BUILDING SCIENCE OUTDOOR TESTING – LESSONS LEARNED

Visit of Vietnamese ReBuMat project partners at Fraunhofer IBP, Holzkirchen 3rd Sept. 2024

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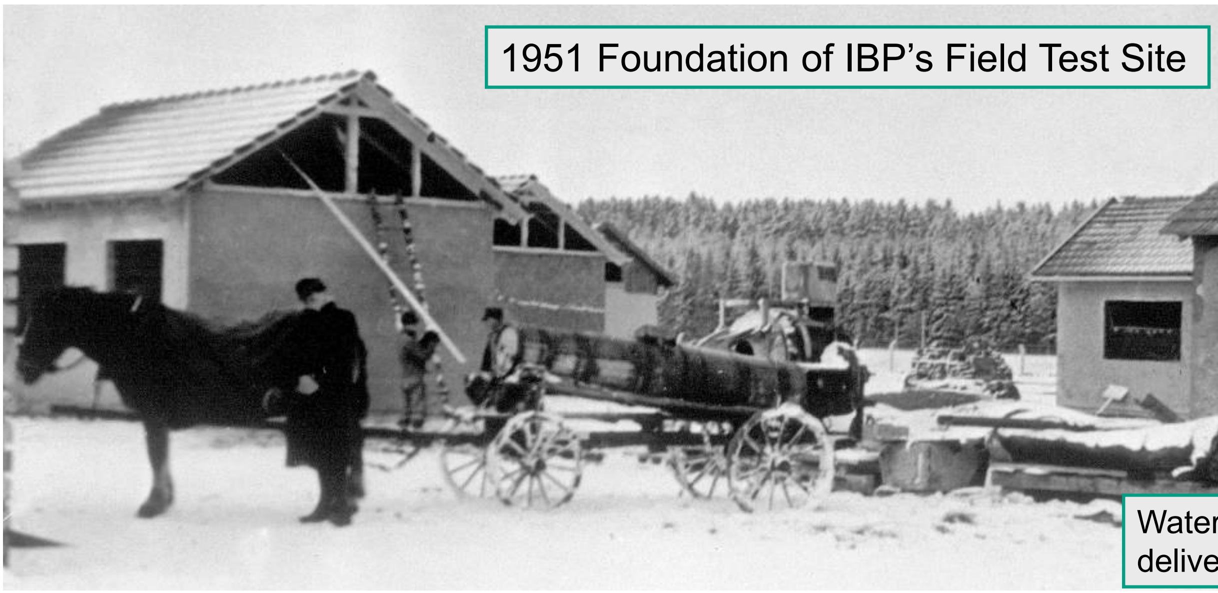
Auf Wissen bauen

Introduction

Fraunhofer IBP field test site



Introduction

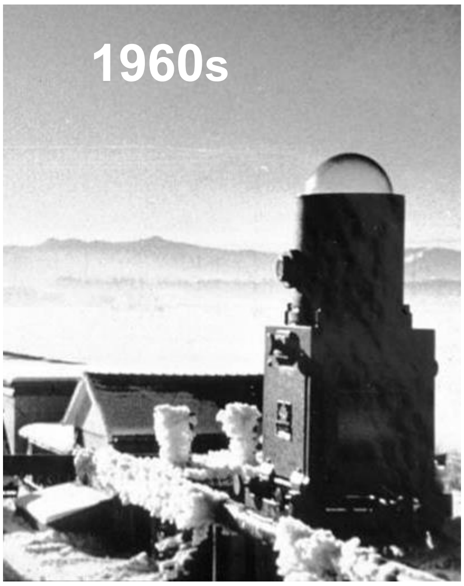
Fraunhofer IBP field test site

70 years of field tests investigating long-term building performance and material durability

Introduction

Fraunhofer IBP field test site – Meteorological station

Since 1986 weather station with automatic data recording (hourly means)

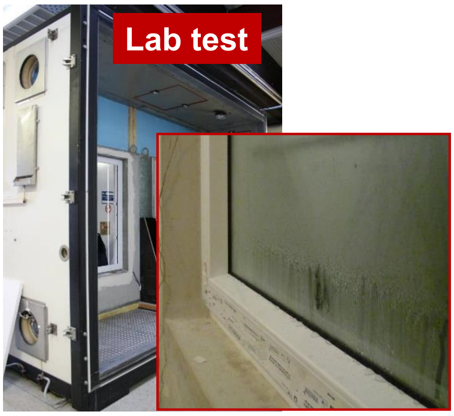


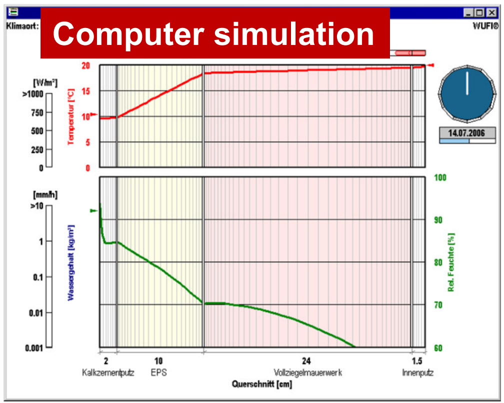
Introduction

Motivation for installing test buildings

Investigations on buildings under well defined boundary conditions provide the most reliable results – they are necessary to understand building performance and to develop and validate computer simulations and climate chamber tests in the laboratory

Building physics research is based on the triplet of field, lab and computer studies





Introduction

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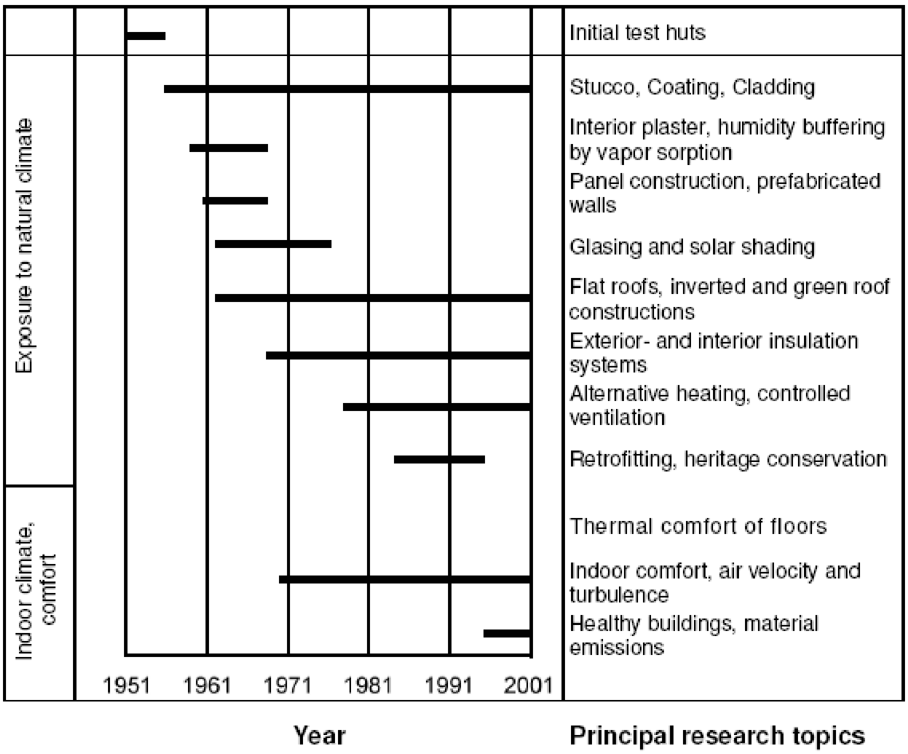
Research Topics

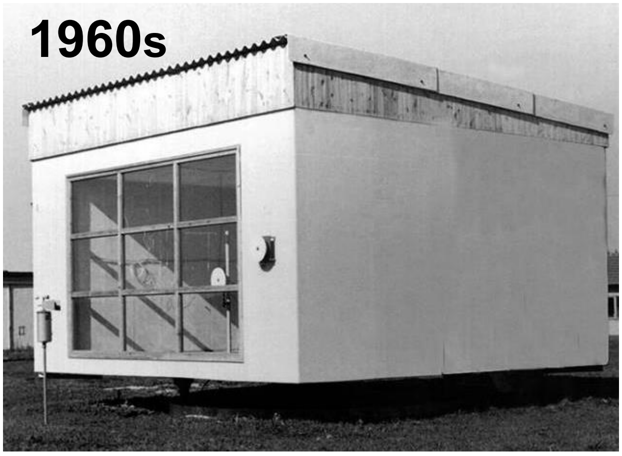


Solar heat gains in winter and summer

Fraunhofer IBP field test site – Energy performance test facilities

Investigation topics:

- HVAC appliances
- Solar absorber, PV systems
- Double skin façades
- Comfort and daylighting vs. shading to safe cooling energy



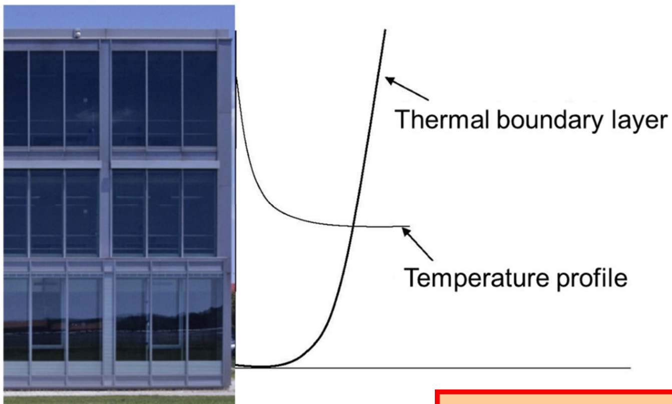
One of two revolving test houses to determine the solar heat gain through glazing systems & their effects on indoor temperature conditions

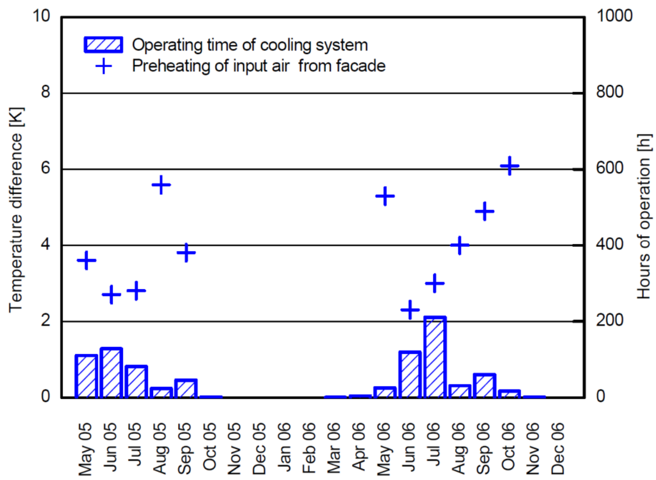
Lessons learned concerning large glazing systems:
- In winter more heat losses than solar heat gains
- More day-light = less comfort

Solar heat gains in winter and summer

Fraunhofer IBP field test site – Energy performance test facilities

Hot façade and indoor comfort

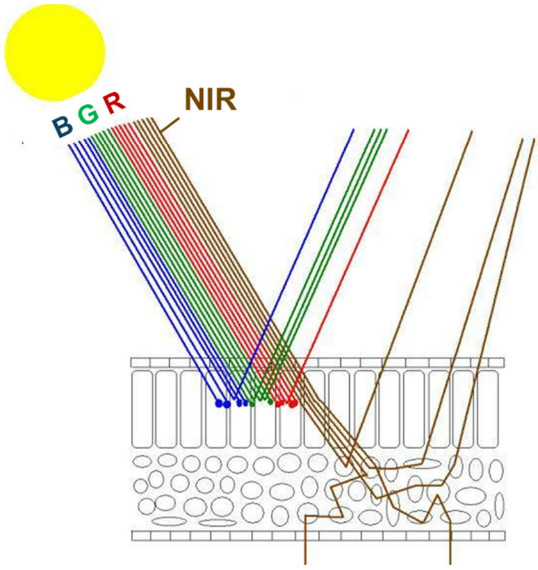


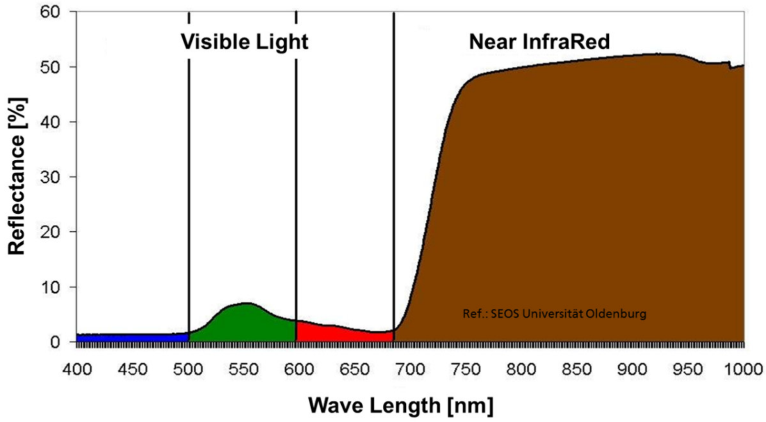


Lessons learned (façades with large glazing systems):
- Monthly mean temperature rise of ventilation supply air +6 K
- Window opening or decentral ventilation systems increase cooling load

Energy performance investigations

Solar reflection of green plants



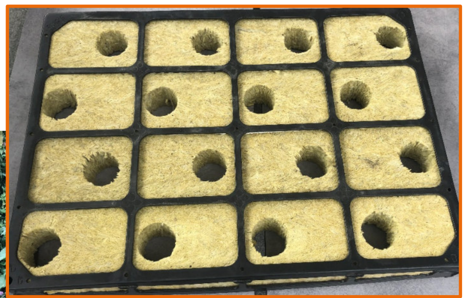


Green façades reflect solar radiation like cool colours and provide some evaporative cooling

They also absorb noise and convert CO_2 to oxygen

Energy performance investigations

Solar reflectance and indoor comfort



Comparison of mineral fiber and reflective film attic insulation

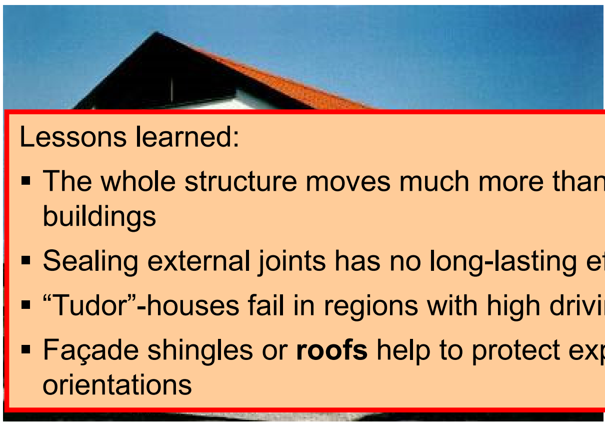
Fraunhofer IBP field test site – Energy performance test facilities

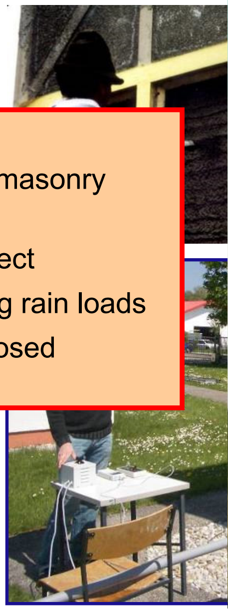
Twin houses for comparative testing of energy efficiency and building simulation model validation

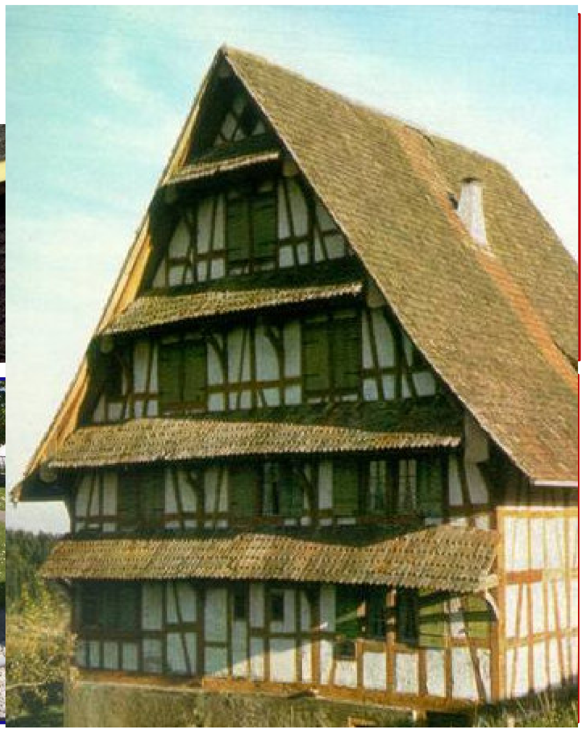
Test objects: conservatories, insulation systems, ventilation and various heating / control systems

Driving rain protection

Heritage preservation and retrofit test building







Lessons learned:

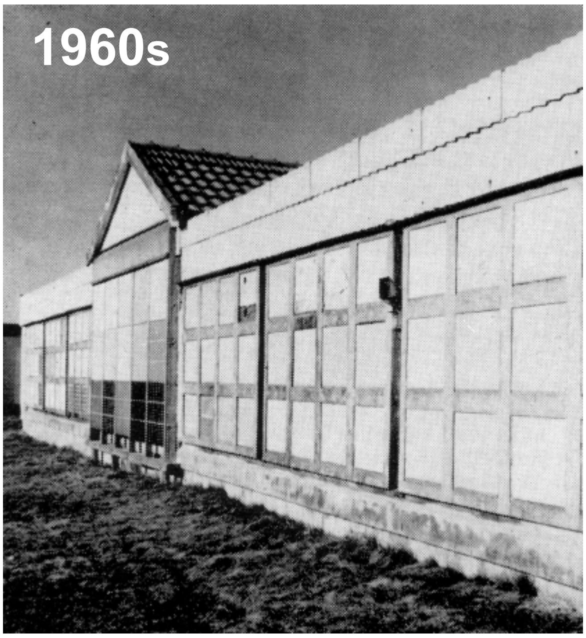
- The whole structure moves much more than masonry buildings
- Sealing external joints has no long-lasting effect
- "Tudor"-houses fail in regions with high driving rain loads
- Façade shingles or **roofs** help to protect exposed orientations

Investigations on half-timbered (Tudor) buildings retrofitted with various interior insulation and fill-in materials & system

Driving rain & air tightness

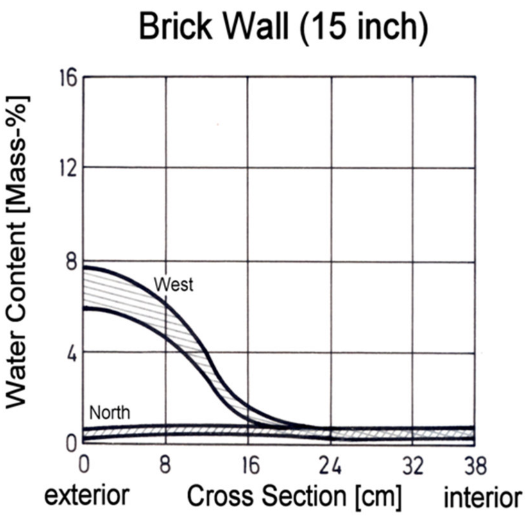
Driving rain protection

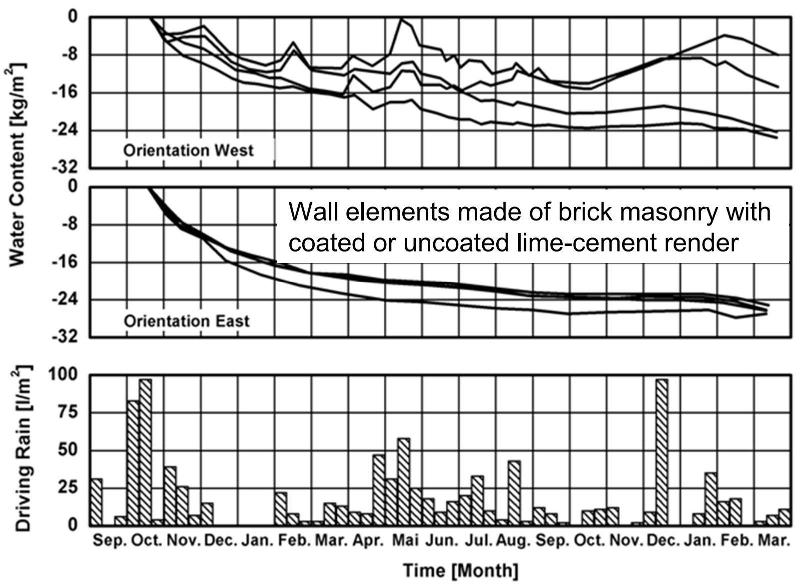
Fraunhofer IBP field test site – Air-conditioned test hall for wall exposure tests



Driving rain protection

Fraunhofer IBP field test site – Air-conditioned test hall for wall exposure tests

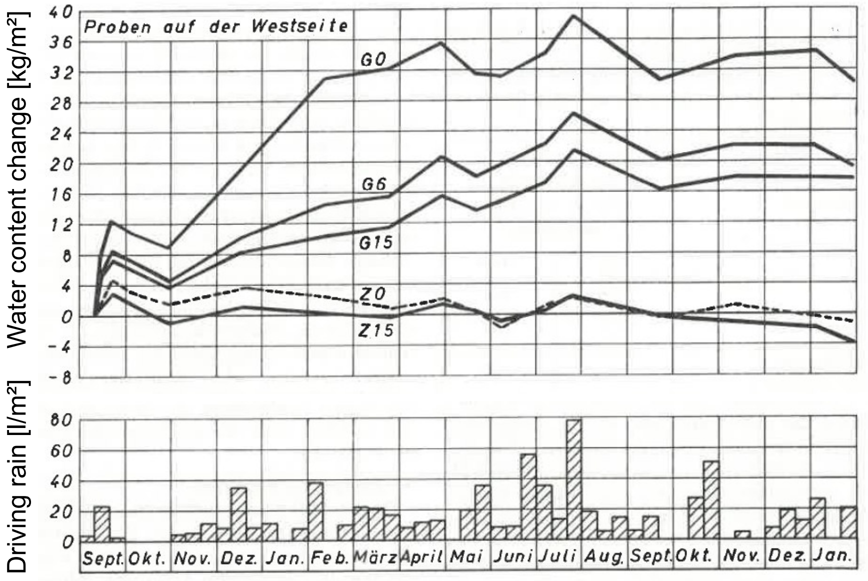




Problem: Insufficient driving rain protection

Driving rain protection

Fraunhofer IBP field test site – Air-conditioned test hall for wall exposure tests



West façade with lime-cement render

G0 AAC wall **without** render wetting

G6 AAC wall with 6 days of wetting

G15 AAC wall with 15 days of wetting

Z0 Brick wall **without** render wetting

Z15 Brick wall with 15 days of wetting

Lessons learned:

- Clay brick is a better substrate for lime-cement render because it provides the water needed for curing.
- AAC walls require special rendering systems that retain water for curing and repel driving rain.

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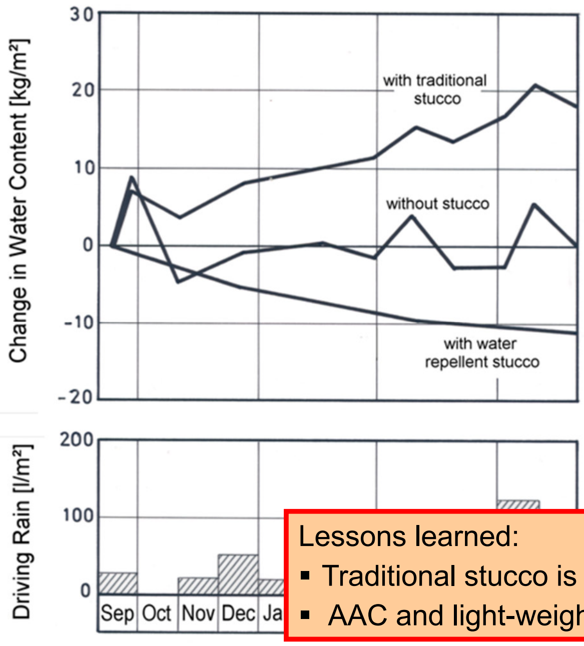
Driving rain protection

Fraunhofer IBP field test site – Air-conditioned test hall for wall exposure tests

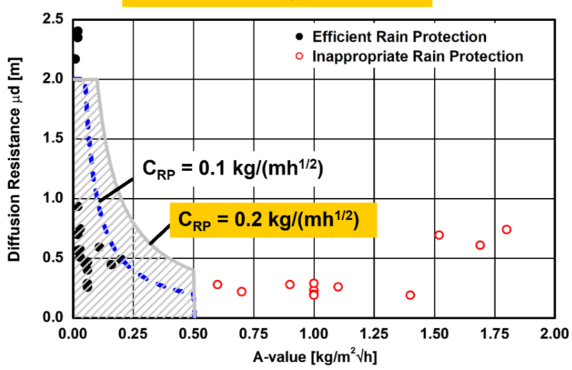


West facing AAC wall elements with

- traditional stucco
- water repellent stucco
- without stucco

Solution: Water repellent stucco systems ►►►►

DIN Standard requirements



Lessons learned:

- Traditional stucco is unsuitable as face seal for masonry exposed to driving rain
- AAC and light-weight concrete blocks are more vulnerable than clay bricks

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Rainwater penetration

Rainwater penetration cannot be completely prevented – there is no perfect seal!

Rainwater penetration through cracks in joints or window-wall connections may cause severe damage

EPS moisture below windowsill ≈ 10 vol.-%

Lessons learned:

- There is no perfect seal
- Replacing stucco by tiles makes EIFS more vulnerable under high driving rain loads (damage starts at the bottom!)

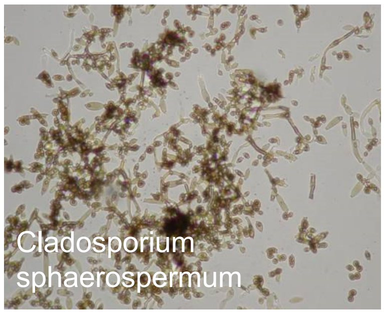
Soiling of façades

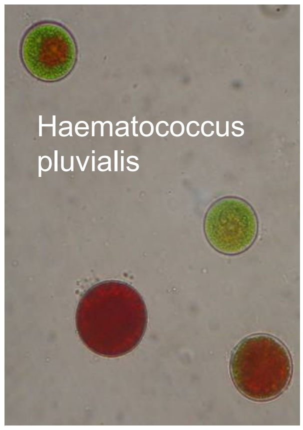
Fraunhofer IBP field test site – Wall test facilities

Red, green, grey or black – as you like it! (red/green = algae, grey to black = fungi)

Soiling of façades

Microbiology laboratory of IBP

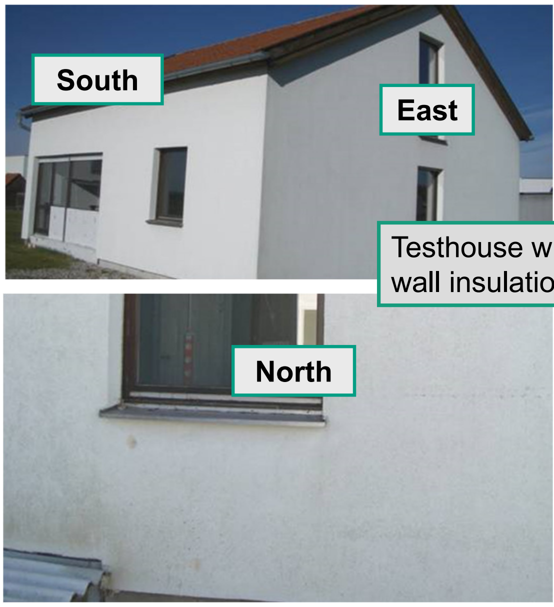


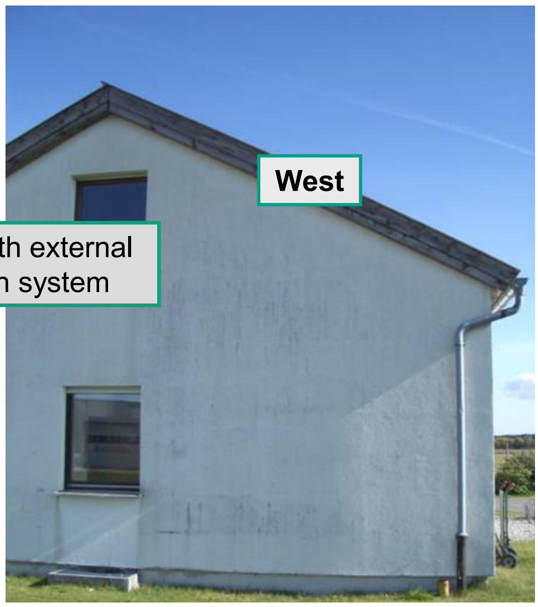


Species of algae and fungi found on façades

Soiling of façades

Fraunhofer IBP field test site – Influence of orientation





Testhouse with external wall insulation system

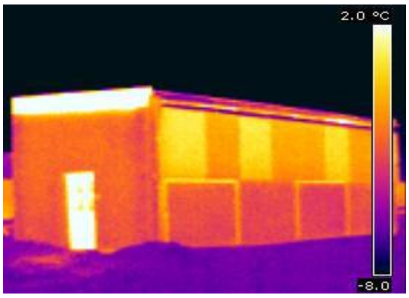
Microbial growth depends on orientation and exposure

Relevant factors:

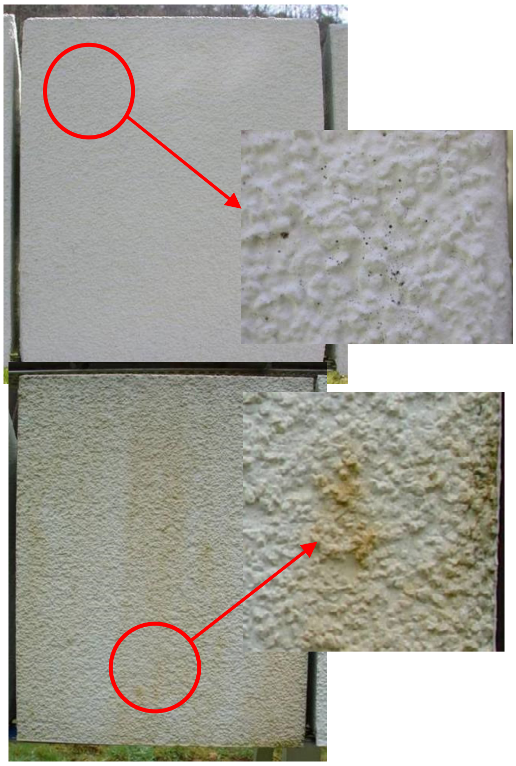
- Driving rain
- Exterior condensation
- Drying conditions

Soiling of façades

Fraunhofer IBP field test site – Samples of stucco on EPS



Recording long-wave radiation, surface temperature and exterior condensation to find solutions against microbial growth



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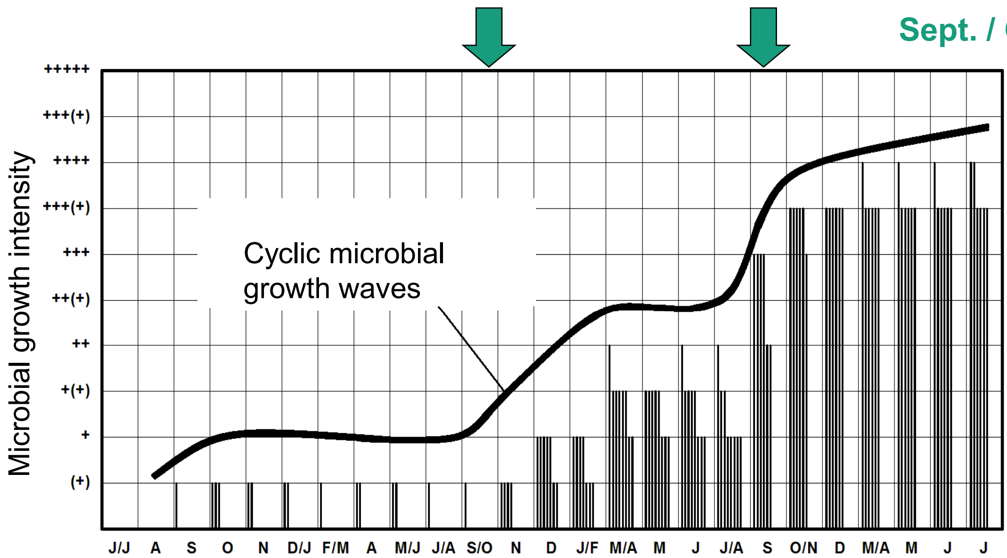
Soiling of façades

Fraunhofer IBP field test site – Influence of seasonal climate conditions

Sept. / Oct.



Fall is the most humid season of the year with above zero temperatures.

This favors microbial growth!

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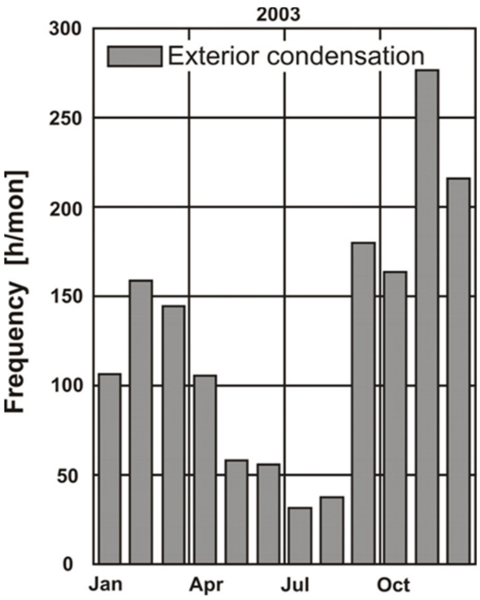
Soiling of façades

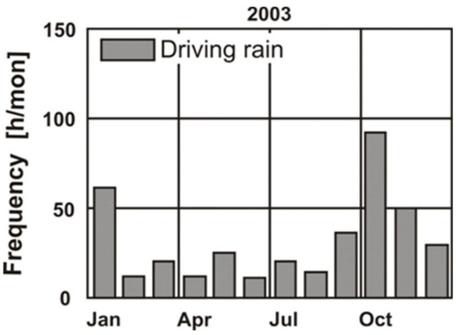
Surface moisture – prerequisite for microbial growth

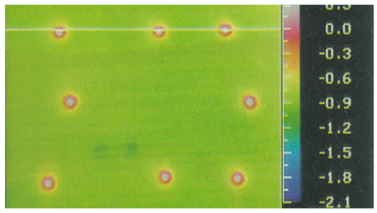


Amount of water from driving rain is approx. 10 times higher than amount of façade condensate

But

Exterior condensation occurs more often than driving rain

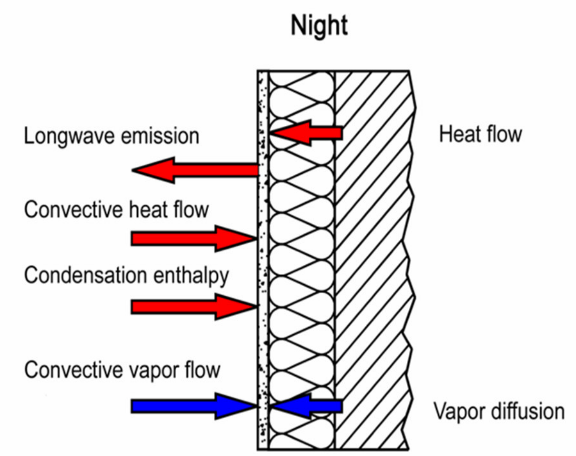


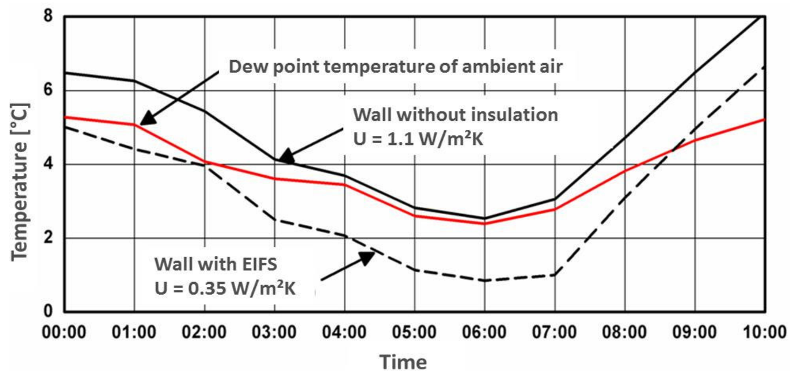


Soiling of façades

Surface temp. recordings

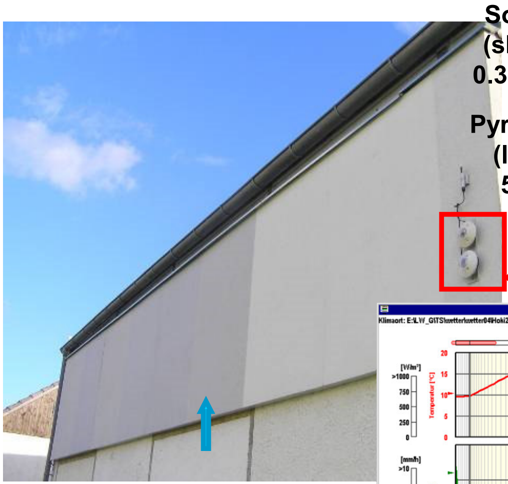
Challenge:
Retrofitted walls look soon uglier than uninsulated walls!!



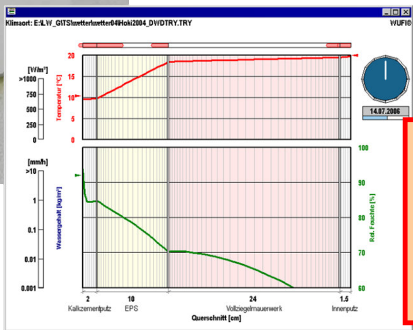


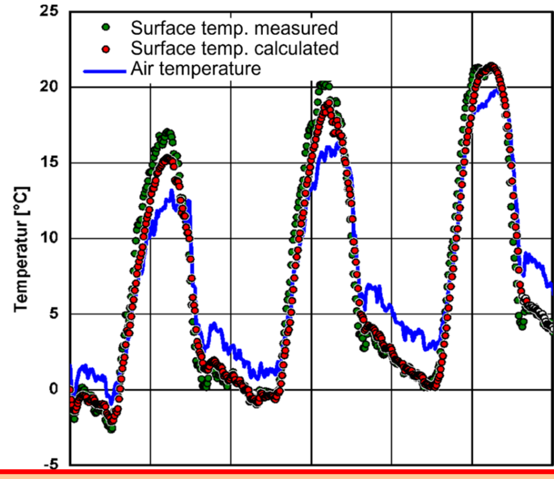
Soiling of façades

IR radiation analyses



Brick with EIFS (EPS 100 mm)
Location: Holzkirchen
Orientation: North



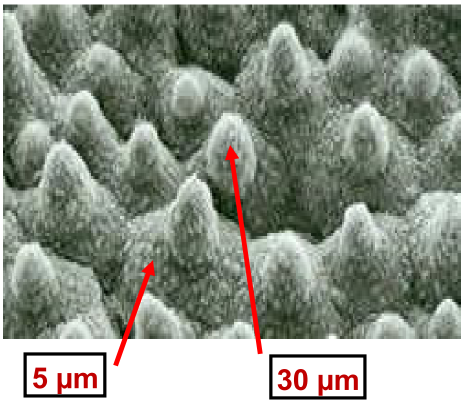


Lessons learned:

- More insulation >> more surface overcooling
- Low-E coatings help to reduce overcooling
- Simulations help to identify risky construction types and microclimates

Soiling of façades

Is condensation water the same as rainwater?



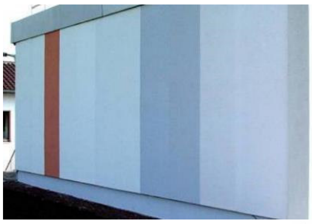
The Lotus Effect –

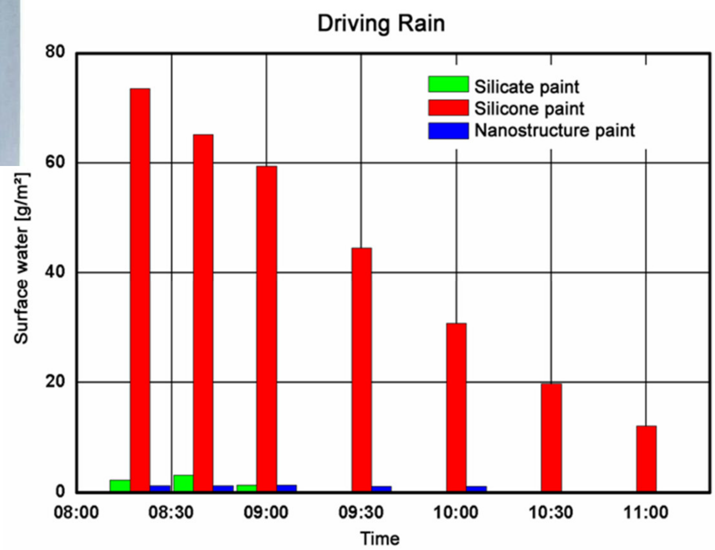
The paint coat revolution !?

Lotus leaves are extremely water repellant

Soiling of façades – prevention by Lotus paint coat

Driving rain protection and removal of dirt particles



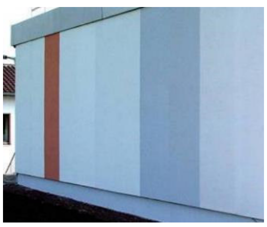


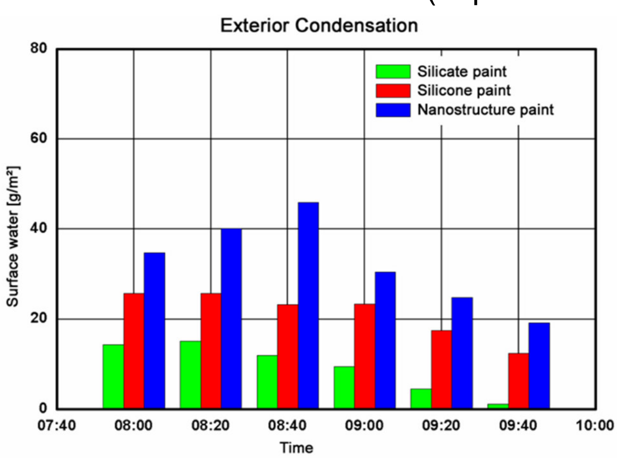
Exterior paint	Water absorption coefficient A [g/(m² √s)]
Silicate dispersion	0.8
Silicone dispersion	0.4
Nanostructure (Lotus)	0.1

Rainwater drains well off nano-paint (Lotus) since droplets run down readily on the spiky surface

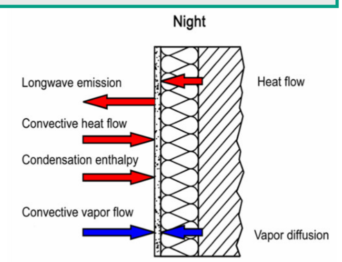
Soiling of façades – prevention by Lotus paint coat

Condensation and rainwater are different animals (deposit on materials very differently)





Night-time radiation to the sky leads to overcooling of the exterior wall surface and subsequent condensation

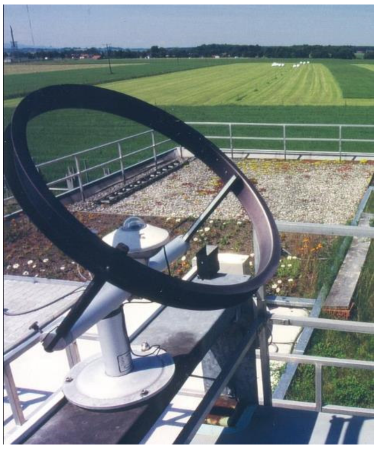


Lessons learned:

- Condensation water gets trapped in the nanostructure of the Lotus paint and does not drain like rainwater
- Condensation peaks in the morning after sun-rise due to rise in ambient dewpoint
- Best performance: silicate paint limiting surface condensate by water absorption

Facilities for green roof investigations

Fraunhofer IBP field test site – Green roof tests



Investigation of the hygrothermal performance of roof structures with vegetation by recording temperature, humidity, water retention and **release of chemicals (root barrier)**

Lessons learned: “green” roofs may be colder that “cool” roofs | Release of herbicides may cause problems

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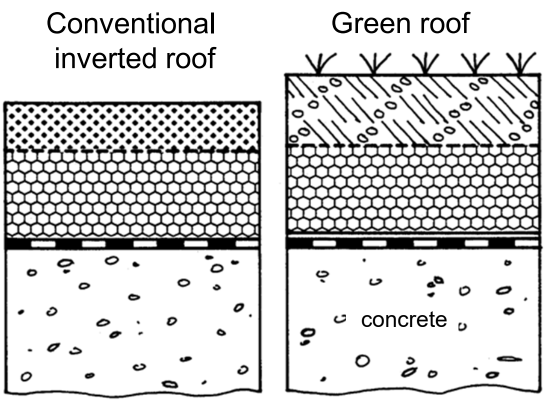
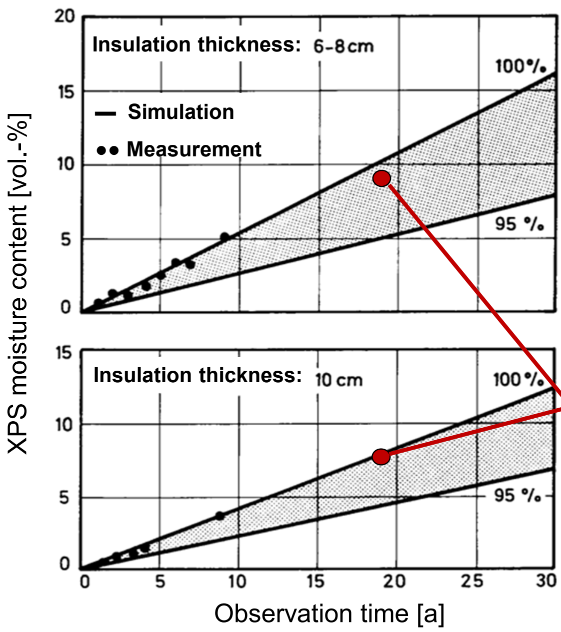
Protected membrane roofs (inverted roofs) with greenery

Determining insulation moisture content by probing and simulation

50 vol.-% in EPS! Too expensive to dispose of!





Probing again after 19 years

Lessons learned (foam insulation):

- Contact with water at the warm side results in moisture accumulation
- The accumulation speed depends on temperature gradients and vapor perm.

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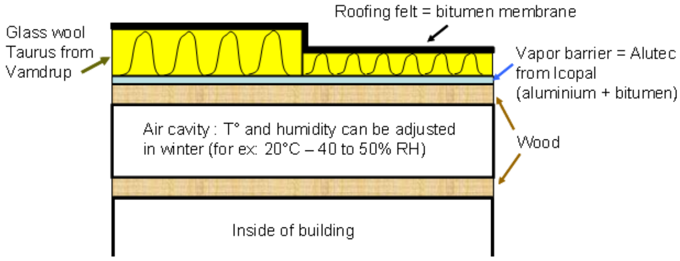
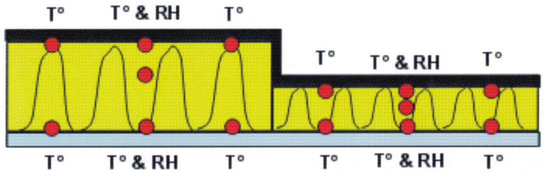
Flat roof investigations with glass fiber

Monitoring moisture due to rain during installation

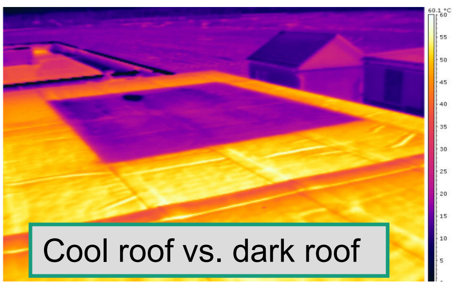


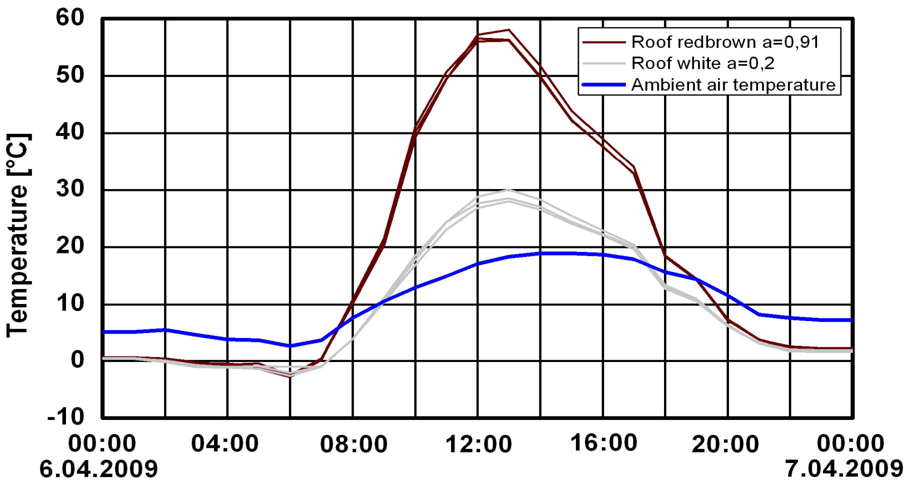


Sensor positions

Flat roof investigations

Roof top temperature day and night as function of surface color (as = 0.9 / 0.2)





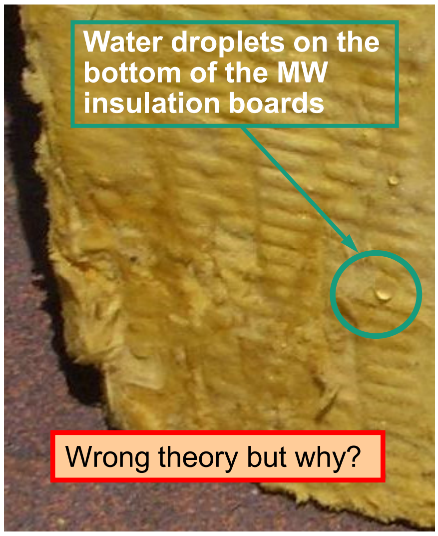
Bright or “green” surface layers reduce the drying potential of flat roofs

Flat roof investigations

Monitoring moisture due to rain during installation

Manufacturers's theory: Rainwater doesn't hurt, because the roof gets so hot in summer and dries quickly due to vapor convection out of the roof driven by the high saturation vapor pressure

Inspection of the roof after 3 years

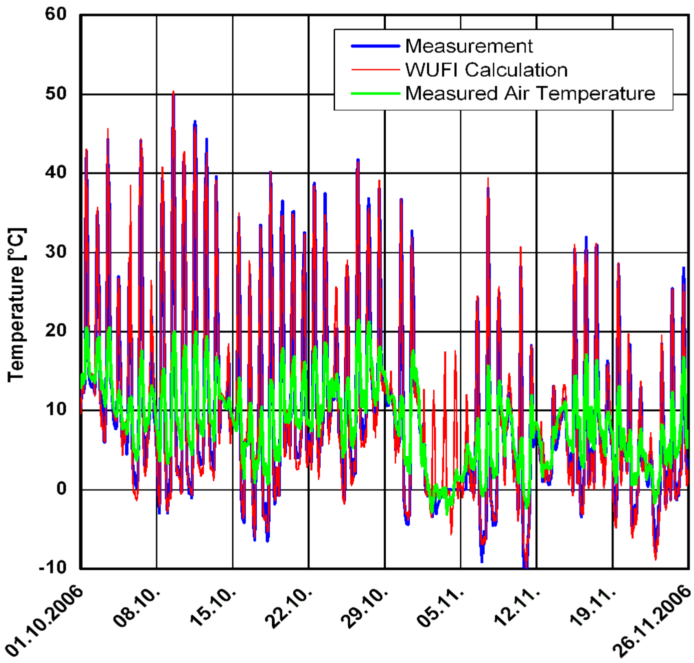


Flat roof investigations

Roof top temperature day and night

Comparison of calculation and measurement

Exterior temperature sensor position (beneath the roofing membrane)

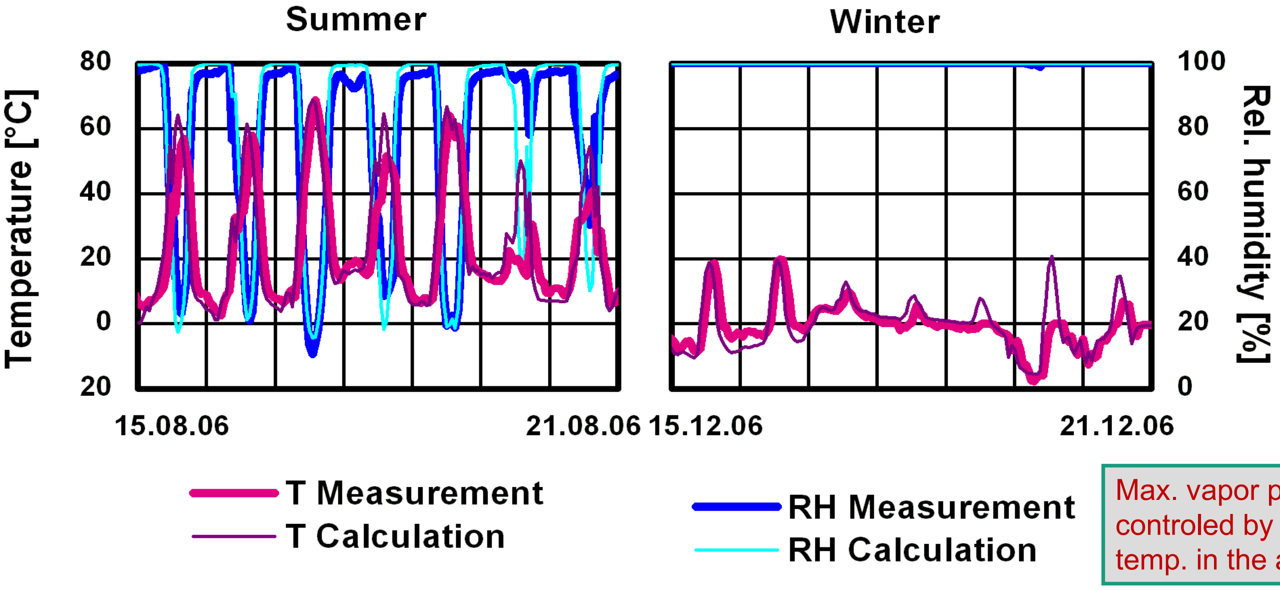


Surface temp. highs and lows are well captured by the simulation

Flat roof investigations

Temp. and RH fluctuation under the roofing membrane

Comparison of calculation and measurement



Max. vapor pressure is controled by the lowest temp. in the assembly

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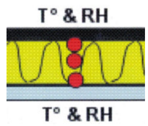
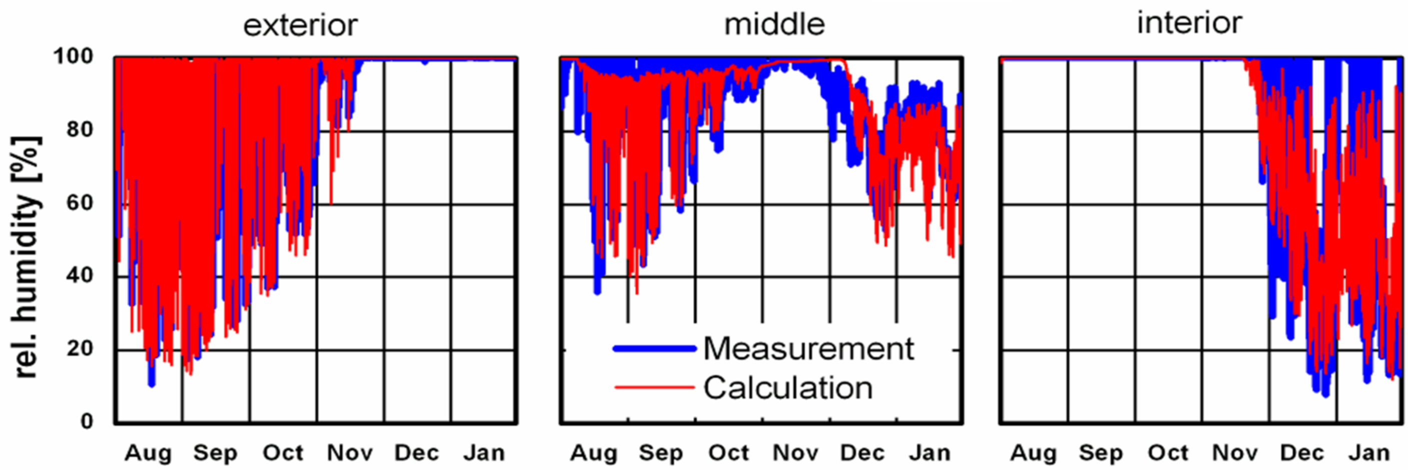
Flat roof investigations

RH fluctuations at different positions in the roof assembly



Sensor positions



The bulk of water moves in fall form the bottom to the top of the roof and vice versa in spring (not shown)

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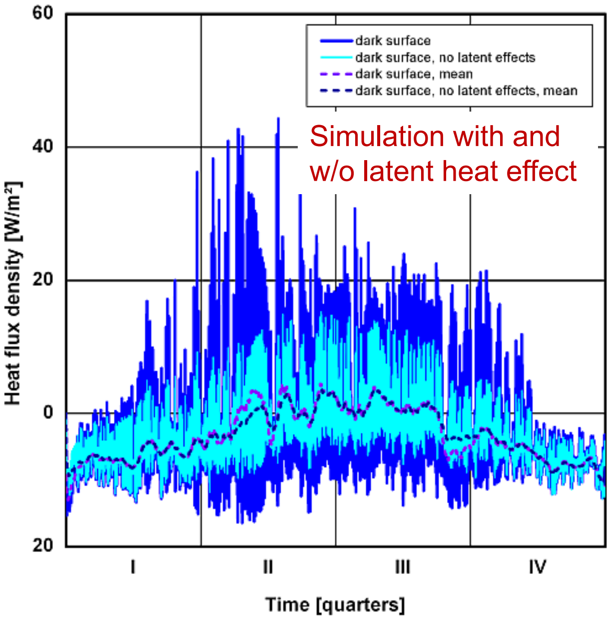
Flat roof investigations

Heat flux calculation for the interior ceiling surface with and **without latent heat effect (h_v = 0)**



- Due to the vapor-tight membranes on both sides no moisture can escape
- Therefore, there are only little net energy losses caused by the latent heat effect
- **But:** short-term latent heat impact may **more than double** the heat flux through the roof

- The net redistribution of moisture between the top and the bottom of the roof happens in spring and fall when neither heating nor cooling is required

Lessons learned:

- Energy penalty due to latent heat transport in fibrous insulation materials is often overestimated
- Moisture accumulation in foam insulation materials may significantly reduce the thermal resistance

Performance of biobased building materials

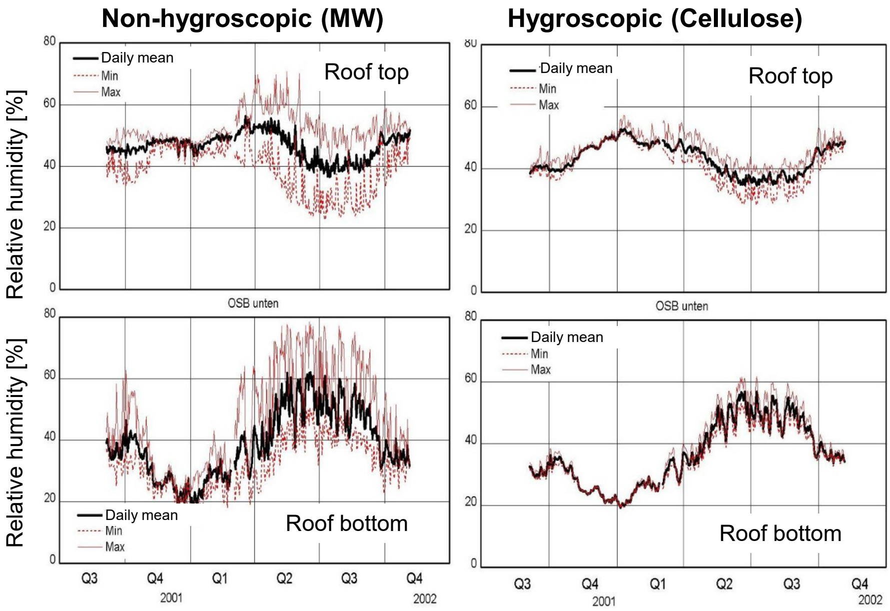
Moisture and Mold Resistance

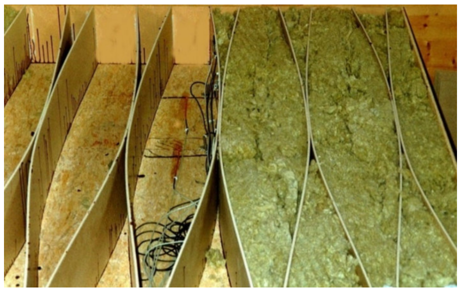
Bio-based building materials have 2 major week points:
Fire (smolderding) resistance & **moisture susceptibility**

Aquaculture materials seem to be more resistant

Performance of biobased building materials

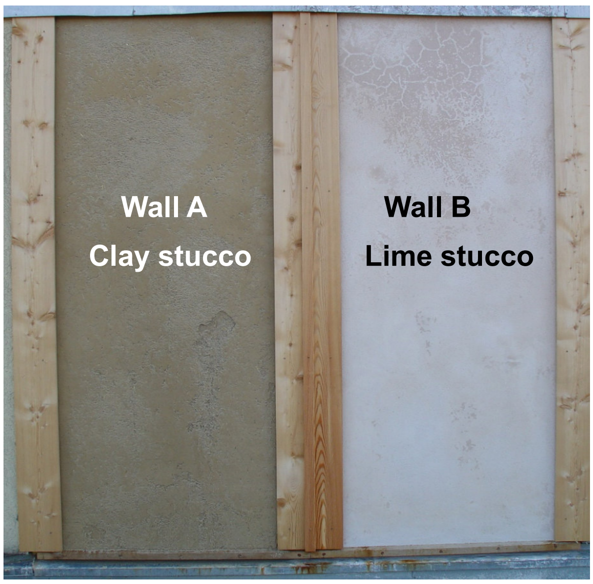
Flat roof with hygroscopic insulation





Performance of biobased building materials

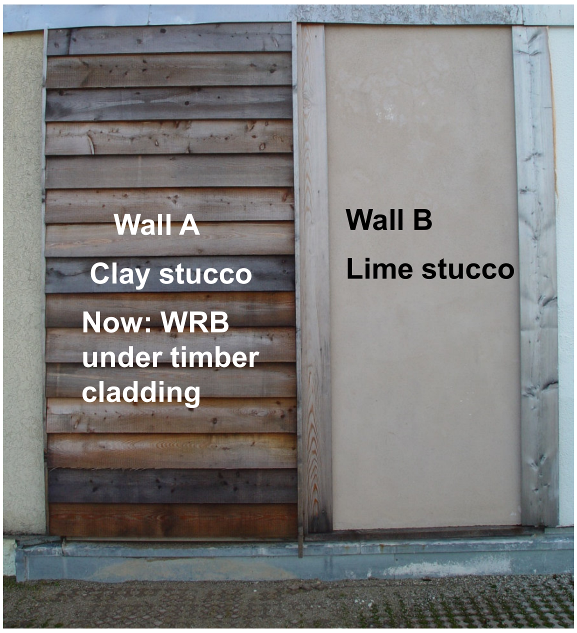
Straw bale walls exposed to driving rain



Performance of biobased building materials

Straw bale walls exposed to driving rain

Clay stucco down after first heavy rain



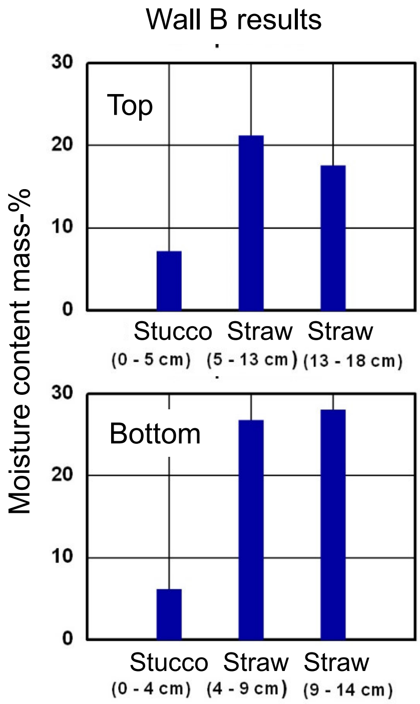
New cladding for wall A, lime stucco of wall B still ok

Performance of biobased building materials

Probing of exposed walls and of reference sample

Straw moisture of reference sample and Wall A after dry-out under cladding:

MC ≈ 10% by mass

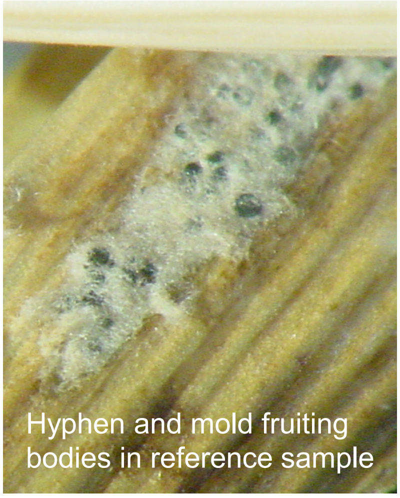


Performance of biobased building materials

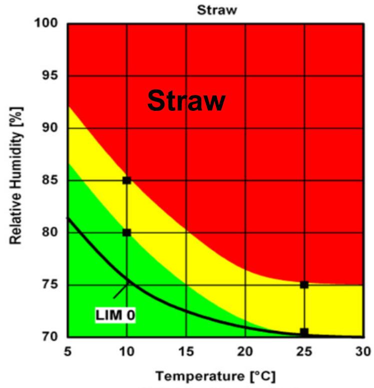
Probing of exposed walls and of reference sample by biologists

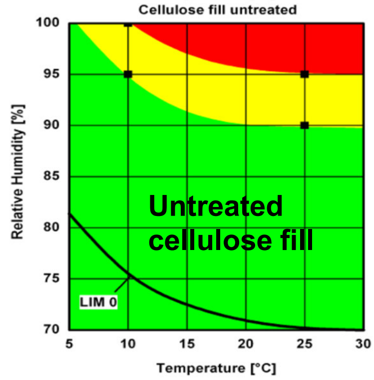

Hyphen of a plant parasite and spores of Alternaria sp. in wall A


Hyphen of Saprophyte in wall B


Hyphen and mold fruiting bodies in reference sample

Problem: initial microbial contamination & mold sensitivity





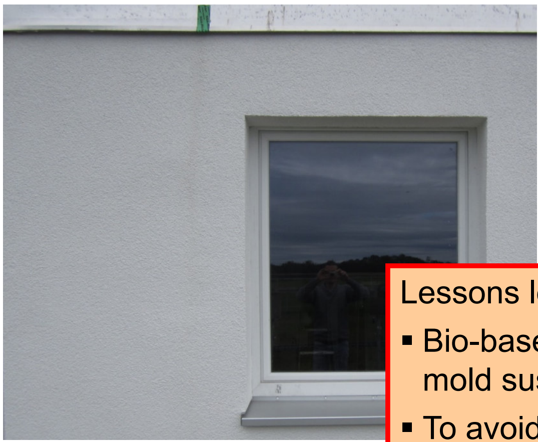
Performance of biobased building materials

EIFS with hemp insulation – installation and sealing

Hemp insulation boards fixed onto brick wall with water repellant stucco directly applied on top of insulation

Performance of biobased building materials

EIFS with hemp insulation – inspection after a year



Careful sealing did not prevent rainwater penetration

Lessons learned:

- Bio-based non-timber building materials may be more moisture and mold susceptible than wood or wood-based products.
- To avoid strong initial microbial contamination, materials should be “disinfected” prior to installation.
- **Only experts in timber construction should attempt to use other bio-based products**

Moisture performance investigations

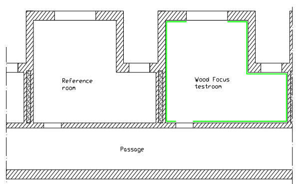
Managing indoor humidity by moisture buffering of the interior lining materials

Reference room

Wall surfaces and ceiling are made of gypsum plaster with paint coat (sd=0,15m) beschichtet.

Test room

Wall surfaces and ceiling are coated with Aluminium foil



Moisture performance investigations

Managing indoor humidity by moisture buffering of the interior lining materials

Volume: 49,5 m³

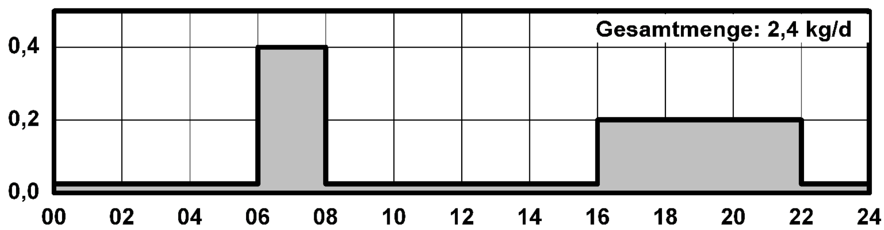
Room temperature: 20 °C

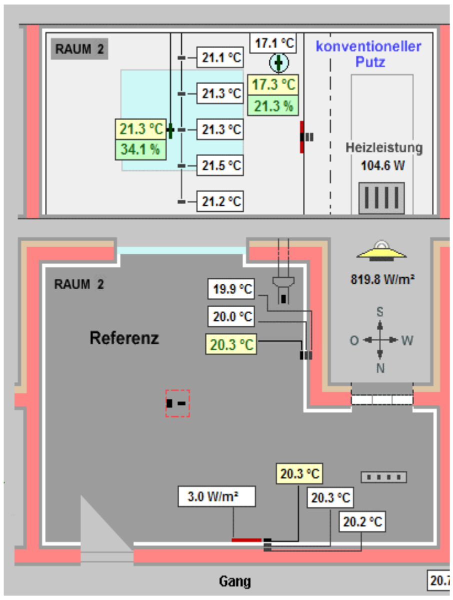
Sorptive surfaces: 67 m²

Air change rate: n = 0,63 h^{-1} und 0,66 h^{-1}

Moisture production: 2,4 kg/d

Daily moisture production cycle kg/h





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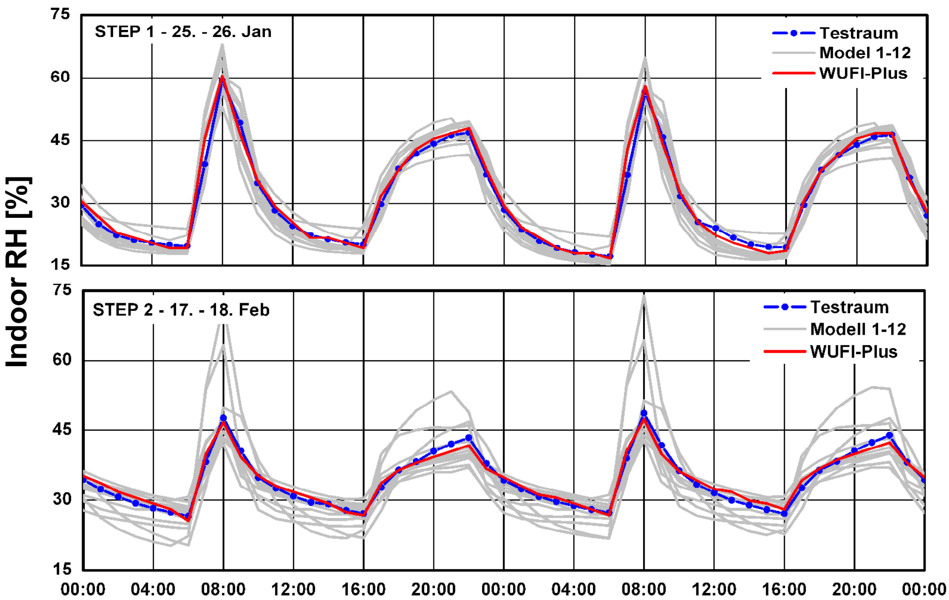
Moisture performance investigations

Validating hygrothermal building simulation models by IBP benchmark case



Test room with Aluminum foil

Reference room with gypsum plaster

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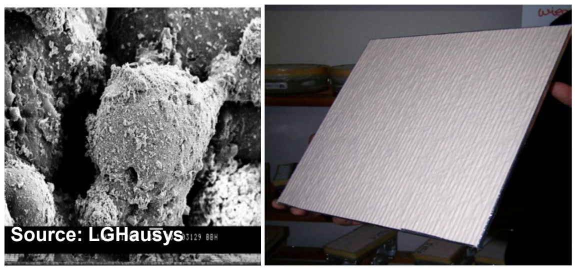
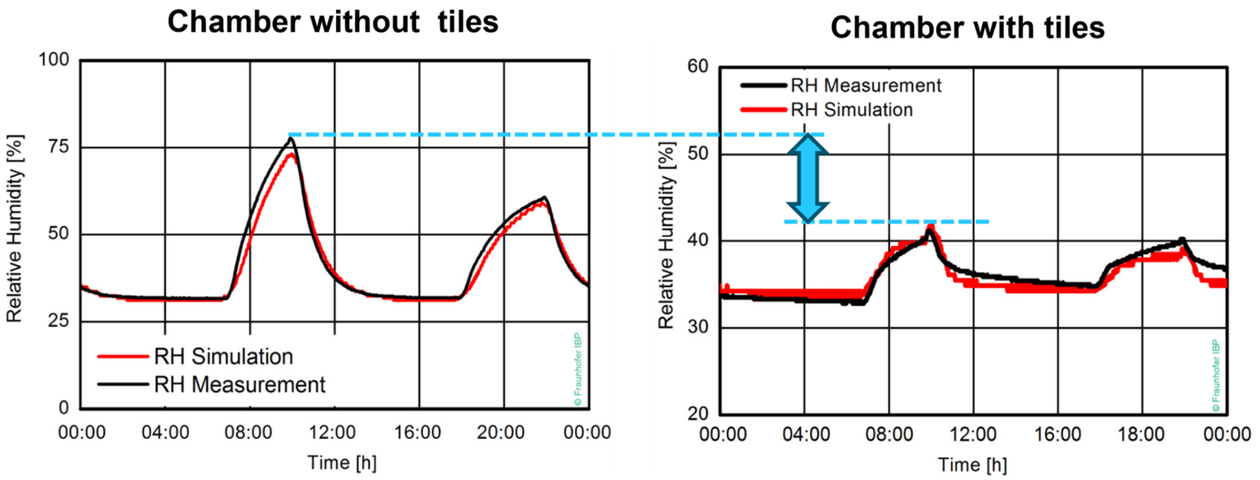
Moisture performance investigations

Impact of moisture buffering interior lining materials

Performance investigation of special moisture buffering tiles





Moisture buffering materials dampen humidity spikes

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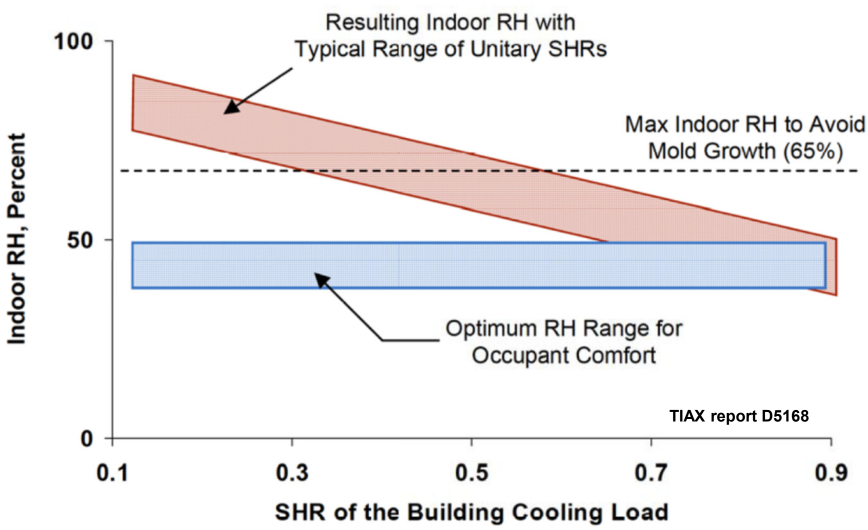
Moisture performance investigations

Moisture removal capacity of standard unitary AC systems



SHR (sensible heat ratio) = sensible heat load / total heat load)

High latent loads may cause high indoor RH

Critical threshold: SHR ≈ 0.55

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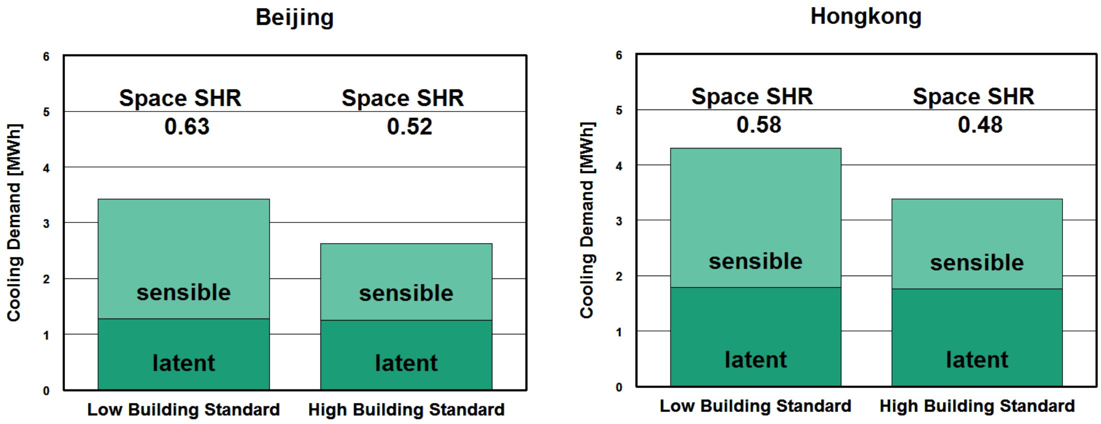
Moisture performance investigations

SHR of cooling loads in apartment building July / August – WUFI Plus simulation

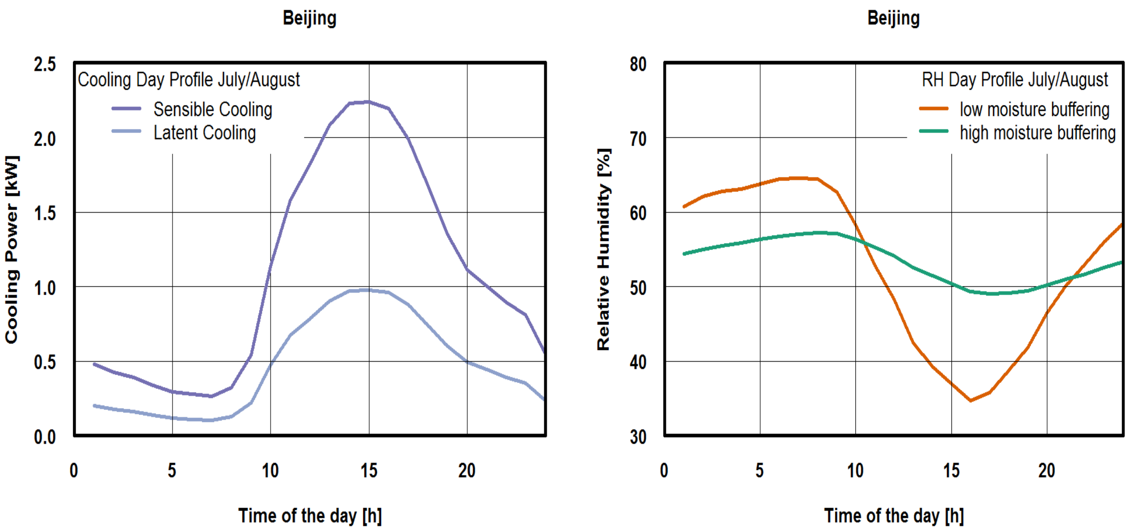


- Low Building Standard: U-wall = 1.2 W/(m²K), U-window = 2.7 W/(m²K), g=0.45
- High Building Standard: U-wall = 0.26 W/m²K, U-window = 1.3 W/(m²K), g=0.3
- Ventilation: 0.6 ACH
- Set-Points: 25°C; 50 % RH

Improving the building standard may require AC system change

Moisture performance investigations

Impact of moisture buffering interior lining materials – WUFI Plus simulation



Cooling loads and indoor RH in apartment building July / August

Moisture buffering capacity of the interior lining dampens daily indoor RH cycles

Energy performance investigations

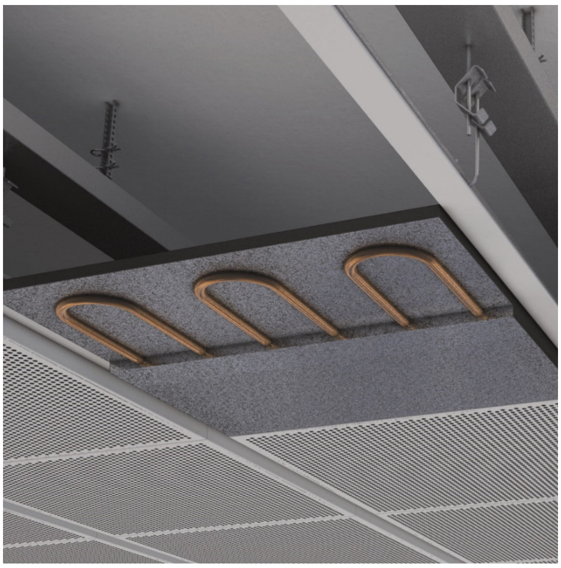
Managing indoor humidity

The Juwel in Singapore

Magnet for tourists but nightmare for HVAC design

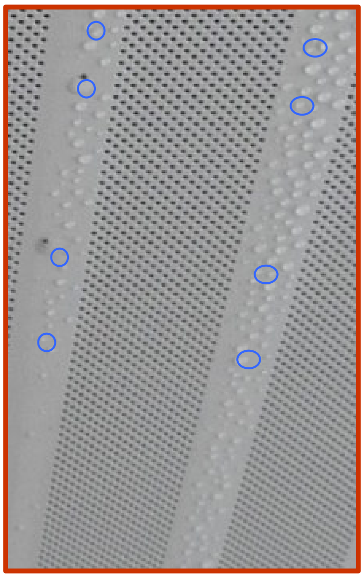
Energy performance investigations

Managing indoor humidity by standard HVAC



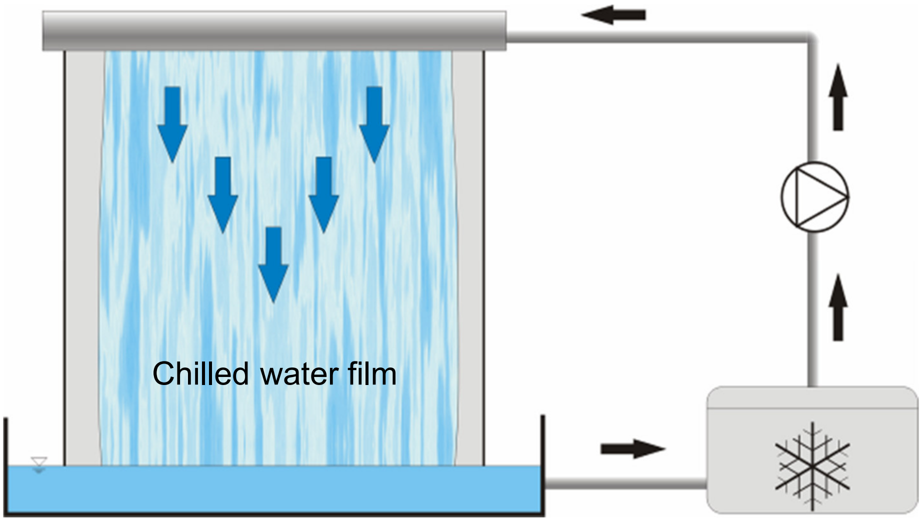
Chilled ceilings

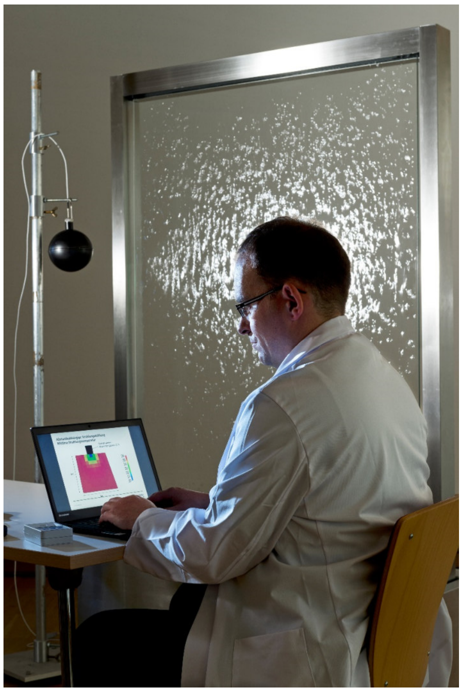
- Comfortable radiative and some convective cooling
- No noise or draft
- Approx. 25% more energy efficient than split units (water based and radiative)
- No air dehumidification
- Risk of condensation or mould growth, therefore limited cooling power



Energy performance investigations

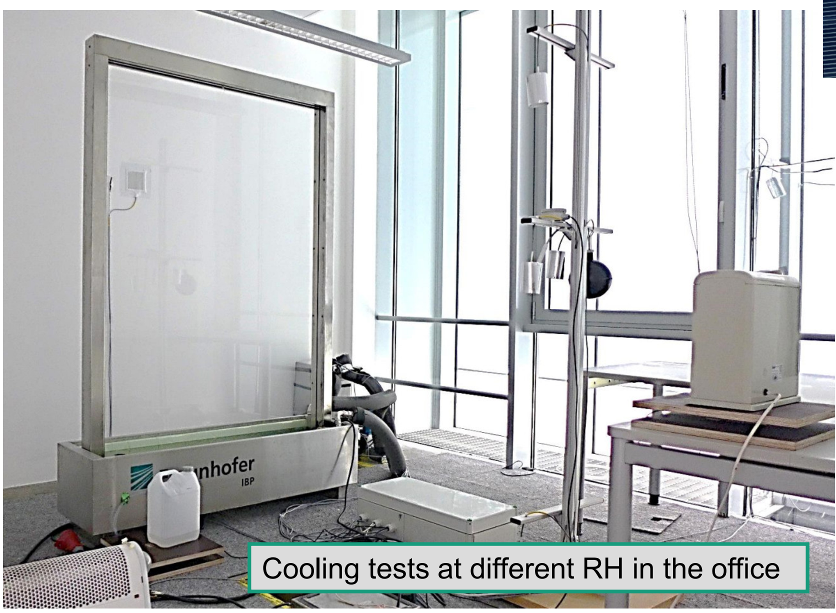
Managing indoor humidity by chilled water wall

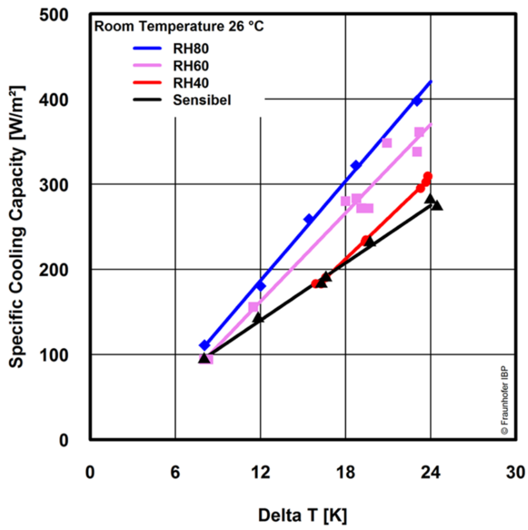




Energy performance investigations

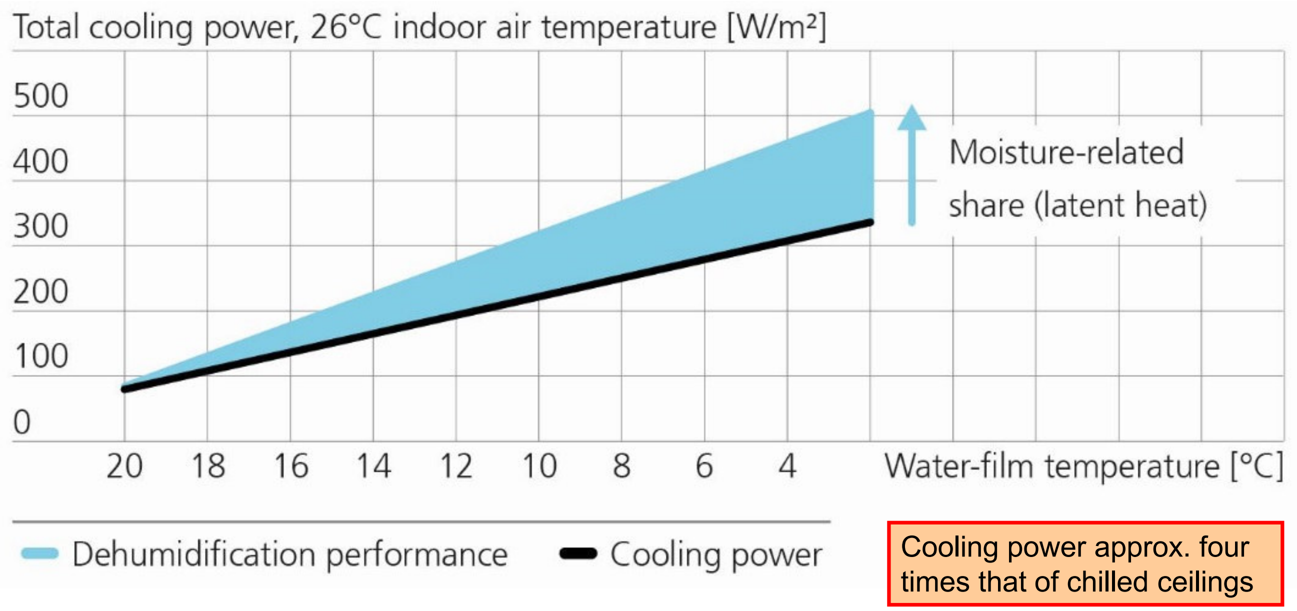
Managing indoor humidity by chilled water wall - Tests





Energy performance investigations

Managing indoor humidity by chilled water wall - Performance



Cooling power approx. four times that of chilled ceilings

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Energy performance investigations

Managing indoor humidity by chilled water wall – Design and application examples

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Summary and outlook

Field tests on 1:1 buildings or envelope components serve as ultimate benchmark for

- Building energy and hygrothermal model development and validation
- Dynamic HVAC performance evaluation and model development
- Laboratory test design and validation

Field test are the sole method to investigate

- Material and system property changes due to ageing or degradation under real life conditions
- Application limits of envelope systems by simulating moderate or severe indoor conditions
- Impact and consequences of installation flaws or usual wear and tear (service life prediction)

Field tests help to

- Demonstrate the performance of innovative solutions in comparison to conventional systems
- Detect and understand unexpected phenomena
- Raise new research questions!

BUILDING SCIENCE OUTDOOR TESTING – LESSONS LEARNED

Visit of Vietnamese ReBuMat project partners at Fraunhofer IBP, Holzkirchen 3rd Sept. 2024

Hartwig M. Künzel

Thank you for your listening!
Please feel free to ask questions

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