Session 1 – Building Mycology

Lone Ross Gobakken

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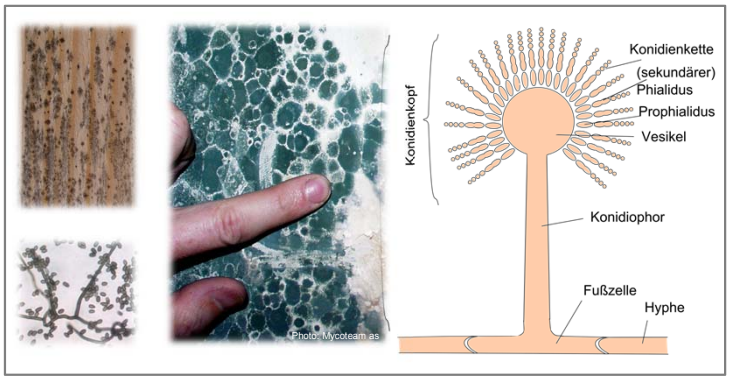
Norwegian Forest and Landscape Institute



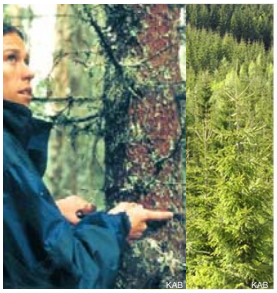
COST FP1303
Performance of bio-based building materials

MYCOTEAM

SP
Your Science Partner

The Norwegian Forest and Landscape Institute

- Established 1st July 2006 through a merger between:
  - The Norwegian Forest Research Institute (Skogforsk)
  - The Norwegian Institute of Land Inventory (NIJOS)
  - Norwegian Genetic Resource Centre
- 220 employees
- Research within:
  - Biological diversity
  - Ecology and the environment
  - Forestry
  - Technology and economy
  - Wood material science
  - Landscape sciences
- An administrative agency under the Ministry of Agriculture and Food



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Section Wood Technology

Section Wood Technology

- Wood anatomy, -mechanics and -physics
- Natural durability
- Wood protection
  - impregnation
  - modification
  - surface treatment
  - testing
- Service life prediction and LCA
- Lumber treatment
  - storing
  - Transport
- Fire testing

- Lumber quality
  - forest management
  - outdoor claddings
- Non-destructive test methods
  - decay
  - surface moulds
  - wood properties
- Drying of wood
- Sawmilling
- Bioenergy
- Molecular biology
- Product development

July 1 2015:

Norwegian Institute of Bioeconomy Research (NIBIO)

Merge of:

- The Institute for Agricultural and Environmental Research (Bioforsk)
- Norwegian Agricultural Economics Research Institute (NILF)
- Norwegian Forest and Landscape Institute
- 750 employees

NIBIO
NORSK INSTITUTT FOR BIOØKONOMI

Building Biology

Building biology is a field of building science investigating the indoor and outdoor living environment for a variety of biological agents.

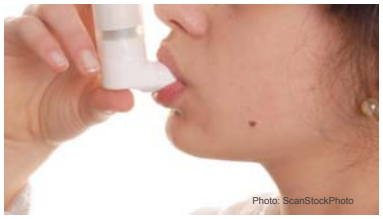
Biological agents: fungi, bacteria, insects, marine borers, lichens, algae, birds

Building Mycology

'*Building mycology* - the study of fungi in and around the building environment, having direct and indirect effect on the health of the building, its materials, structures and occupants.

- Mould – 1) affects the quality of the adjacent air space with volatile compounds and spores, 2) make the materials and components less aesthetically acceptable.
- Decay fungi - forms a serious risk for structural strength depending on moisture content, materials, temperature and time

Causes: natural aging and damage of materials due to different chemical, physical, and biological processes



- Any experience with fungal damages in/on a building?
- Can we have an building environment without any fungal activity/occurance?

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‘Natural and unnatural’ occurrence of fungi in buildings

- An building environment will always have some type of fungal activity/occurrence
- What is excepted?
- What can we accept?
  - Indoors (guidelines and regulations)
  - Outdoors
- Not a defined line between what is ‘natural’ and what is ‘unnatural’
  - Threshold levels – will vary depending on type of construction and use
  - Technical issues
  - Health related issues
  - Aesthetic appearance

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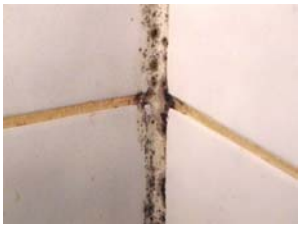
Natural occurrence indoors
(- in buildings without major failures, leakage, heavy weather impacts)

- Airborne fungal spores – in the air and as sediment on surfaces
- Bathrooms/showers/kitchens/gully - wet and humid areas
- On soil in flower pots
- On food; fruit, bread, cheese etc
- On garbage, food waste for recycling
- Condensation; ‘sweating’ around pipework, ‘cold’ corner/walls, windows



Natural occurrence outdoors
(- in buildings without major failures, leakage, heavy weather impacts)

- Fungal spores present in the air at all times
- Over time – on facades, roofs, trim, deckings, fences, banisters, rain gutters etc

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Typical causes that lead to fungal damages in/on buildings
– indoors and outdoors

- Climate – severe weather incidents
  - Hurricanes, tornadoes, floods, heavy snow/rain etc.
- Construction
  - Malfunction and sub-optimal solutions, detailing, craftsmanship
  - Architecture and design
  - Handling and storage
- Material/product selection – material/product not fit for the use class / application or not 'good enough'
- Fires and extinguish of fire with water
- Occupants and their use of the building
  - Maintenance / cleaning
  - Ventilation combined with heating/temperature / condensation
  - Production of moisture/damp – cooking, laundry, showering etc
  - Positioning and storage of object/furniture
- End of life - components, materials and constructions
- Regulations?

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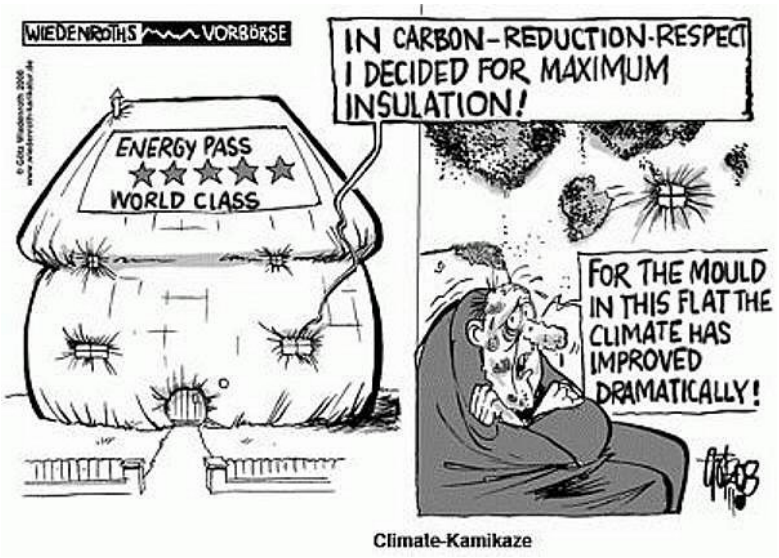

Climate-Kamikaze

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The kingdom of fungi

- Approx. 100 000 species have been described
  - worldwide distribution
  - wide range of habitats

Kingdom: Fungi ("the real fungi")

6-8 phyla/divisions (classified on the basic of their sexual reproductive structures):

- *Microsporidia* - unicellular parasites of animals and protists
- *Glomeromycota* (*Zygomycetes*)- form of symbiosis wherein fungal hyphae invade plant root cells and both species benefit from the resulting increased supply of nutrients
- *Chytridiomycota* - produce zoospores that are capable of active movement through aqueous phases
- *Blastocladiomycota* - saprotrophs, feeding on decomposing organic matter, and they are parasites of all eukaryotic groups
- *Neocallimastigomycota* - anaerobic organisms, living in the digestive system of larger herbivorous mammals and in other terrestrial and aquatic environments enriched in cellulose
- *Ascomycota* - form meiotic spores called ascospores, which are enclosed in a special sac-like structure called an ascus
- *Basidiomycota* - produce meiospores called basidiospores on club-like stalks called basidia, mushrooms decay fungi

- Anamorphic fungi (*Deuteromycetes*)
  - a group of fungi observed to produce asexual spores or no spores

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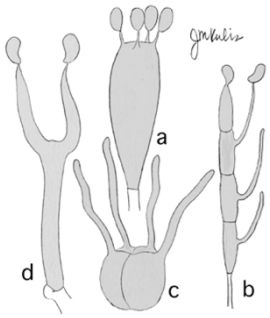
Decay fungi

- Basidiomyceter
  (some exceptions)

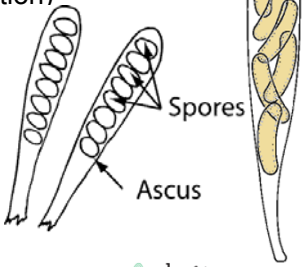


Moulds and blue stain fungi

- Deuteromyceter (fungi imperfecti – asexual reproduction)
- Ascomyceter
- Zygomyceter

Deuteromyceter - acervuli

Sordaria fimicola - an ascomycete



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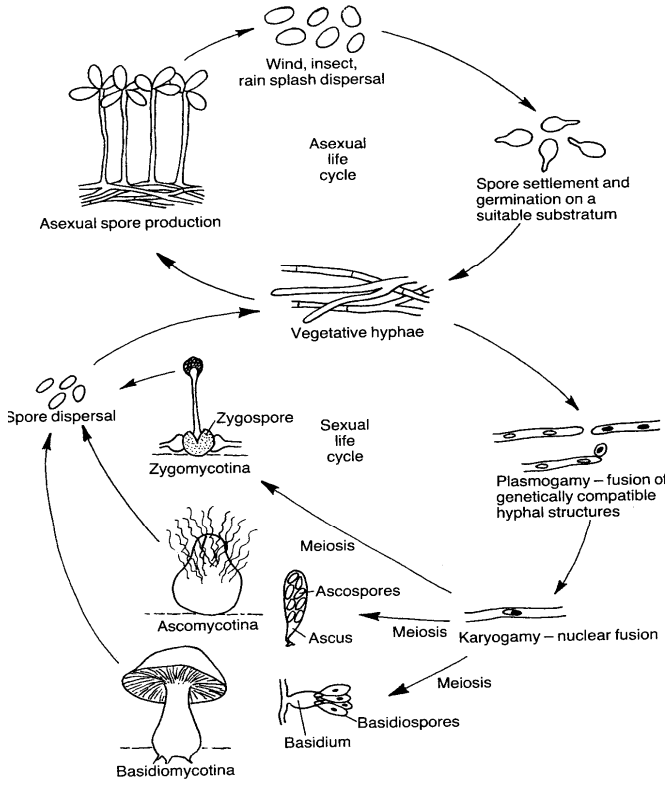
- Deuteromycetes has only asexual reproduction
- Asco- og zygomycetes have both sexual and asexual reproduction
- Basidiomycetes reproduce seldom asexual.



- The spores are the breeding units, often small and adapted to spread in air
- Hyphae are microscopically thin threads made up of rows of tubular fungus cells
- Mycelium is a continuous web of hyphae and may be visible with the naked eye

Mycelium on coated wooden cladding

Spores and hyphae

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Decay fungi

Brown rot – the most common decay fungi in buildings

- Prefer conifers, particularly in standing forests.
- Utilize cellulose and hemicellulos
- Wood becomes brown and cracks up across the fiber direction (to crack bricks).

White rot – not so common in building, but can occur

- Commen on stored soft wood, generally on hardwood and on living/standing forest
- Utilize cellulose, hemicellulose and lignin
- Wood turns soft, spongy, stringy and relatively bright

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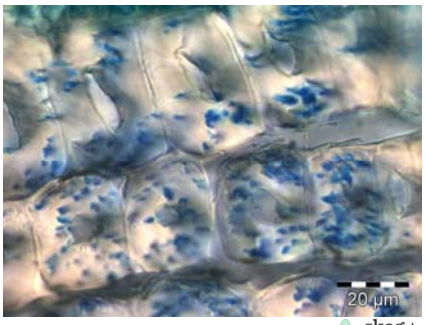
Soft rot – important fungi when very high and continuous level of wetness and in soil contact

- Damages caused by micro fungi – form microscopic cavities inside wood and breaks down cellulose
- Decay start in the surface and move slowly inwards
- Cause seldom major damages – except poles
- Wood turn soft and grey/brown – can have similar cracking pattern as brown rot



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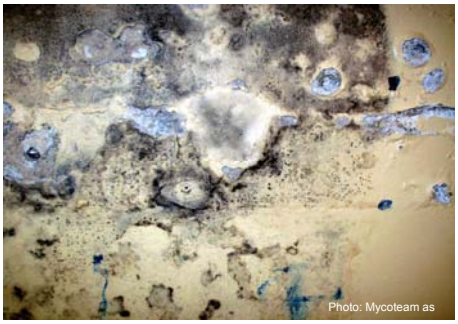
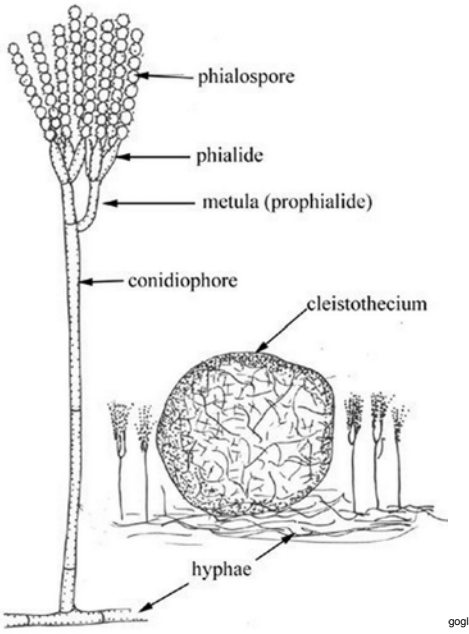
Moulds

- Ascomycetes, Zygomycetes and Deuteromycetes
- Can grow on any organic material, indoors and outdoors, when optimal growth conditions
- Are not able to utilize cellulose, lignin or hemicellulose – do not degrade wood
- Often appear as powdery or/and spotty pattern in a variety of colors (green, black, brown, yellow, pink, orange)
- Often fast growing
- Often large spore production
- Can cause discoloration, odors and health problems
- Some species produce mycotoxins (toxic substance which can be pathogenic)

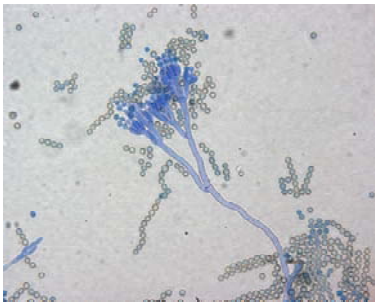


Penicillium

Deuteromycetes – anamorphic fungi



- Dominate often after water damages indoors
- Fruit, garbage, compost, soil



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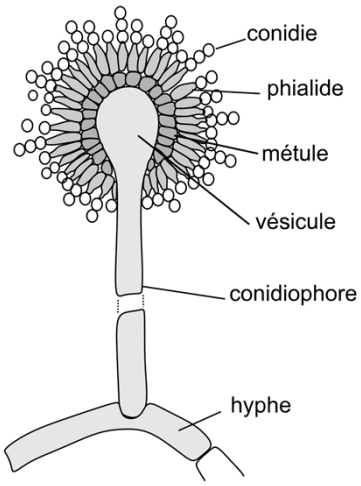
Aspergillus

Deuteromycetes – anamorphic fungi



- Colonize many types of materials
- Soil, nuts, beans, straw

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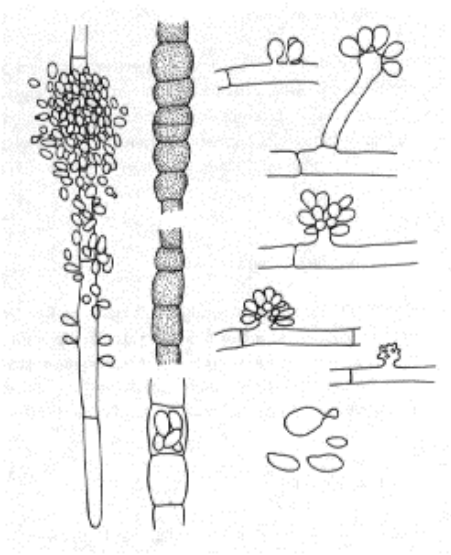
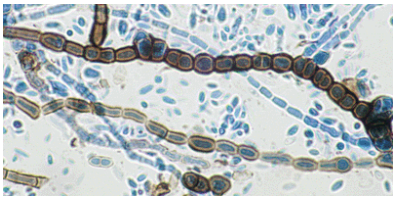
Aureobasidium

Deuteromycetes – anamorphic fungi



- Often found in buildings – ecpecially on exposed wood and paint
- Soil, leaves, grains, fruit, nuts



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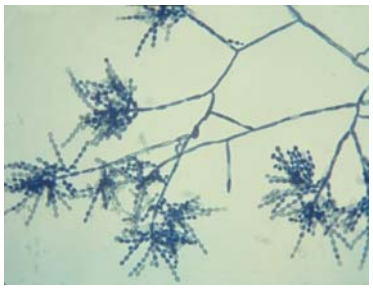
Cladosporium – Ulocladium – Alternaria

Deuteromycetes – anamorphic fungi

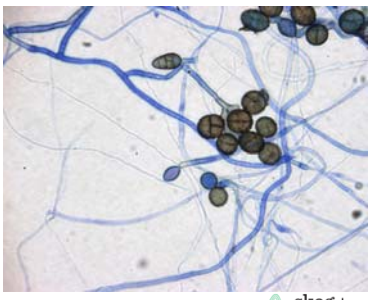


Cladosporium

- Paint, wall paper, wood, gypsum boards
- Dead plants, fruit, leaves, grasses, dung

Alternaria

Ulocladium



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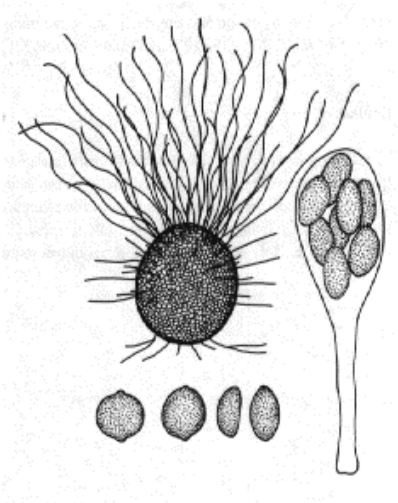
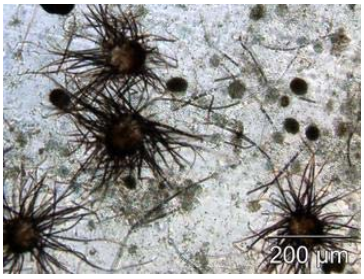
Chaetomium
Ascomycetes



- Wood and cellulose containing material
- Soil, straw, wood



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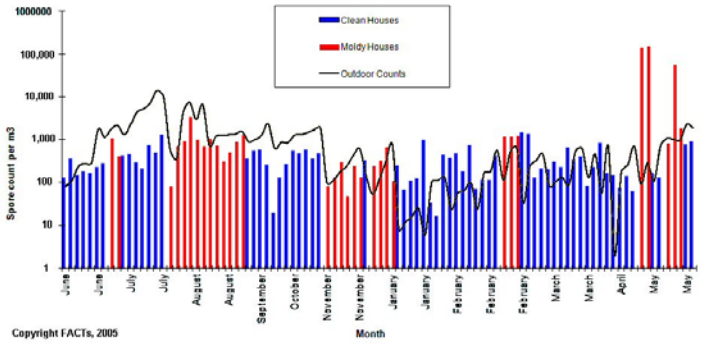
The most common building associated fungi (Fog Nielsen 2002)

Chaetomium	*globosum*	Soil, straw, wood	Mostly on wood and cellulose containing materials
Stachybotrys	*chartarum*	Hay and straw[56], paper, soil	Gypsum boards, pipe insulation
Ulocladium	*chartarum* and *atrum*	Soil, dung, grasses	Wood, wallpaper, gypsum boards
Trichoderma	*harzianum, citrinoviride, atro-viride* and *longibrachiatum*	Wet wood, soil	Mostly on wood
Alternaria	*tenuissima*	Saprophyte on plants, foods Cereals, leaves	Wallpaper, gypsum
Aureobasidium	*pullulans*	Soil, leaves, cereals	Paint especially in bathrooms, window frames, paint
Rhodulotorula	*rubra*		Paints, wood
Phoma	*sp.*	Plant material, soil,	Paints, wood, wall papers, caulk-ings, especially in bathrooms
Aspergillus	*versicolor*	Cheese, cereals, spices, dried meat products	Most materials, primary coloniser, grows in dust
Penicillium	*chrysogenum*	Various foods, spices, dry cereals	All materials
Penicillium	*brevicompactum*	Soil, nuts, fruits and juices	Especially wooden materials
Penicillium	*corylophilum*	Various foods	Most materials, primary coloniser
Aspergillus	*Sydowii*	Soil, cotton, beans, nuts and straw	Most materials, primary coloniser
Aspergillus	*ustus*	Soil, cereals, groundnuts	
Cladosporium	*sphaerospermum*	Dead plants	Paints, wood, wall papers, caulk-ings, especially in bathrooms
Cladosporium	*herbarum*	Dead plans, stored fruits	Paints, wood, wall papers, caulk-ings, especially in bathrooms
Penicillium	*palitans*	Cheese, wood	Most materials, but especially wooden
Eurotium	*repens*	Cakes, dried food, cereals	
Wallemia	*sebi*	Dried foods, jam, cakes, dates, salted fish, sugar, chocolate	
Paecilomyces	*variotii*	Compost	
Penicillium	*polonicum*	Cereals, meat products	
Aspergillus	*niger*	Dried food, spices	
Penicillium	*expansum*	Nuts, fruits (apples)	Wood

Requirements for mould growth

- Fungal spores are nearly always present in the air, but may vary in intensity and species composition
  - Time of year / season, climatic conditions, location
  - Environment; forest area, built environment etc.
- Conditions that are conducive to fungal growth will inevitably lead to fungal colonization
- The requirements are often different for spore germination and fungal growth (colonization)



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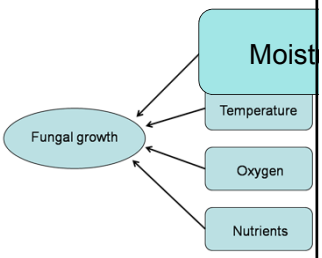

- Moisture a decisive criterion for mould growth
- Mould exploit moisture from the substrate and the air
- Each mould has a particular humidity range
- Relative humidity above 80-85% - germination and colonization will occur for the majority of the mould species

→Higher relative humidity will generally give more mould growth

Photo: Mycoteam as

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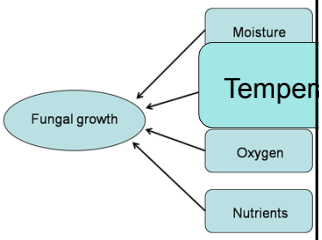

- Moulds have a wide tolerance for temperature
- Lower limit for fungal colonization is generally around 0-5℃
- Upper limit for fungal colonization is generally around 40℃
- Most moulds prefer a warm environment; 20-28℃
- Temperature below minimum often induce dormancy
- Specific species adapted to high and low temperatures

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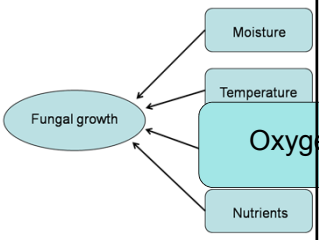

- Generally moulds need oxygen, but moulds can grow well at lower oxygen levels than those of air
- Oxygen is rarely a limiting factor for mould growth
- Mould growth may occur on the surface as a consequence of the oxygen requirement

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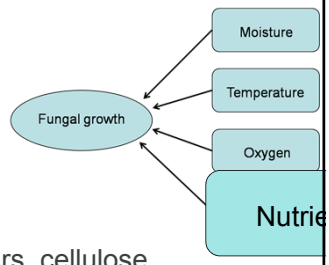

- Carbon compounds are required; simple sugars, cellulose, alcohols etc.
- Nitrogen is required; inorganic and organic compounds
- Optimal ratio of carbon and nitrogen is about 30:1
- Nutrients are decided by the substrate or the host
- Generally moulds are easily satisfied

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Bio-based building materials

….more than solid wood

Oriented strand board (OSB)

Insulation made of flax

Paper

Insulation made of straw

Wood plastic composite

Cob Insulation made of flax

Bio-based material is a material intentionally made from substances derived from living (or once-living) organisms.

Strict definition: low processed materials such as wood and leather
But: typically refers to modern materials that have undergone more extensive processing.

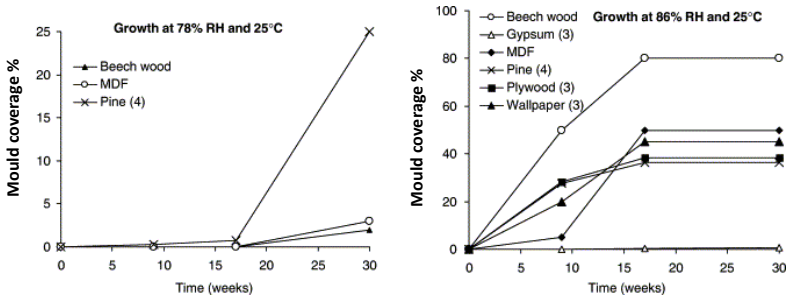
Broader definition: bioproducts or bio-based products which includes materials, chemicals and energy derived from renewable biological resources

Bio-based materials are often biodegradable, but this is not always the case.

Bio-based building materials – materials where the intended use are in buildings

- Wood – as solid wood, fibers, chips and also chemically and thermally modified
- Wood plastic composites
- Bio plastic composites
- Natural fibers – flax, hemp, sisal, coir, corn cobs, straw, cotton etc.
- Paper
- (Bio oil)

- Exist a lot of performance data for wood and wood based materials/products



Nielsen at al. (2004)

- Need data for biobased materials
  - Lab tests
  - Field test
  - In-service performance
- Small change in a material or process can make a great difference when it comes to the susceptibility to mould
  - Process, ingredients – amount and types, quality of basic material (fiber, straw etc), ….

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Research and practical insight in building mycology

- Essential to know in what type of environment the product shall be used
  - Indoors
  - Outdoors
  - Type of construction
  - Construction fase
  - Design of the building
  - Level/quality of craftsmanship
  - Interaction with other materials
  - Maintenance
  - Transportation of material to building site
  - Handling, packaging, storing of materials
  - Climatic conditions

- Service-life and aesthetic appearance
- CIC – the critical in-situ conditions
- Identify the influencing factors
- Quantify the influencing factors

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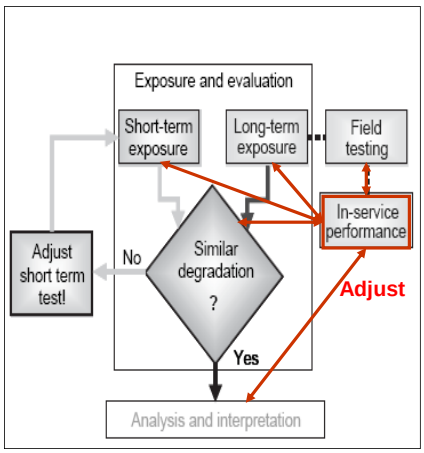
Service life of building materials

- Methods for service life prediction:
  - standards (EN 335, EN 350, EN 460), the factor method, various models, mapping of climate index (decay hazard), surveys etc.
- Reliability of the methods – no better than the:
  - in-put data
  - capability to describe reality
- Data source
  - In-service performance
  - Field tests
  - Lab. tests
  - Surveys



From ISO 15686-2

Important to know the performance of components in real life situations and to transfer this knowledge into lab/field tests.

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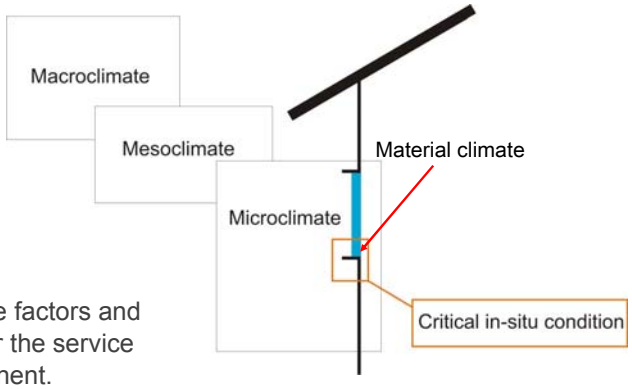
Critical in-situ condition



- A term used for emphasizing the factors and interaction that are important for the service life of a specific wooden component.
- Described by the material climate and other parameters that serve as triggering factors for a specific component.

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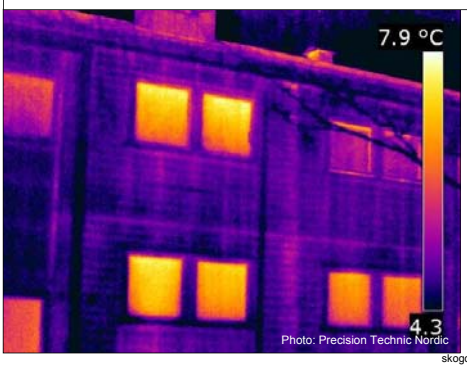
Influencing factors

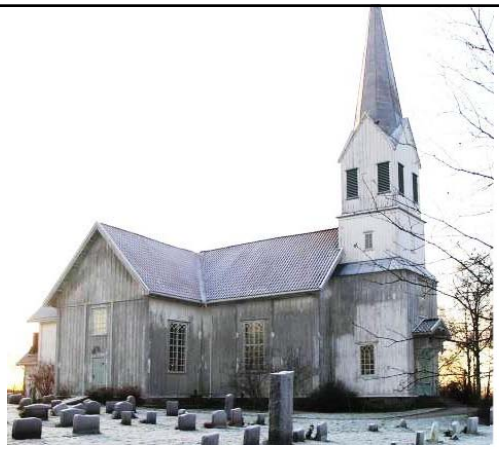
Many factors have an influence on the weathering and the fungal discoloration of a wooden façade.

Knowledge about the impact of the influencing factors can be actively used to:

- develop performance models
- identify the main contributing factors in specific applications
- offer predictability when using discolouring fungi and weathering as a design option
- create façades and elements with an aesthetical appearance that are in demand from architects, building owners and end-users
- extend the aesthetical service life of wood

- Correspondence between areas with less mould and areas with higher temperature.
- Compact wooden constructions have slower release of heat which can lead to less time of surface condensation and is less susceptible to fungal growth.





Need tools to predict the performance of the facade

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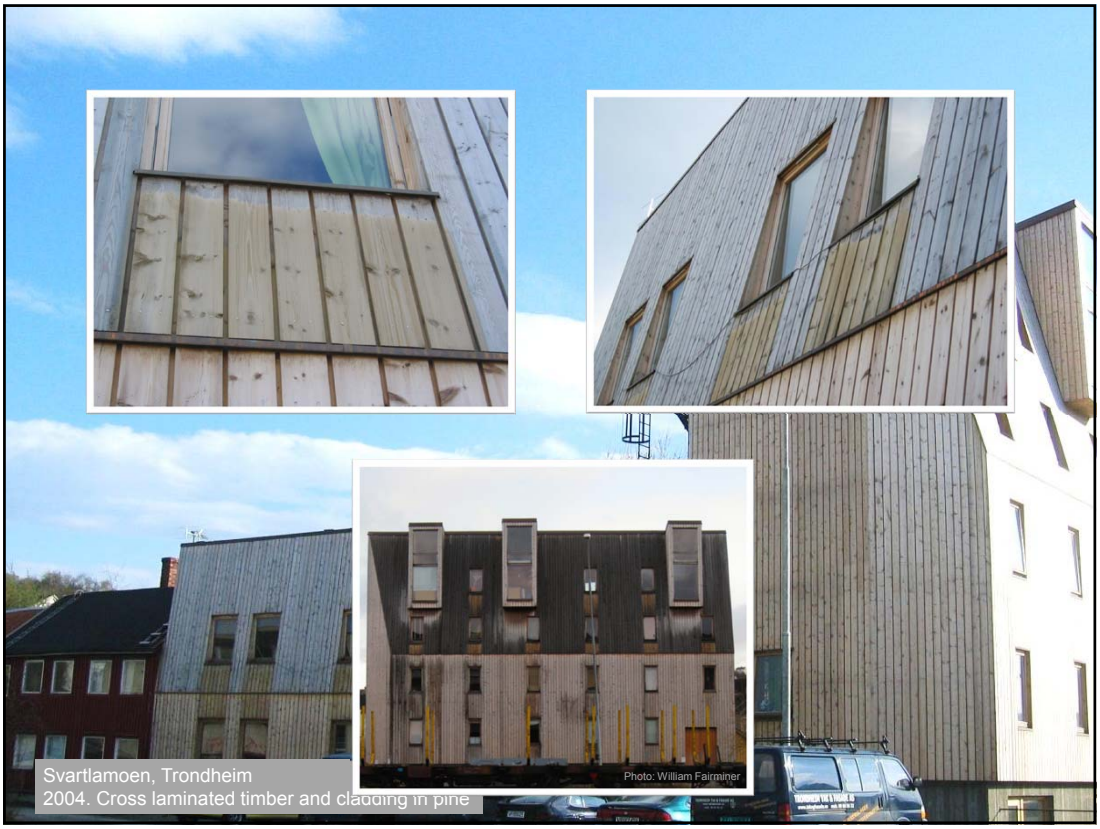
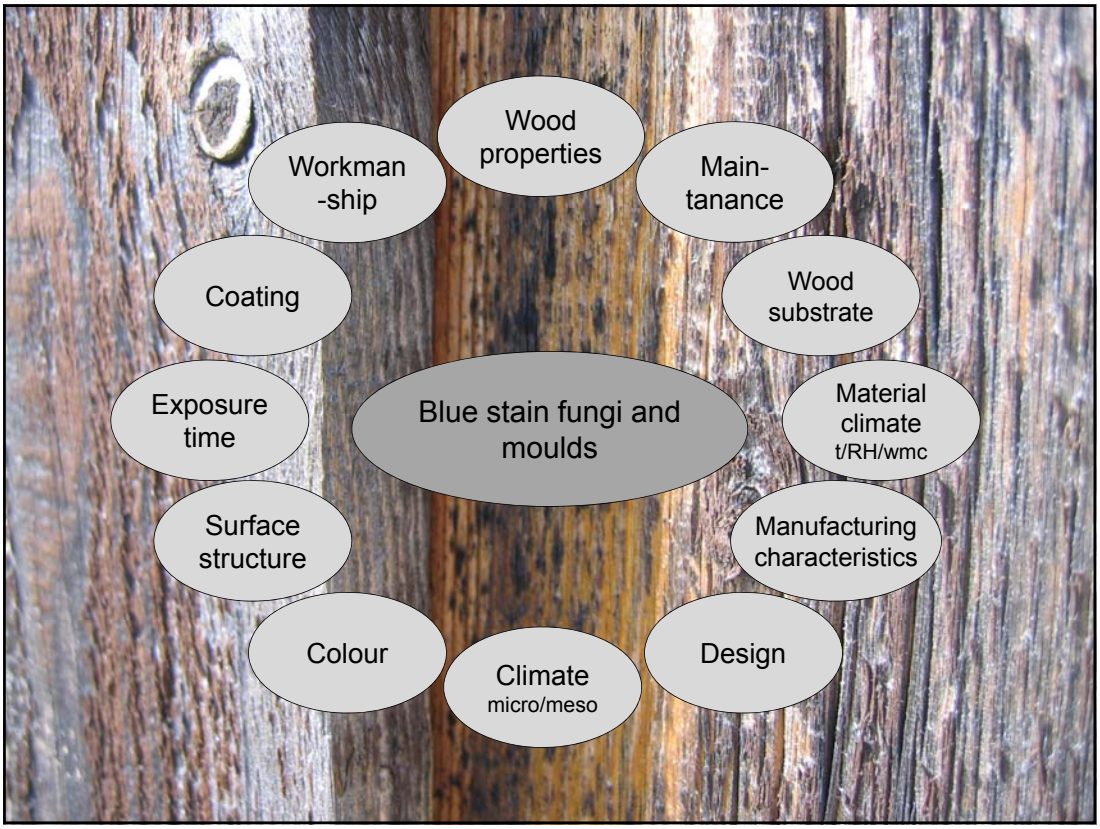


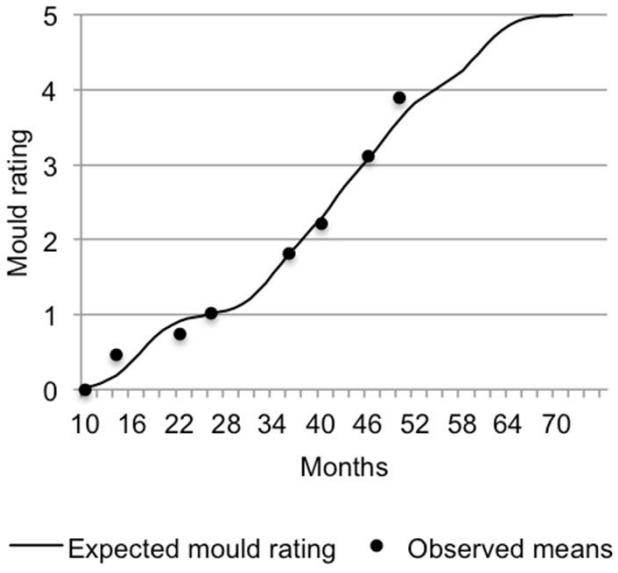
Svartlamoen, Trondheim
2004. Cross laminated timber and cladding in pine

Photo: William Fairminer

Borgund Stavechurch Vsitor's center, Jostedalen 2005. Cladding in pine



Which factors are most important?



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Influencing factors	Uncoated	Coated
Exposure time	+++	+++
Wood substrate	+++	++*
Wood properties	+++	+*
Coating	N/A	+++
Colour	(++)	++
Manufacturing characteristics	(+)	-*
Surface structure	(++)	++
Workmanship	(++)	(++)
Design	(+++)	(+)
Material climate	+++	++
Cardinal direction	++	++
Climate (meso / macro)	++	++

+++=great impact
++=moderate impact
+=impact
- =no impact
( ) ='expert' opinion/inspections
**=depends on the type/product of coating*

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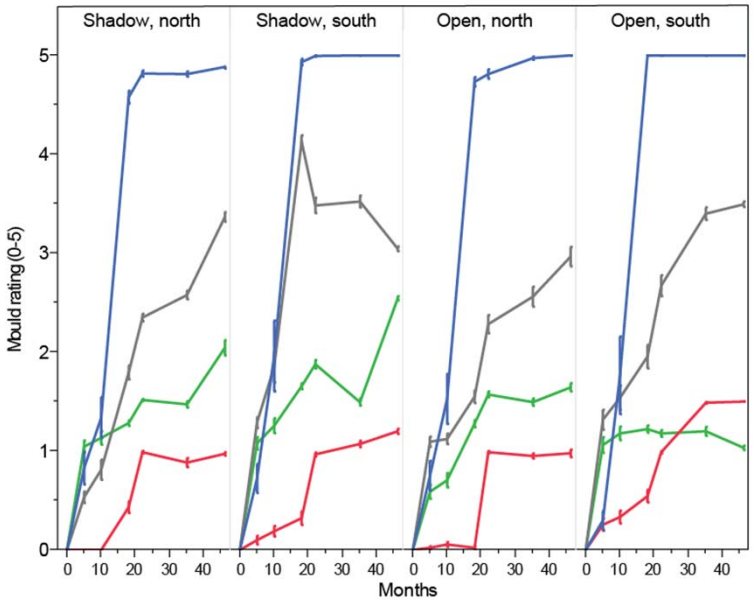

- Low mould rating on red samples
- Uncoated and white samples rapid colonization in the beginning
- Small variation between environment and cardinal direction

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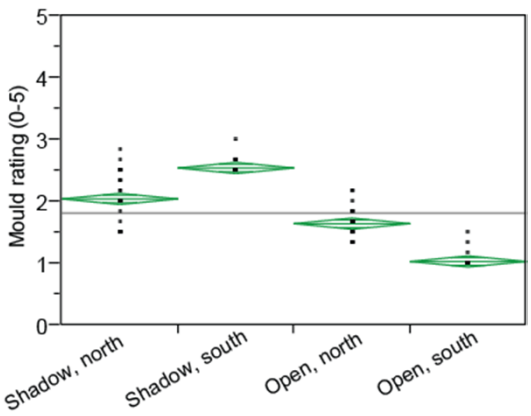
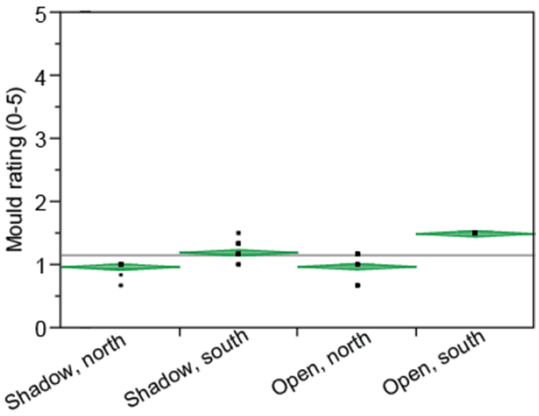


White coating system with fungicide, 46 months



Red coating system with fungicide, 46 months

- White samples against south in an open environment had lowest mould rating
- Red samples exposed against south in an open environment had highest mould rating

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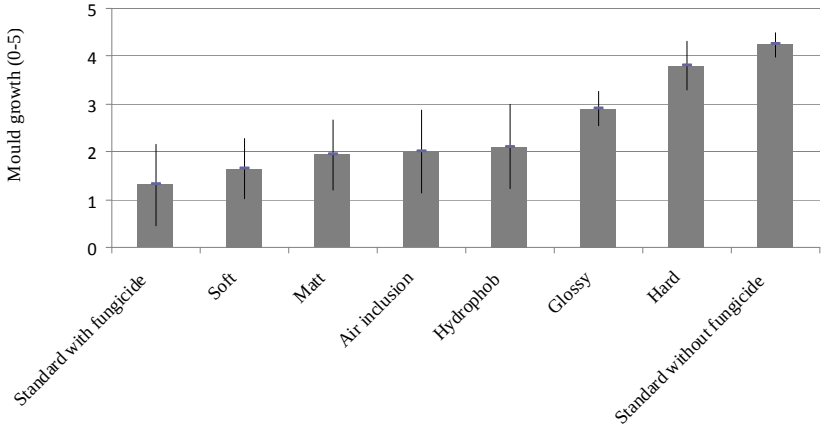
Surface structure



- Surface structure (type of model paint) had significant effect on mould growth
- Hard and glossy model paint were most susceptible to mould growth

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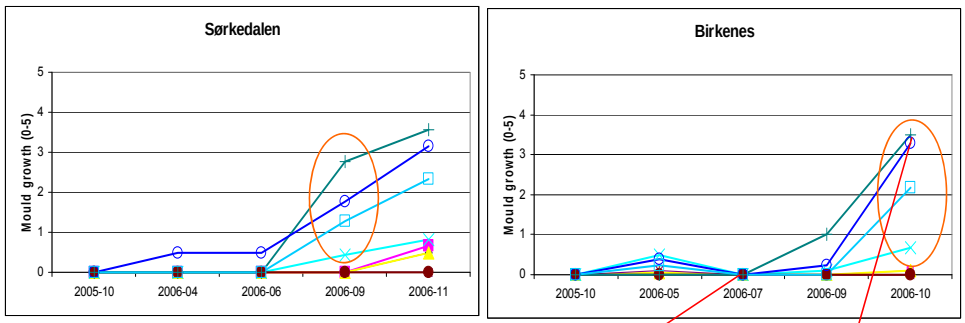

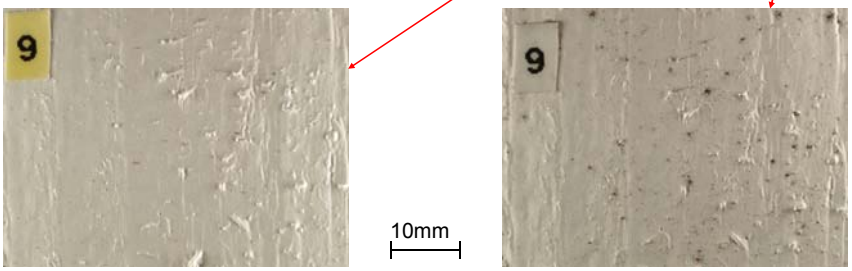

2006-07: W Al_Ac 2

2006-10: W Al_Ac 2

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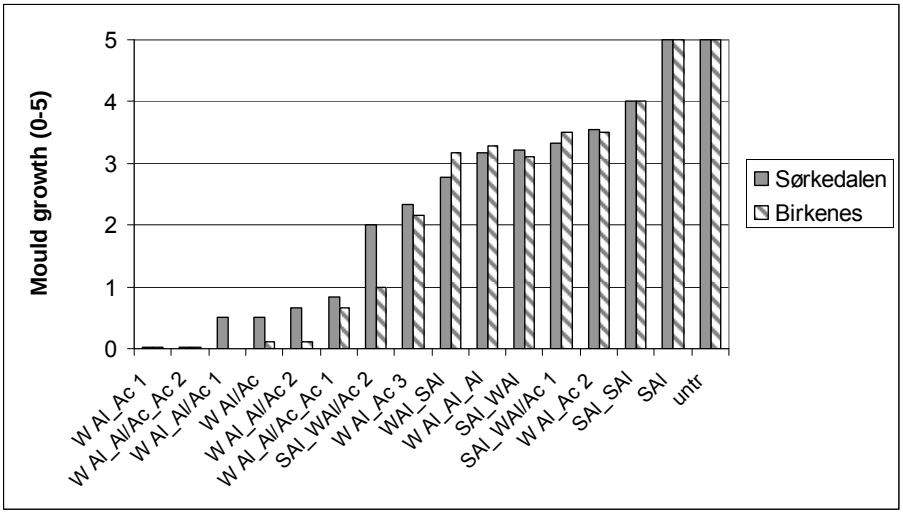

16 months in the field

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54

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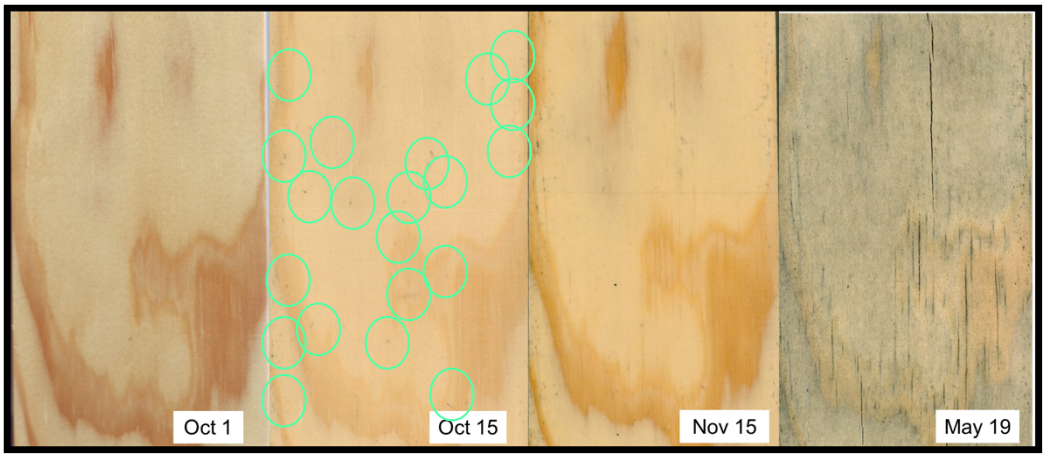

Acetylated panels (level 1), Ås

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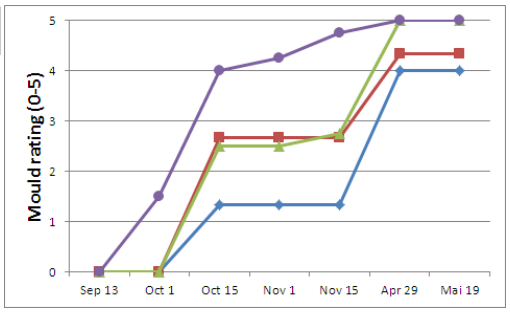
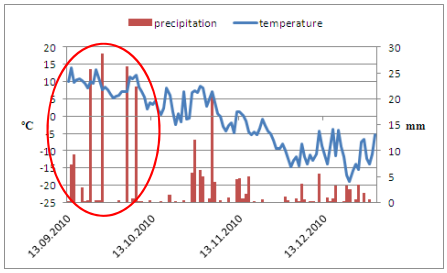
Exposed south

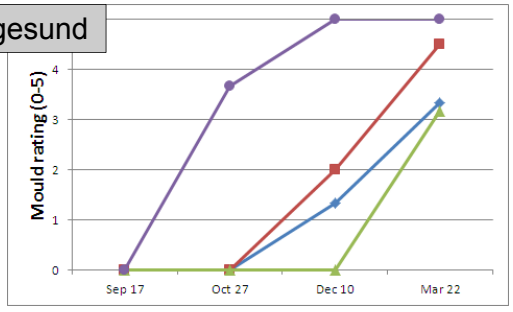
Ås

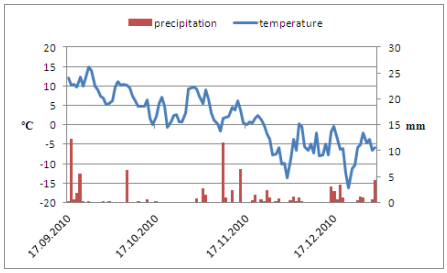




level 1 level 2 level 3 untre

Bogesund





Field test – panels exposed south

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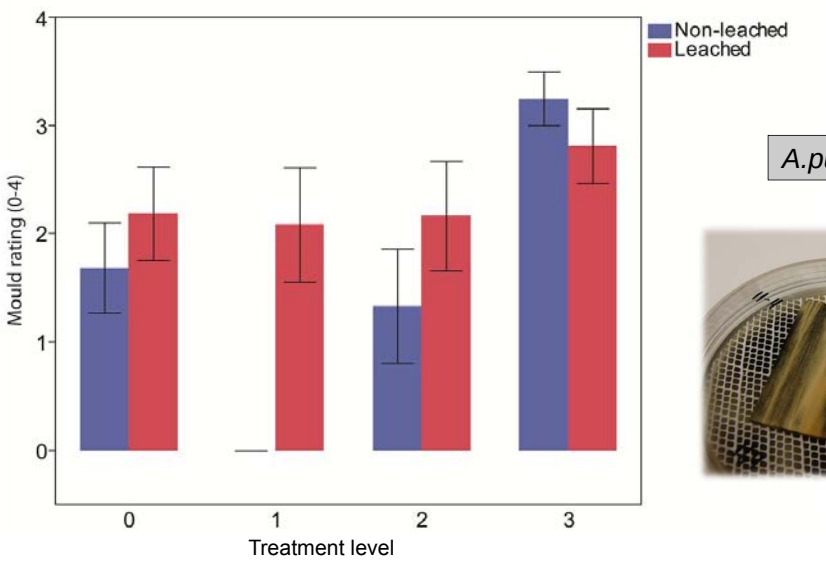
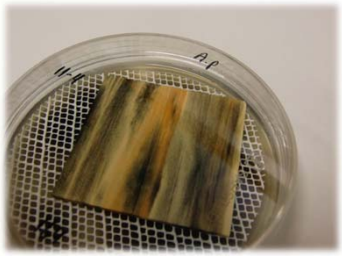


A.pullulans



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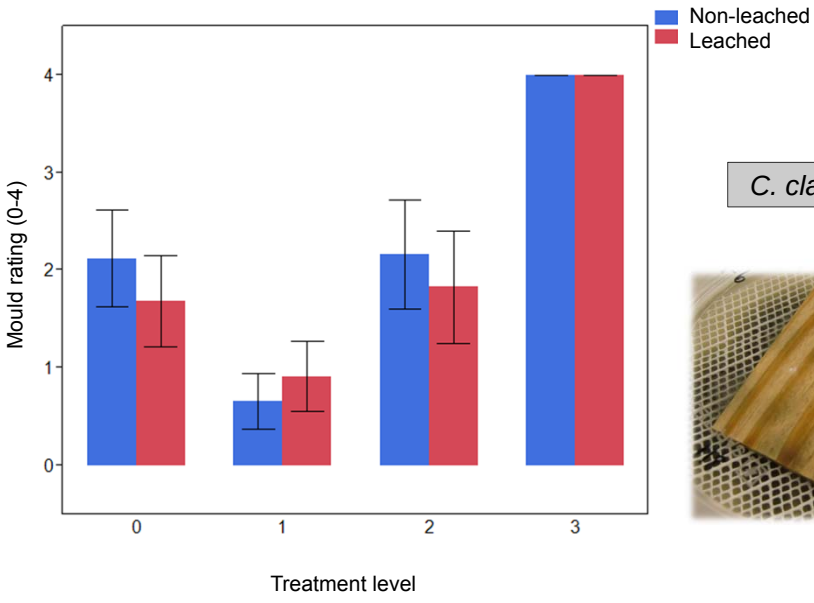
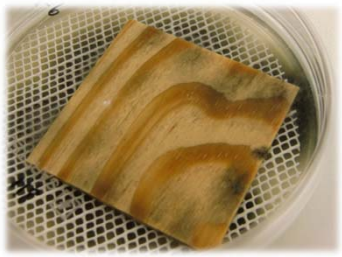


C. cladosporioides



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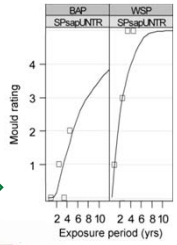
- Predict the visual appearance of coated and uncoated wood
- Combine data on mould growth development with wmc, RH, temperature and solar radiation (field data)
- Simulate and visualize weathering and mould growth over time - depending on design and climate



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Coating	N/A	+++
Colour	(++)	++
Manufacturing characteristics	(+)	-*
Surface structure	(++)	++
Craftsmanship	(++)	(++)
Design	(+++)	(+)
Material climate	+++	++
Cardinal direction	++	++
Climate (meso / macro)	++	++

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Thank you!
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