Mold growth prediction with Biohygrothermal Model
Mold growth prediction with Biohygrothermal model

Contents:

Mold problems in practice
Growth Conditions
Steady State Model
Dynamic Model
Validation
Mold problems in practice

Mould on a thermal bridge (concrete header joist)
Mold problems in practice

Mould at corners and edges
Mold problems in practice

Mould behind interior insulation slabs (EPS)
Growth conditions

- Humidity
  - Probability of growth
  - Relative humidity [%]

- Substrate
  - Quality
  - 0 to 1

- Temperature
  - Probability of growth
  - Temperature [°C]
  - 0 to 50

- Time
  - Probability of growth
  - Hours/Day
  - 0 to 12

- Photographs of mold growth on different substrates.
**Growth conditions**

<table>
<thead>
<tr>
<th>Mould Species</th>
<th>Temperature Range</th>
<th>Optimum °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absidia glauca</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Alternaria alternata</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Alternaria sp.</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Asp. amstelodami</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Asp. candidus</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Asp. chevalieri</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Asp. flavus</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Asp. fumigatus</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Asp. nidulans</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Asp. niger</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Asp. penicillioides</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Asp. repens</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Asp. restrictus</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Asp. ruber</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Asp. terreus</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Asp. versicolor</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Aureobasidium pullulans</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Botrytis cinera</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Cla. cladosporioides</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Fusarium culmorum</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Fusarium oxysporum</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Mucor plumbeus</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Neurospora sitophila</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Pen. bervicompactum</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Pen. chrysogenum</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Pen. citrinum</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Pen. cyclopium</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Pen. expansum</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Pen. frequentans / glabrum</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Pen. glabrum</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Pen. italicum</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Rhizopus stolonifer</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Scopulariopsis brevicausalis</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Stachybotrys atra</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Trichoderma viride</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Trichothecium roseum</td>
<td>0-60</td>
<td>30</td>
</tr>
<tr>
<td>Wallemia sebi</td>
<td>0-60</td>
<td>30</td>
</tr>
</tbody>
</table>
Growth conditions

Humidity range for growth of different mold species

- Eurotium amstelodami
- Xeromyces bisporus
- Eurotium halophilicum
Growth conditions

Aspergillus restrictus (Smith)

Hygrothermal Iso-lines for germination time and growth rate of a typical mould species
Growth conditions

Aspergillus restrictus and other species

![Graph showing growth conditions for Aspergillus restrictus and other species.](image)
Growth conditions

Critical species:
- *Aspergillus fumigatus*
- *Aspergillus flavus*
- *Stachybotrys chartarum*

Potentially hazardous mold species need higher humidity to germinate.
Growth conditions

IBP mold growth test set-up:
Observation of the growth of a typical mold cocktail on different building materials
Growth conditions

Substrate Classification

II  non biodegradable building materials

I  biodegradable building materials

0  optimum substrate
Growth conditions

Comparison of LIM with literature data

IEA-Annex 14 & German Standard DIN 4108: 80 %
Steady State Model

Steady-state conditions

Temperature outside: -5 °C

R = 3.5 m²K/W

Temp. in the room: 20 °C
RH in the room: 50 %
RH in the room: 60 %

Cabinet

13 °C  19 °C  17 °C
78 % RH  53 % RH  62 % RH
94 % RH  63 % RH  74 % RH

18 °C
55 % RH
66 % RH
Steady State Model

Substrate group I

Temperature outside: -5 °C
R = 3.5 m²K/W

Temp. in the room: 20 °C
RH in the room: 50 %

Cabinet

13 °C
78 % RH
94 % RH

19 °C
53 % RH
63 % RH

17 °C
62 % RH
74 % RH

18 °C
55 % RH
66 % RH

Daily temperature and humidity readings for different months.

Degree of germination [

Corner
Behind cabinet

Date [month]
Nov Dec Jan Feb Mar
Steady State Model

Transient conditions

Steady state model for transient conditions ?!
Dynamic Model

Dynamic model for transient conditions

model spore

- outside
- wall
- inside
- spore interior (moisture retention curve)
- spore wall (permeability)
Dynamic Model

Model spore

Water retention curve

Spore wall permeance
Dynamic Model

Definition of critical spore water content for germination

![Graph showing the definition of critical spore water content for germination. The graph illustrates the relationship between temperature and relative humidity, with different curves representing different levels of water content. The critical limits (LIM0, LIM1, LIM2) are marked on the graph, indicating the threshold points for germination.]
## Dynamic Model

### Model assumptions of WUFI-Bio

<table>
<thead>
<tr>
<th>Factor</th>
<th>Real life</th>
<th>WUFI-Bio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humidity &amp; Temperature</td>
<td>determining factors</td>
<td>critical water content $= f (\varphi, \theta)$</td>
</tr>
<tr>
<td>Time</td>
<td>strong influence</td>
<td>germination, growth rate $= f(t)$</td>
</tr>
<tr>
<td>Substrate</td>
<td>availability of nutrients,</td>
<td>LIM 0, LIM 1, LIM 2</td>
</tr>
<tr>
<td></td>
<td>(concentration of growth inhibiting chemicals)</td>
<td>material specific isopleths</td>
</tr>
<tr>
<td>pH-Value</td>
<td>high pH is toxic</td>
<td>not accounted for</td>
</tr>
<tr>
<td>Spore dissemination</td>
<td>spores are ubiquitous in air</td>
<td>spores are assumed to be present</td>
</tr>
<tr>
<td>Lethal conditions</td>
<td>high and low temp. or low RH</td>
<td>decline not yet accounted for</td>
</tr>
<tr>
<td></td>
<td>may be lethal</td>
<td>$&gt;&gt;$ evaluation should be confined to 12 month starting anytime within the simulated period</td>
</tr>
</tbody>
</table>

---
Mold growth prediction with Biohygrothermal Model