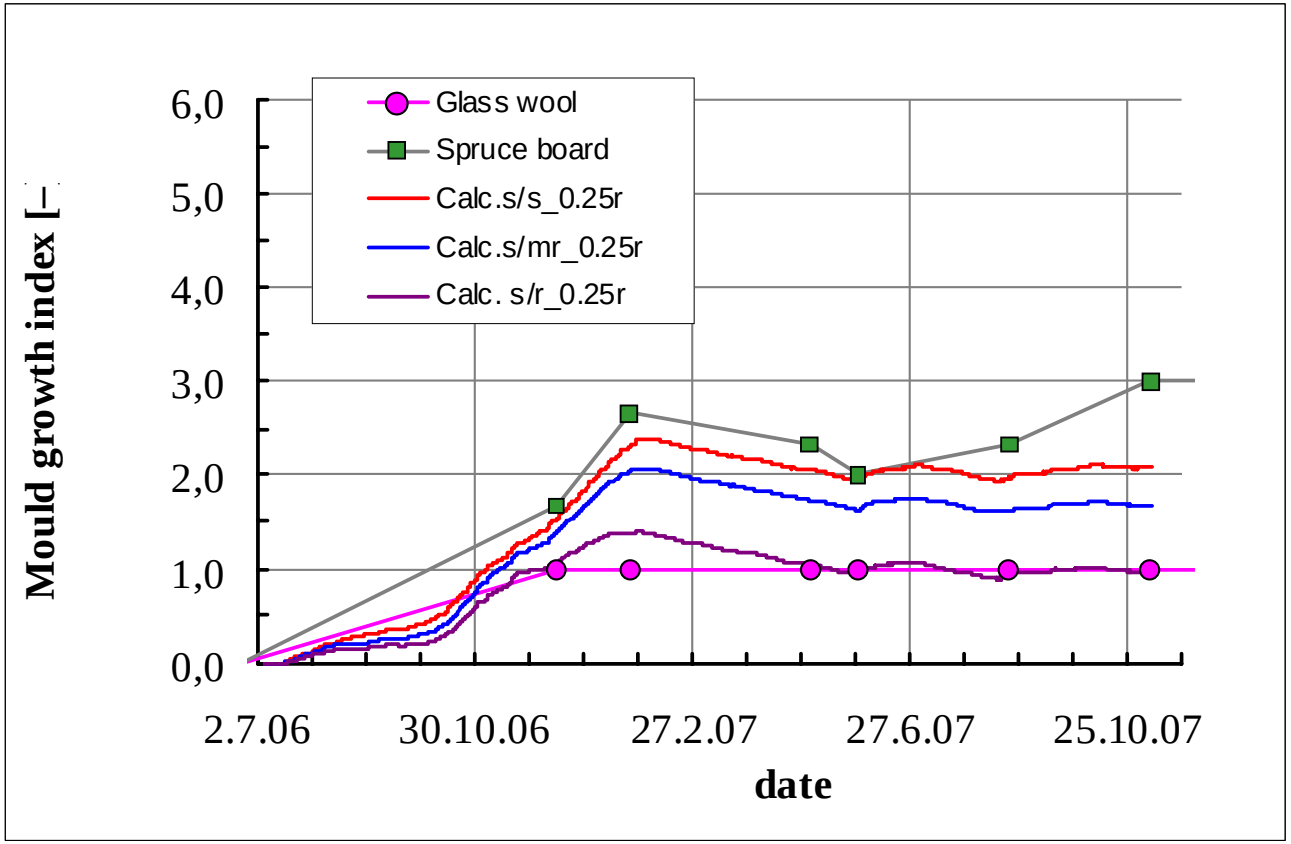
- Interface of two materials inside a structure
- The conditions (RH and T) and the mould index levels were monitored
- RH and T values used in simulations
- Model parameters were adjusted according to material sensitivity classes



Measured vs. simulated : Concrete and paper covered polyurethane foam insulation (PUR)

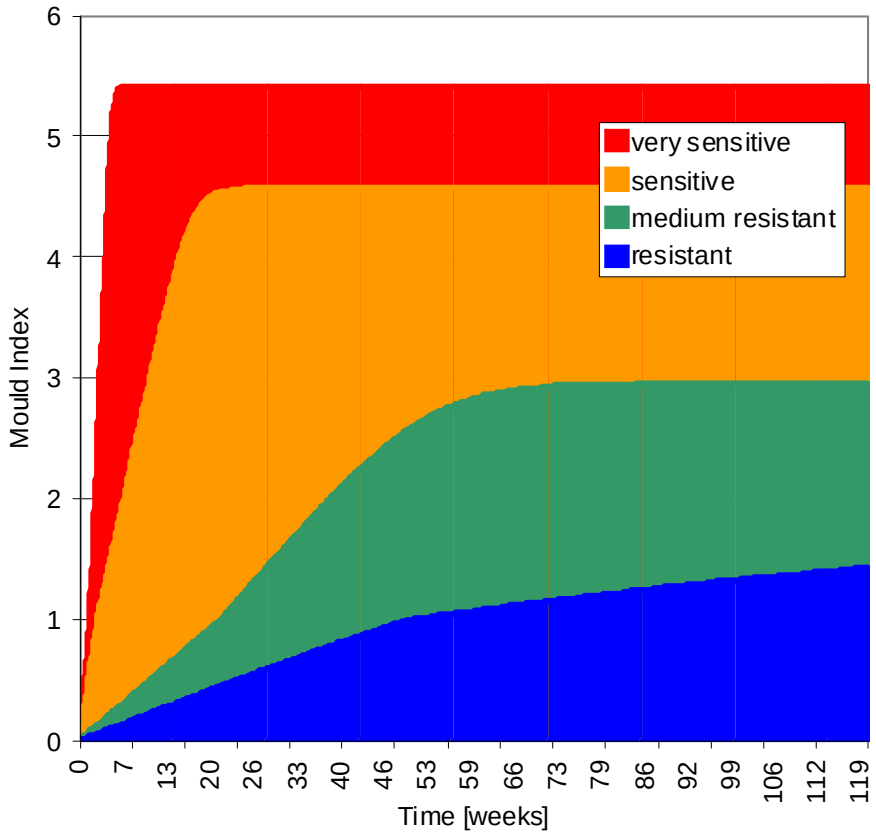


Case 3: Spruce board and glass wool insulation



Mould growth sensitivity classes for materials used in this research

Mould sensitivity class	Typical materials
Very sensitive	Untreated wood, Materials including nutrients
Sensitive	Planed wood, Paper coated products, Wood based boards
Medium resistant	Cement based materials, Plastic based materials, Mineral fibers
Resistant	Glass products, Metal products, Materials with protective compound treatments



Summary

- Improved mould growth model for general building materials
- Mould growth sensitivity classes are used to present different materials
- Sensitivity class factors :
  - Limit conditions for growth
  - Mould growth intensities
  - Maximum mould growth levels
  - Decline of mould under cold or dry periods
- Classification makes it possible to do sensitivity analysis also for biological growth
- The sensitivity classes of materials / products have to be considered and set separately
- Mould growth is one of the performance criteria of structures

Thank you !