Professor Carsten Rode,
Technical University of Denmark, DTU
Department of Civil Engineering

# Some Recent Challenges and Peculiarities in Moisture Practices and Assessment of Buildings

# Agenda

- Experiences with MgO boards.

MgO boards became the most used material for sheathing in the years 2010-2014 before it was realized that they gathered water from ambient air, which caused disintegration of the boards themselves and damage to the adjacent building with salty water. We will account for some investigations of the boards.

- Interior insulation of solid brick walls.

There is great interest in adding thermal insulation to the solid brick façade walls of historic buildings, and it cannot always be permitted on the outside. Adding insulation on the inside is potentially a challenge with regards to moisture risk. This has been investigated in several projects, and we will communicate some of the experiences.

- Moisture modelling with hysteresis in sorption isotherms

Transient moisture models need the sorption isotherms to calculate the equilibrium between relative humidity and moisture content of materials. However, most models do not take into consideration that the equilibrium is not unique, since there can be significant differences between sorption curves for moisture uptake and drying – so a situation of hysteresis exists. What could be the implication for the results of moisture calculations and for subsequent assessment of mould risk?

# Experiences with MgO Boards

# Problem Outline

- Sheathing boards based on magnesium oxide (MgO) were widely used in the Danish market during the years 2010-2015: 1 million $m^2$.
- Obtained a dominating share of the market due to good properties regarding
  - Fire protection
  - Ease of handling
  - Water vapour transmittance
  - Favourable price
- Most of the boards have been used for wind barrier in new buildings and in connection with facade renovation

# Consequence

- However, a strong affinity to absorb humidity from ambient air, has led to
  - leaks of corrosive salt water
  - moisture uptake in adjacent structural members
  - degradation of the boards themselves
- MgO boards are now banned from use in the Danish market
- Damage cases valuing almost 300 M€ have been under reconciliation

- However, $MgSO_4$ is an alternative to $MgCl_2$ and *may* have smaller moisture uptake so damages can be avoided

# The story about MgO boards

(1) Characterization of MgO boards and practice of their use

(2) Determination of some characteristics of MgO boards:

- Optical examination in microscope for structure and composition
- X-ray methods (XRF & EDX) to identify elemental composition
- Determination of moisture retention
- Analysis of chemical composition of ions of leaked salty water
- Determination of water vapour permeability
- Corrosion test on zinc sheets
- Field methods to determine the chloride content

(3) Conclusions

# Characterization of MgO boards

MgO Boards - Composition

- Binder: MgO–cement. Similar to so-called “Sorel-cement”.

$$5\ MgO + MgCl_2 + 13\ H_2O \rightarrow 5\ Mg(OH)_2\ MgCl_2 \cdot 8\ H_2O$$

Molar fraction

Mg/Cl = 3/1

Mass fraction

Mg/Cl = 72/35 ≈ 2

- Filler: Sand, perlite and wood
- Surface: Glass fiber facer
- Thickness: 9 mm or 12 mm
- Colour: off-white or grey

# Characterization of MgO boards

JOURNAL OF RESEARCH of the National Bureau of Standards—A. Physics and Chemistry
Vol. 81A, No. 1, January–February 1977

**Humidity Fixed Points of Binary**

Lewis Gre

Institute for Basic Standards, National Bureau

(October 22

$$RH = \sum_{i=0}^{3} A_i t^i$$

$t$: Temperature [°C]

| Salt | $A_0$ |
|---|---|
| Cesium Fluoride | 6.20938 |
| Lithium Bromide | 7.75437 |
| Zinc Bromide | 9.28455 |
| Potassium Hydroxide | 16.7049 |
| Sodium Hydroxide | 11.5581 |
| Lithium Chloride | 11.2323 |
| Calcium Bromide | 23.5670 |
| Lithium Iodide | 22.8216 |
| Potassium Acetate | 22.4388 |
| Potassium Fluoride | 65.7907 |
| Magnesium Chloride | 33.6686 |
| Sodium Iodide | 42.6040 |
| Potassium Carbonate | 43.1315 |
| Magnesi | |
| Sodium | |
| Cobalt C | |
| Potassiu | |
| Strontiu | |
| Sodium | |
| Sodium Chloride | 75.5164 |
| Ammonium Chloride | 81.8777 |
| Potassium Bromide | 86.6424 |
| Ammonium Sulfate | 81.7794 |
| Potassium Chloride | 88.6190 |
| Strontium Nitrate | 94.2127 |
| Potassium Nitrate | 96.3361 |
| Potassium Sulfate | 98.7792 |
| Potassium Chromate | 103.934 |

Deliquescenc
$MgCl_2$: 33

## Thorpe's Dictionary (1946)

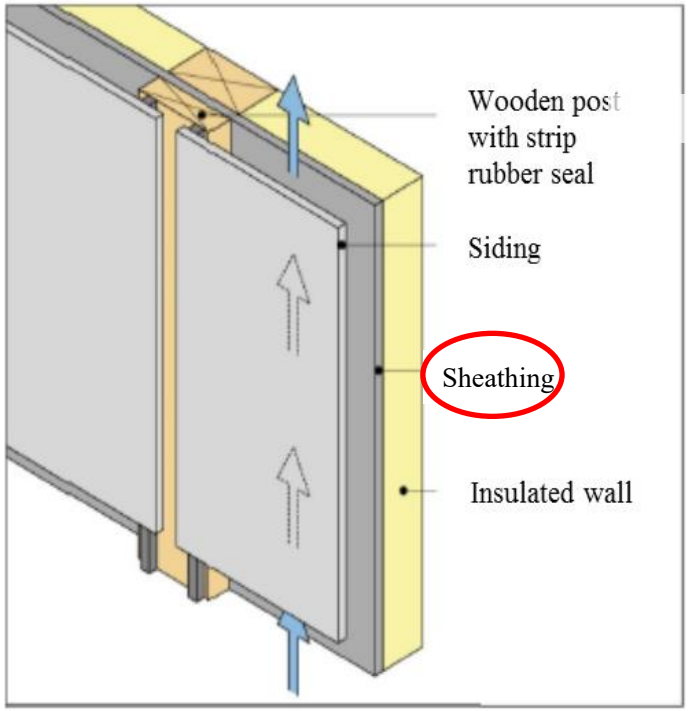
Magnesium oxychloride is not completely stable under atmospheric conditions, as the hydroxide is slowly converted to the carbonate or basic carbonate by atmospheric carbon dioxide, but this, by forming a surface coating, protects the oxychloride from the action of water. In the absence of carbon dioxide, the magnesium chloride will absorb water when the humidity of the air exceeds 93%. This will cause decomposition of the oxychloride, and ultimately the mass will be converted into the hydroxide and a dilute solution of magnesium chloride.

Information collected by:

Peter Svane, Overfladeteknik

# Practice of Use

## Ventilated Facades with Sheathing of MgO Boards




Drawing: Danish Building Research Institute, BUILD

Photo: Tommy Bunch-Nielsen, BUNCH Building Physics, ApS

# Practice of Use

## Problems Due to Content of Salt, $MgCl_2$

With $MgCl_2$:

- Moisture absorption from the surrounding air
- At high humidity the boards start ”crying” salty tears
- Corrosion of metal parts from $MgCl_2$
- Mould growth due to content of wood fibres/saw dust
- Decomposition

Photo: Tommy Bunch-Nielsen, BUNCH Building Physics, ApS

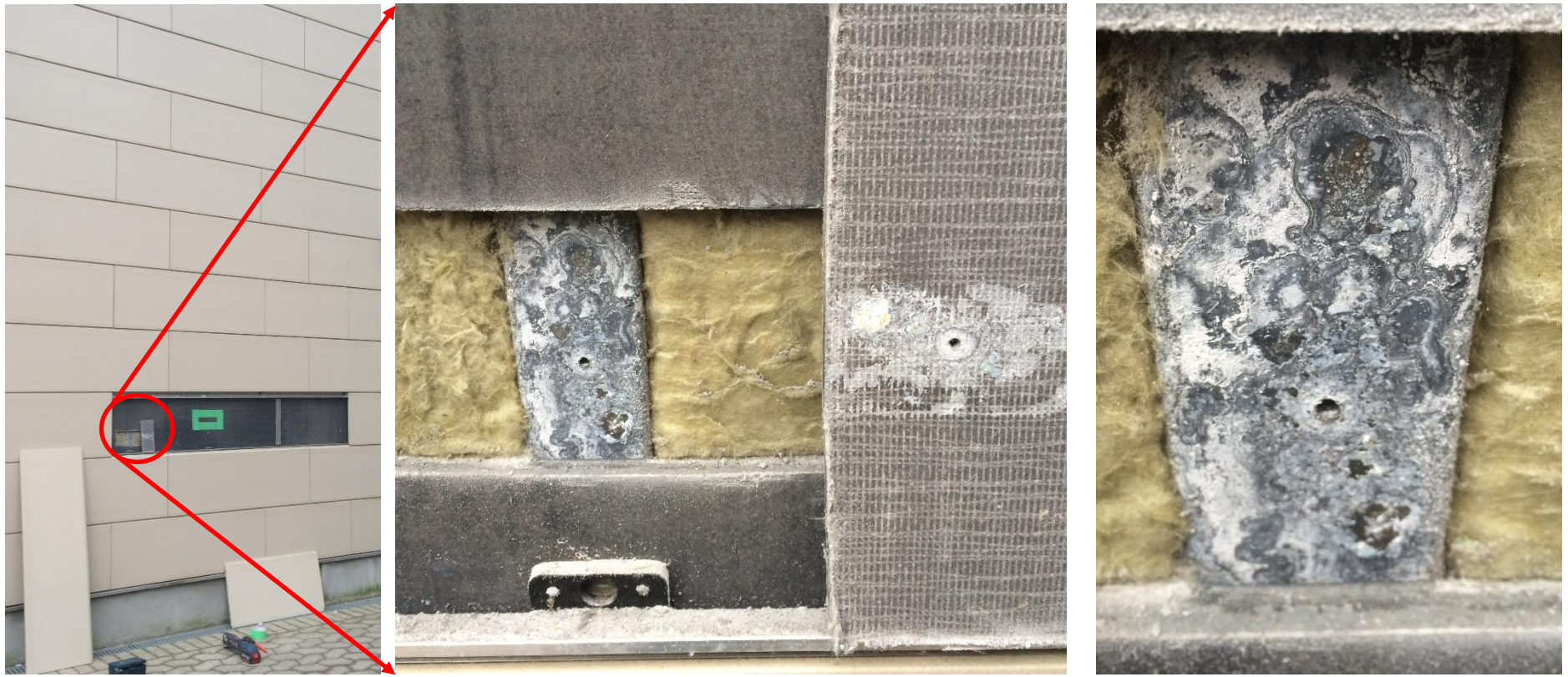
# Practice of Use

## Salt Water Absorbed in Concrete Foundation

Photo: Tommy Bunch-Nielsen, BUNCH Building Physics, ApS

# Practice of Use

## Corrosion of Galvanized Steel Behind MgO boards



Photos: Tommy Bunch-Nielsen, BUNCH Building Physics, ApS

# Practice of Use

## Mould Growth on the Surface of MgO Board

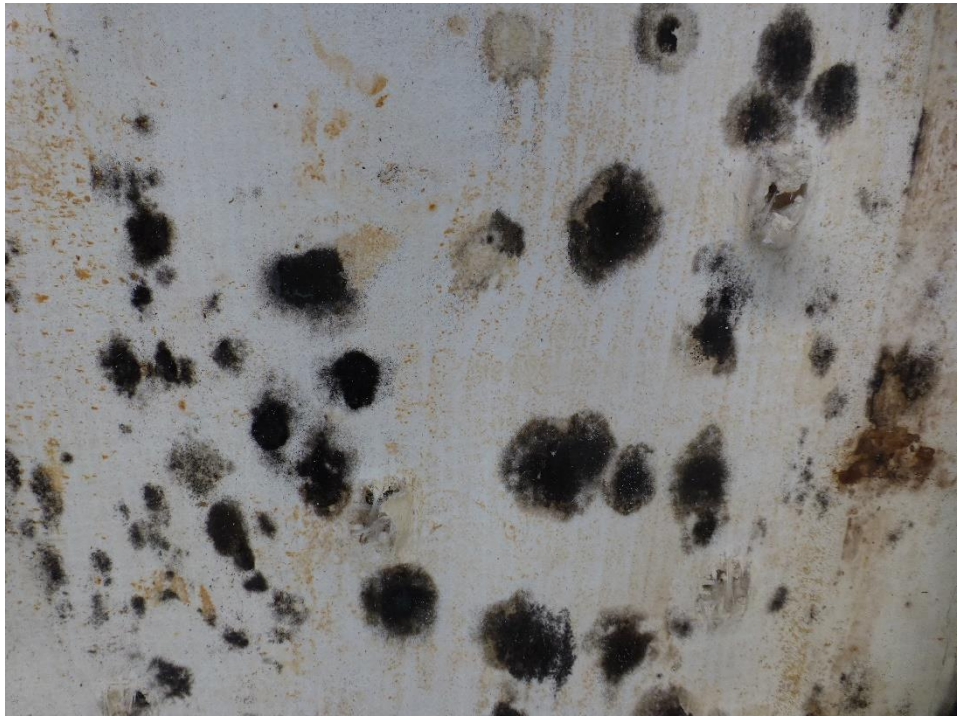


Photo: Tommy Bunch-Nielsen, BUNCH Building Physics, ApS

# Water Penetration in Windows from the MgO Boards

Photos: Tommy Bunch-Nielsen, BUNCH Building Physics, ApS

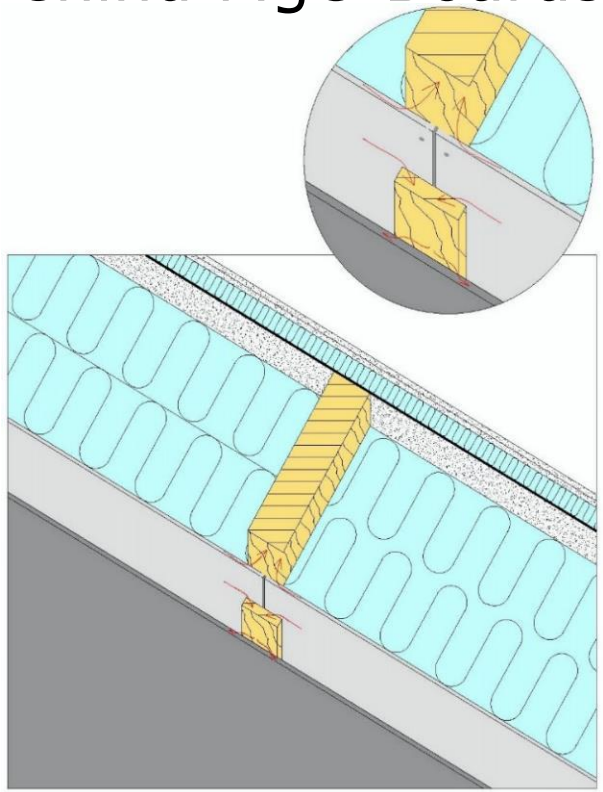
# Discolouring of ventilated ETICS facades

Photos: Tommy Bunch-Nielsen, BUNCH Building Physics, ApS

# Practice of Use

## Investigation of Wood Frame Behind MgO Boards

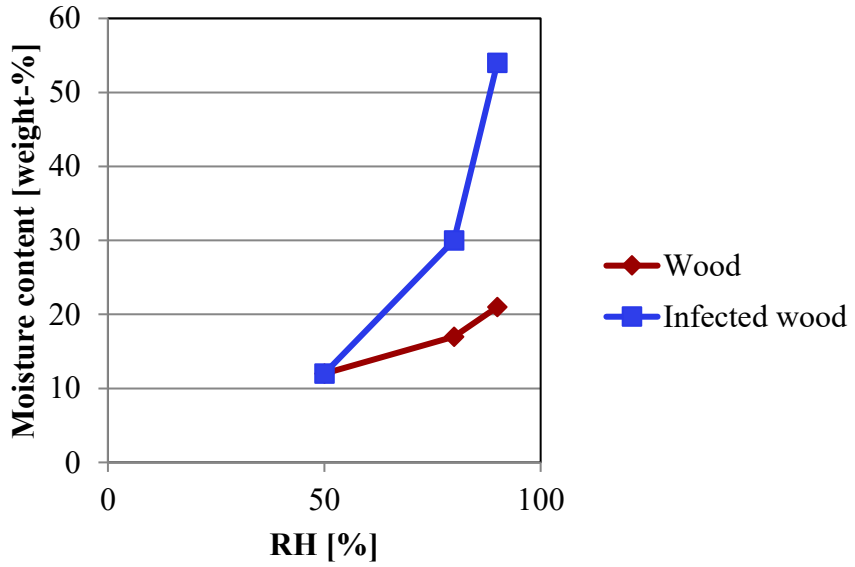
- The salty water from the boards is absorbed in the wooden members of the facade
- The wood's sorption curve will be dramatically changed
- Risk of mould growth
- Penetrates 5 to 10 mm into wood



Drawing: Danish Building Research Institute, BUILD

# Practice of Use

## Infected Wood




Photos: Tommy Bunch-Nielsen, BUNCH Building Physics, ApS

# Practice of Use:

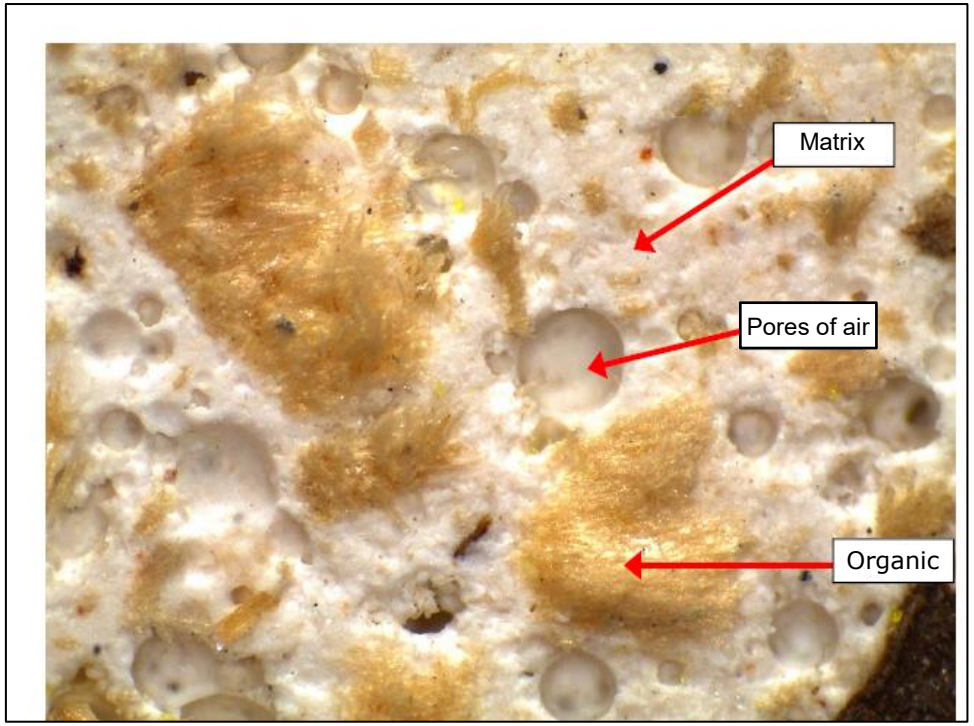
## After long exposure the MgO-boards begin to decompose

Photos: Tommy Bunch-Nielsen, BUNCH Building Physics, ApS

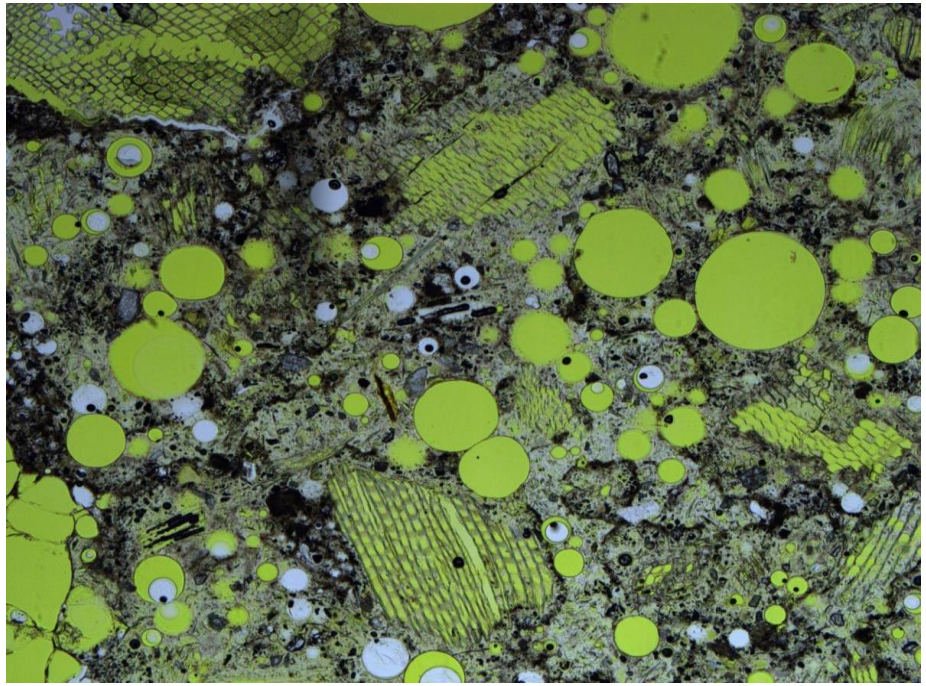
# Characteristics of MgO boards

## Microscopic Analysis

”10 times” magnification



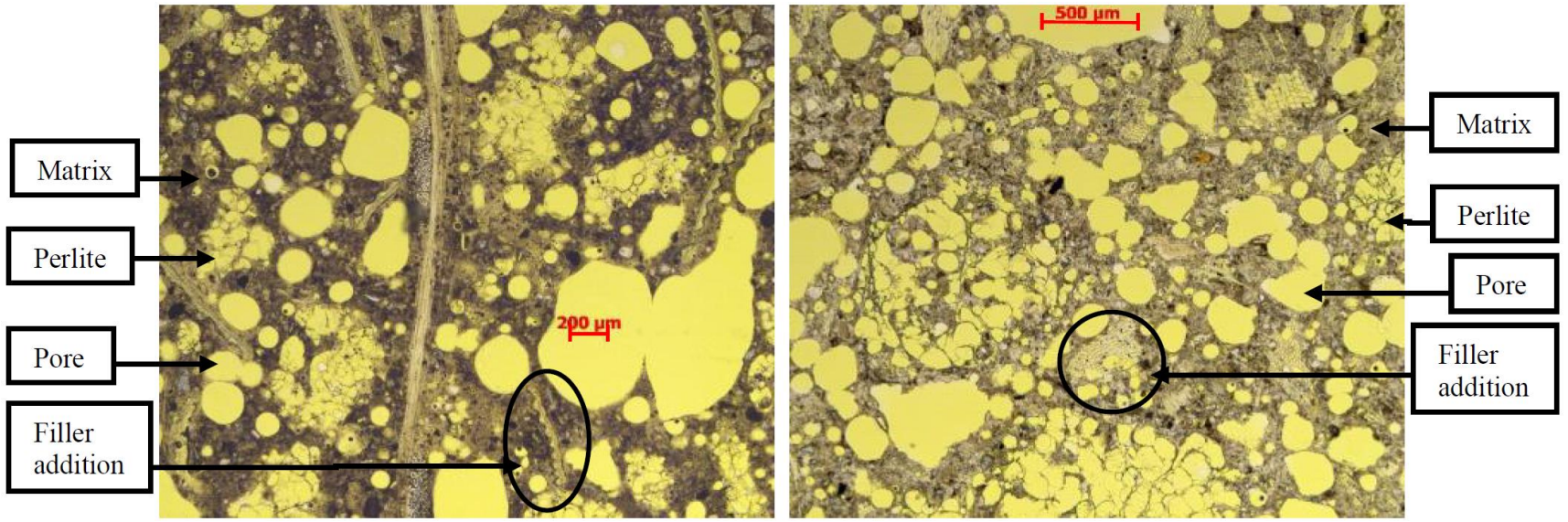

”50 times” magnification



# Characteristics of MgO boards

## - Optical examination in microscope for structure and composition

MgO Board - Microscopic Analysis



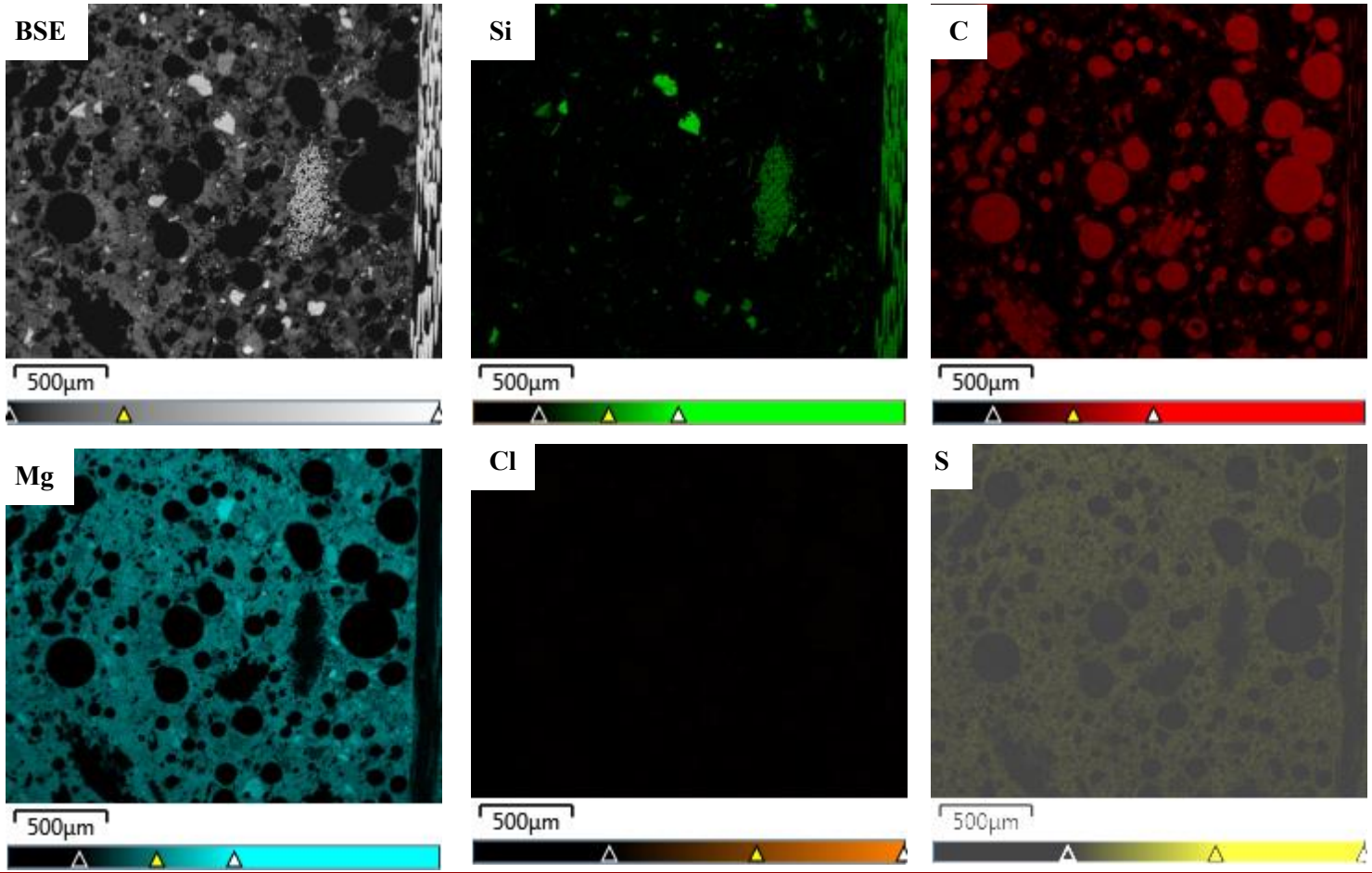

Volumetric share of air, organic and perlite filler, and the matrix

| | Air | Organic + perlite | Matrix |
|---|---|---|---|
| #1 – $MgSO_4$ 9 mm | 15% | 15% | 70% |
| #2 – $MgSO_4$ 9 mm | 20% | 15% | 65% |
| #3 – $MgSO_4$ 12 mm | 20% | 15% | 65% |
| #4 – $MgCl_2$ 12 mm | 15% | 20% | 65% |

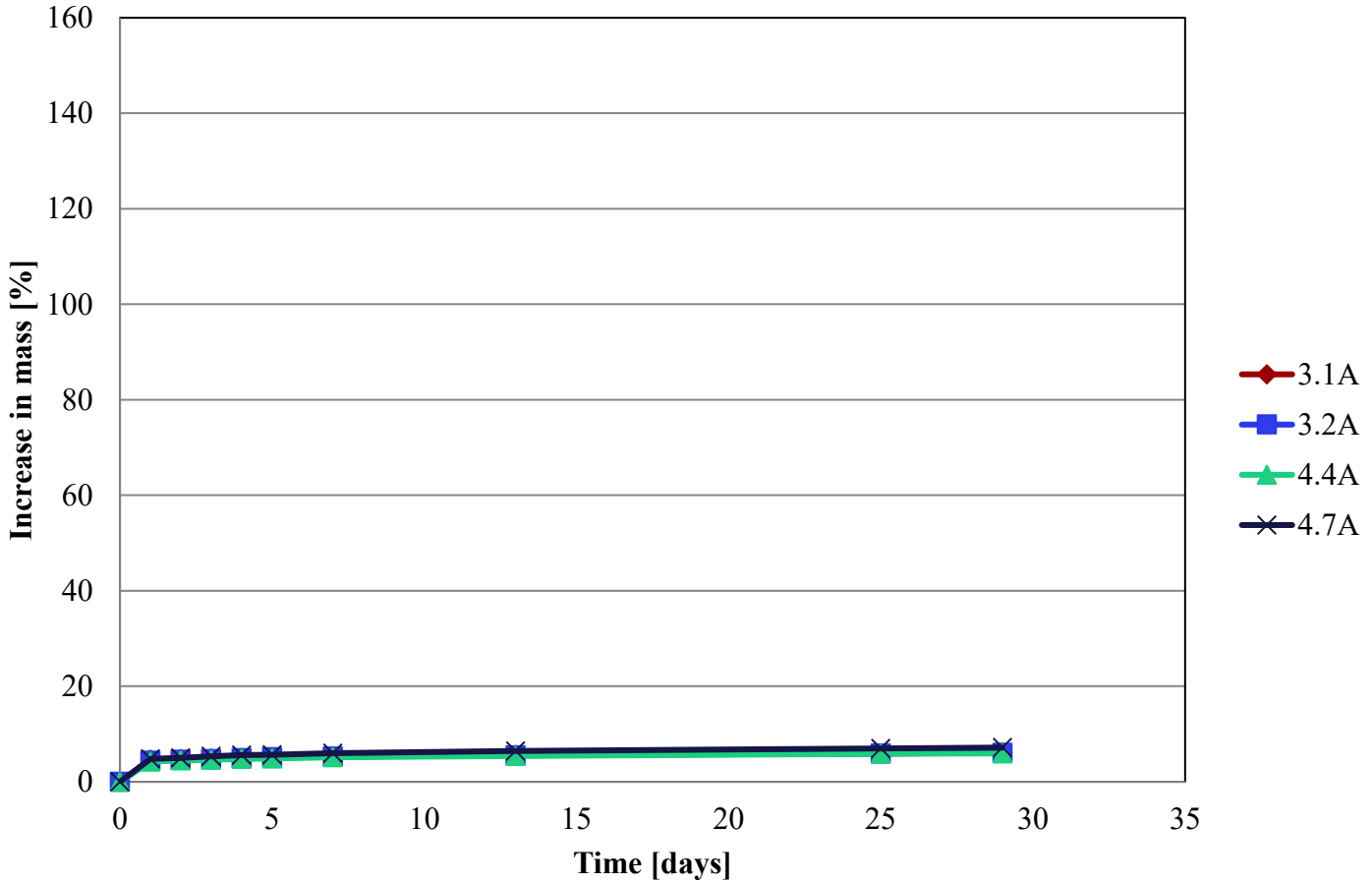
# Characteristics of MgO boards

## - X-ray methods to identify elemental composition

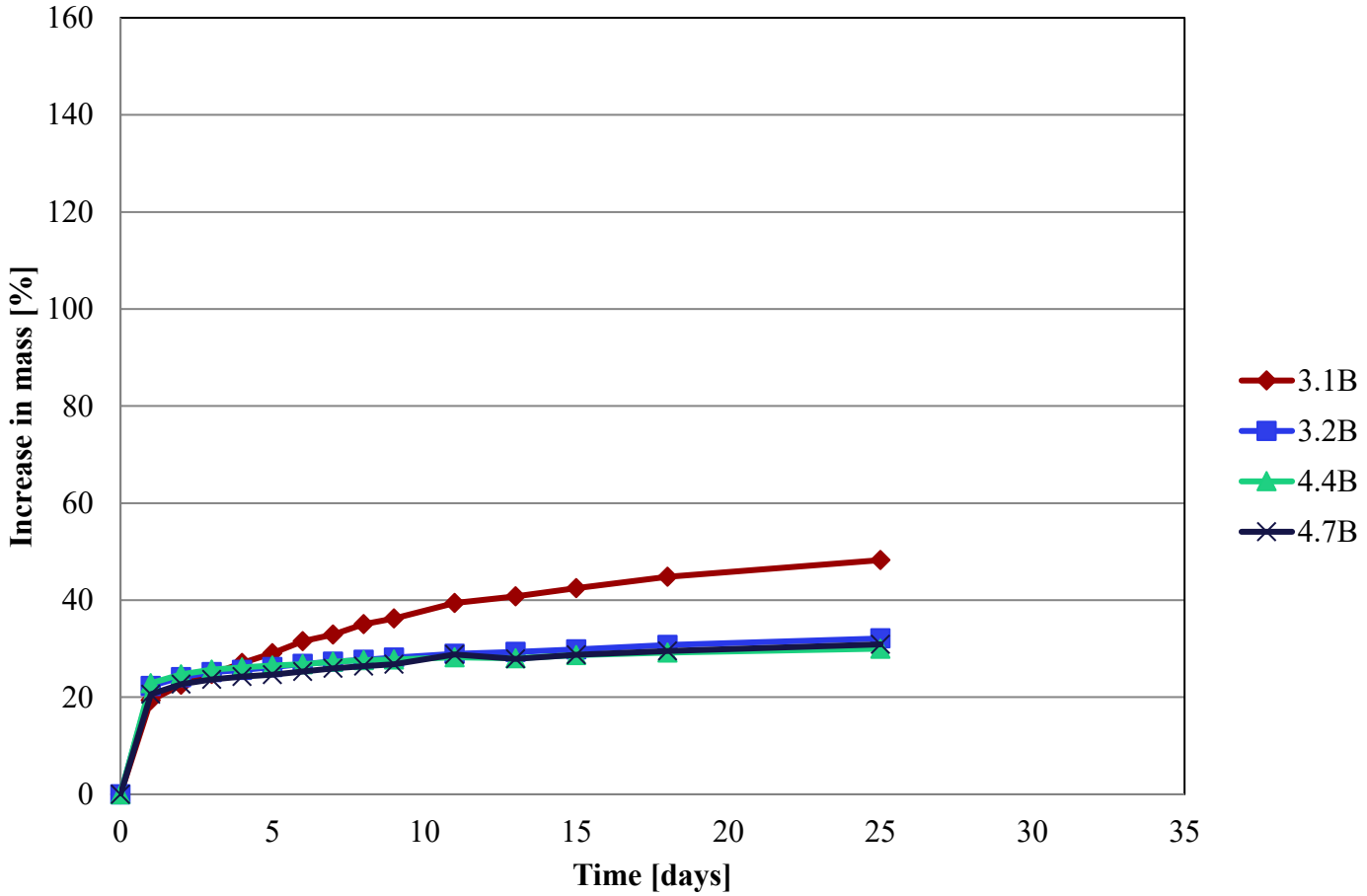
SEM-EDX



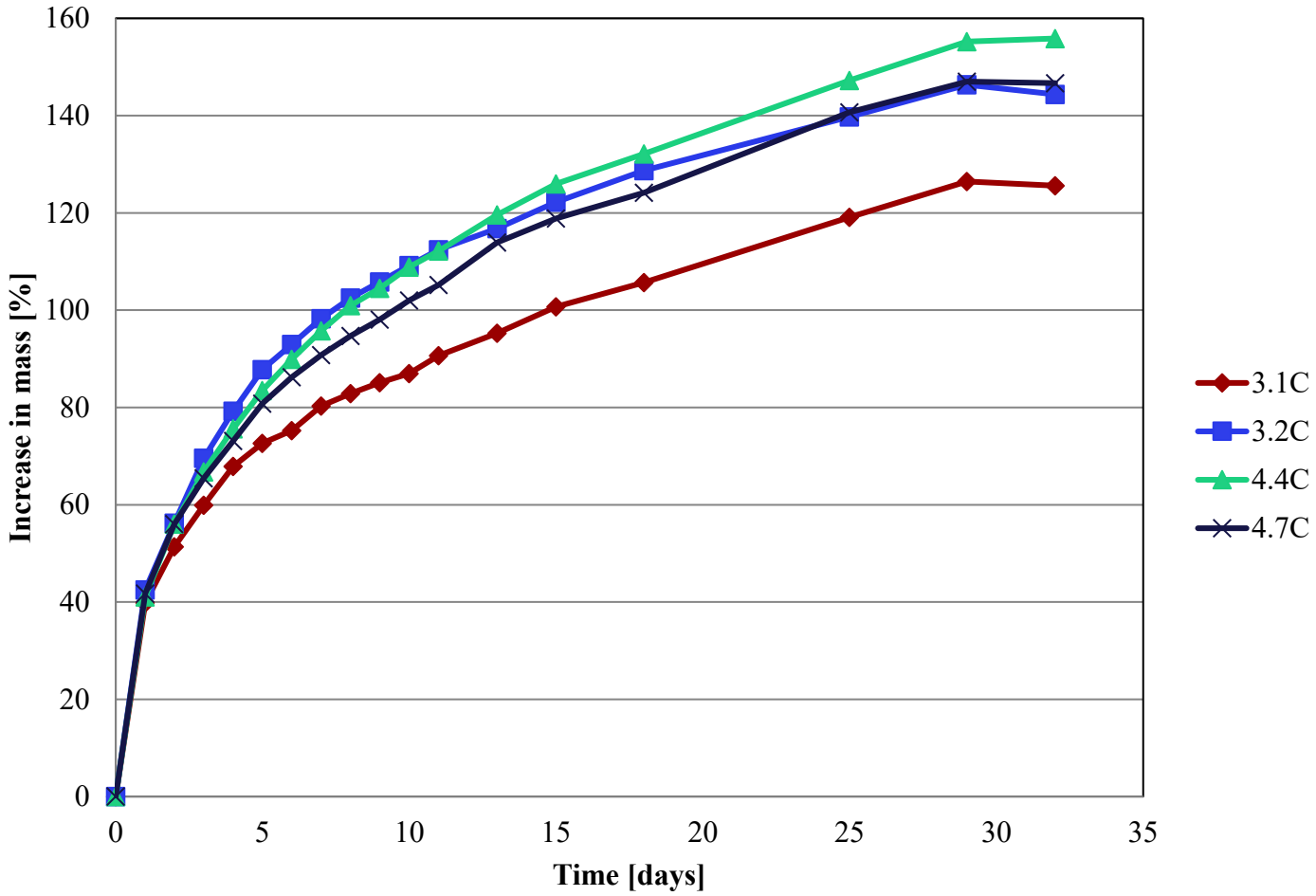
# Absorption at 35 % RH



# Absorption at 80 % RH



# Absorption at 95 % RH

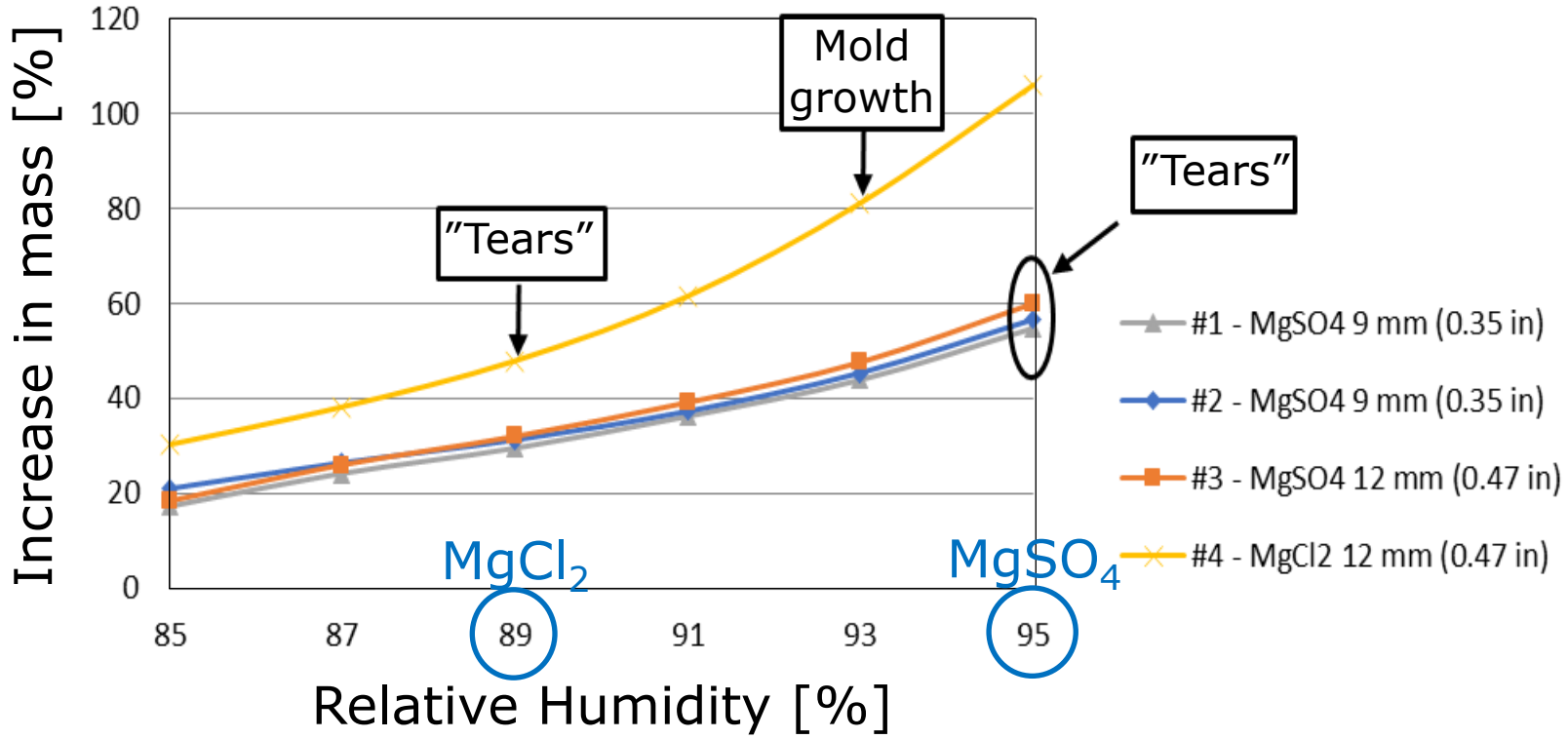


# Finding the “Weeping Point”
# Absorption: 80% -> 82% -> … -> 92% RH

- The “Weeping point” of the investigated MgO boards is approximately 84% RH
- $MgCl_2$ is in equilibrium with humid air at 33 % RH, so the content of salt in the boards is a mixture of different salts

# Characteristics of MgO boards
## - Determination of moisture retention

Finding the Weeping Point, weekly increments
Absorption: 85% -> 87% -> … -> 95% RH



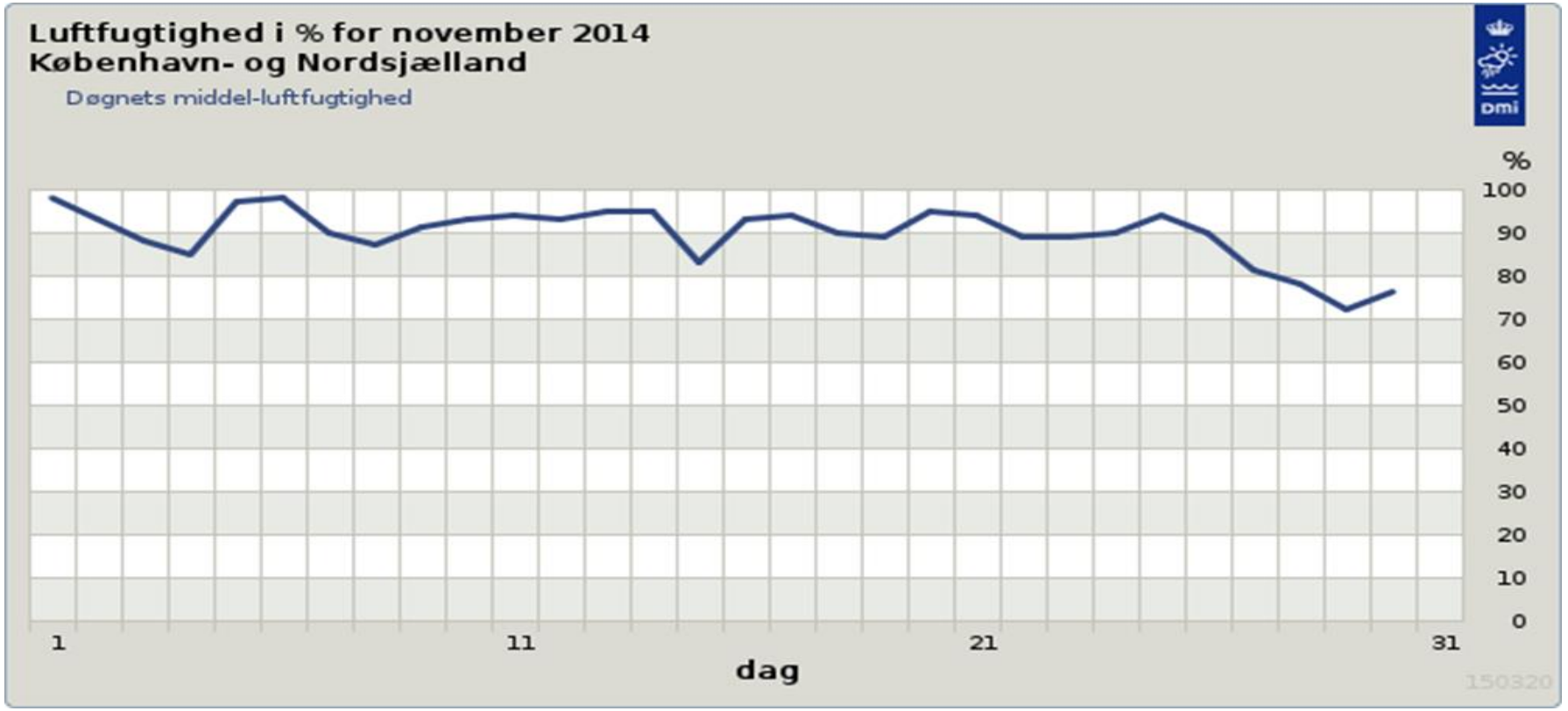
# Desorption: 92% -> … -> 30% -> ”0”

- In view of the risk of mould growth at RH higher than 92% RH, desorption was started at this RH.
- After equilibrium at 30% RH, drying of the specimens was performed as follows:
  - 105 ºC (two samples),
  - over $Mg(ClO_4)_2$ at room temperature (two samples).
- Purpose of drying in the end: to see if the dry masses were the same as before the experiments.
- One sample had lost 0.3% in dry weight, while the other three samples had lost 12-15 %

# Characteristics of MgO boards

## - Determination of moisture retention

Outdoor Climate, Denmark in November 2014

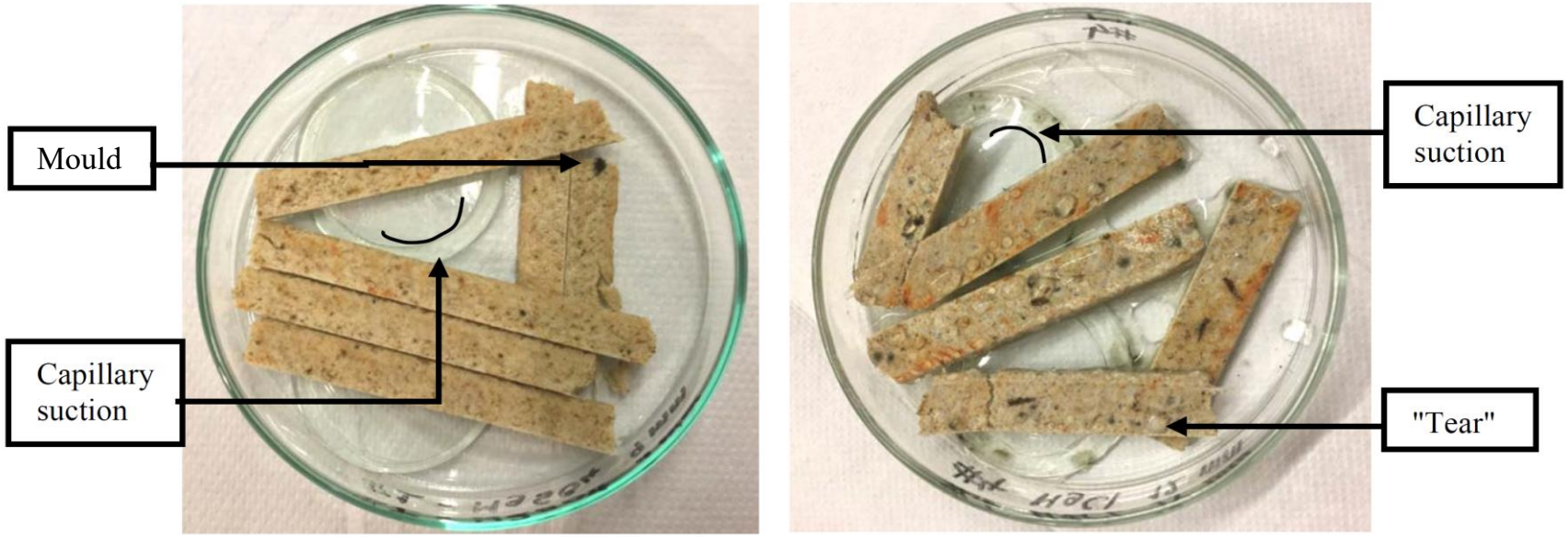


# Characteristics of MgO boards

## - Determination of moisture retention

Left : $MgSO_4$ after nine weeks

Right : $MgCl_2$ after seven weeks



# Characteristics of MgO boards

## - Analysis of chemical composition of ions of leaked salty water

Ions Found in ”Tear” Drops from MgO-Boards

Analysis by use of

ICP (Inductively Coupled Plasma Optical Emission Spectrometry)

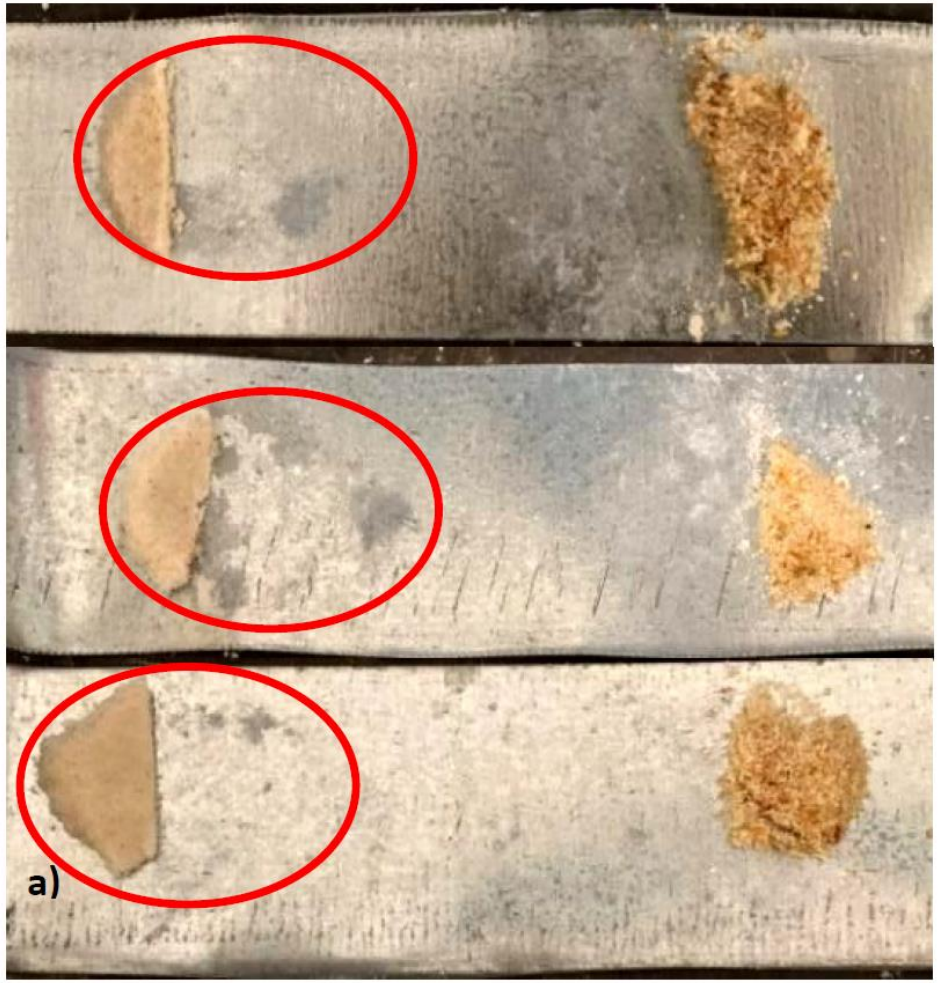
IC (Ion Chromatograph) equipment

| | $Na^{+}$ | $Mg^{++}$ | $S^{--}$ | $Cl^{-}$ | $K^{+}$ | $Ca^{++}$ |
|---|---|---|---|---|---|---|
| #1 – $MgSO_4$ 9 mm | 413 | 27,794 | 36,172 | 1490 | 269 | 323 |
| #2 – $MgSO_4$ 9 mm | 439 | 28,295 | 37,055 | 414 | 152 | 445 |
| #3 – $MgSO_4$ 12 mm | 406 | 28,099 | 34,721 | 1227 | 153 | 291 |
| #4 – $MgCl_2$ 12 mm | 540 | 14,053 | 753 | 44,123 | 322 | 0 |

mg/L

# Characteristics of MgO boards

## - Corrosion test on zinc sheets




# Corrosion of Metallic Parts of the Facade

- Salt from MgO-boards is highly corrosive on metal fasteners and profiles.
- Zink flashings of 0.8 mm corrode in 1-2 years.
- Electro galvanized steel profiles, nails and screws will corrode to the steel in 1-2 years.
- Aluminum alloys have different resistance against corrosion and the best alloys have been seen undamaged for 2-3 years.
- Stainless steel type A2 and A4 can be used without problems.
- When MgO boards have been sitting on a wooden structure, $MgCl_2$ salt will have been absorbed by the wood, which is then corrosive to metallic fasteners other that stainless steel

# Characteristics of MgO boards

## - Field methods to determine the chloride content

Free chloride content

Silver nitrate spray

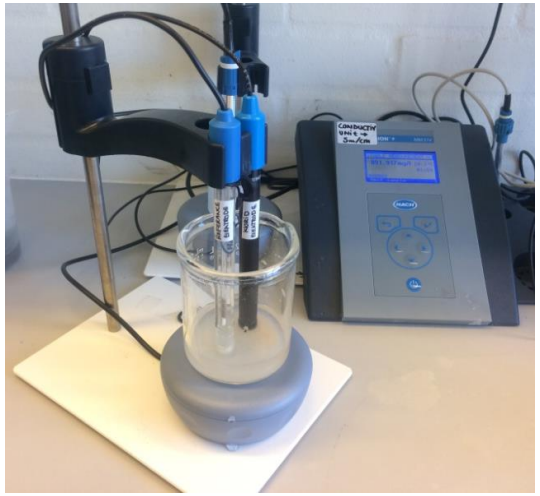
-Qualitative method
-Often used on concrete
-Forms $AgCl_2$ (purple by exposure to light)


Quantab Chloride test strips

-Quantitative method
-Interval: 30-6000 mg/L
-Applicable on construction site

Chloride Ion Selective Electrode (ISE)

-Quantitative method
-Interval: 1-35.000 mg/L
-Interference from other, non-desired ions



# Conclusions (1)

- MgO boards are not suitable for exterior use in the Danish climate
- Weeping starts at 84 % RH which is lower than the typical outdoor humidity in the Danish winter.
- The salty water causes corrosion on metal parts in contact with boards Salt from the MgO boards will infect wood in contact with the boards
- Mould can grow on the boards and the infected wood
- The MgO-boards will decompose after long exposure to moist air
- Repair methods, e.g. by adding additional insulation may be “risky”

# Conclusions (2)

Both sulfate- and chloride-based MgO-boards have an ability to absorb high amounts of moisture from a humid ambient.

MgO-boards based on sulfate absorb less water from the ambient environment than boards based on chloride.

The limit of RH at which the boards start to leak salty water is higher for sulfate-based than for chloride-based boards.

The RH-level at which boards start to “cry” should be determined and compared to the ambient conditions in locations where the boards are intended to be used.

# Perspective

- The use of MgO boards as wind barrier has led to repair costs of appr. 2 billion DKK or ~270 M€ in Denmark
- How can we avoid such a scandal in the future ?
  - Use knowledge from building physics on moisture and materials
  - Consult with this knowledge before - rather than after - introducing new materials and methods to the market!