MEETING GLOBAL BUILDING CHALLENGES REQUIRES IMPROVED HYGROTHERMAL DESIGN!

Finnish Building Physics Symposium, Tampere 2019

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Auf Wissen bauen

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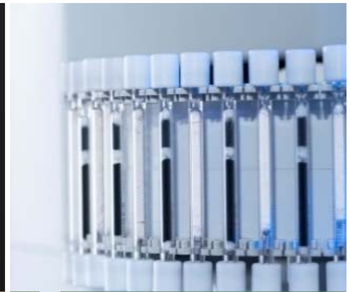

ENVIRONMENT, HYGIENE AND SENSOR TECHNOLOGY

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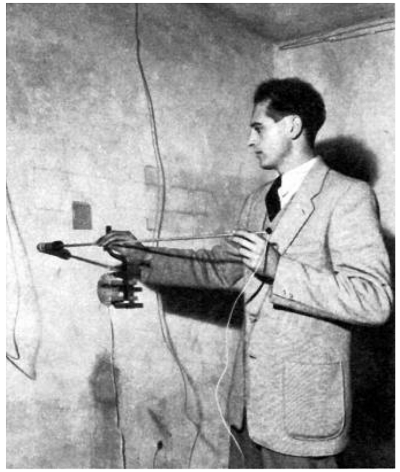
Introduction

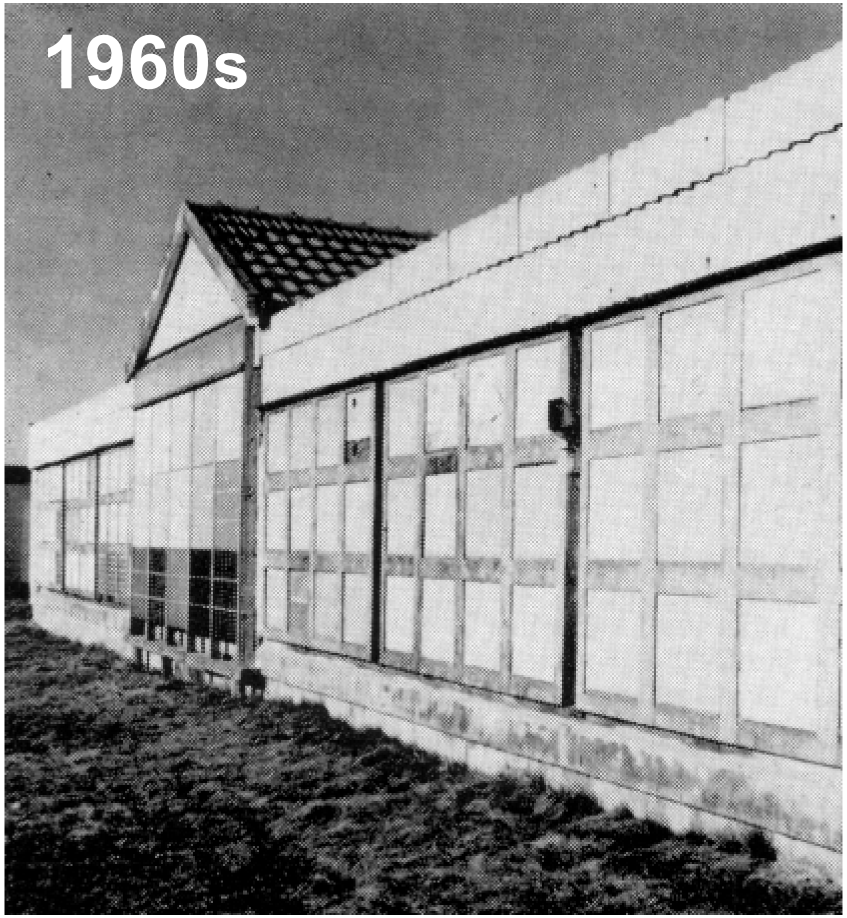
Fraunhofer IBP field test site



More than 65 years of field tests investigating long-term building performance and material durability

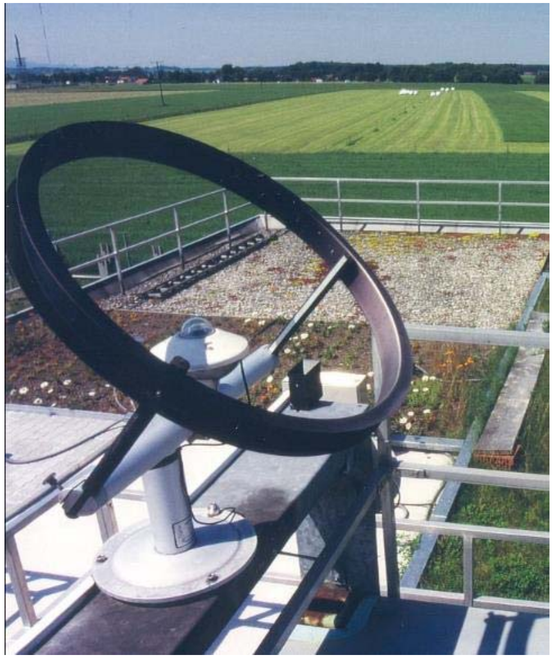
Introduction

Facilities for field investigations – Air-conditioned test hall for wall exposure tests



Introduction

Facilities for field investigations – 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)

Introduction

Facilities for field investigations – Heritage preservation and retrofit test building

Investigations on half-timbered building retrofitted with various interior insulation and fill-in materials & system

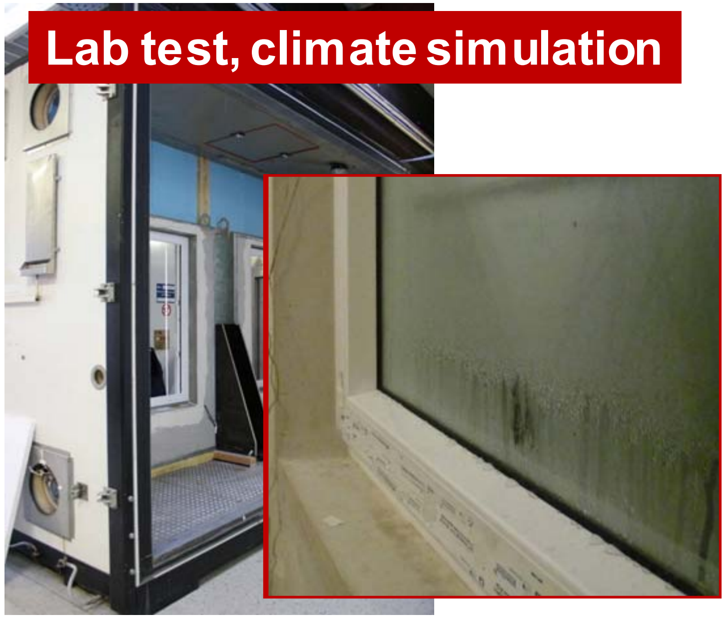
Driving rain & air tightness, moisture content

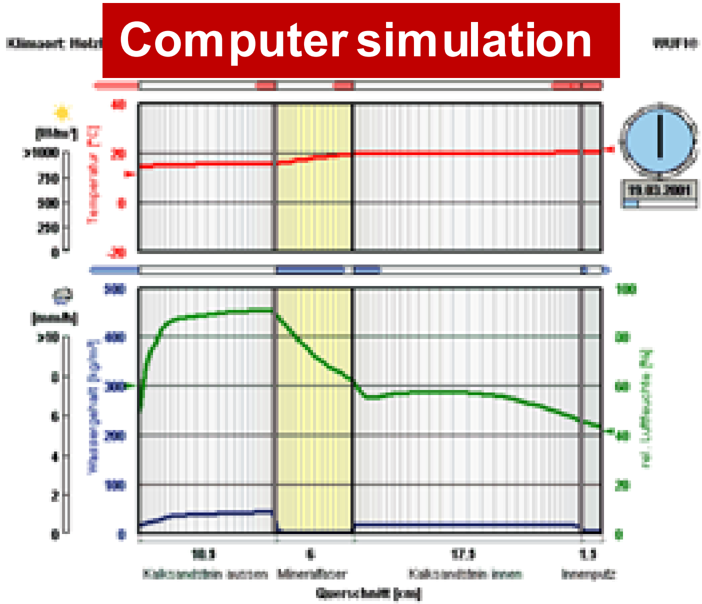
Introduction

Department of Hygrothermics – Research

Investigations of integral building performance focusing on heat, air and moisture transfer in building materials, systems and components (hygrothermal performance).

Hygrothermal research is based on the triplet of **field**, **lab** and **computer studies**





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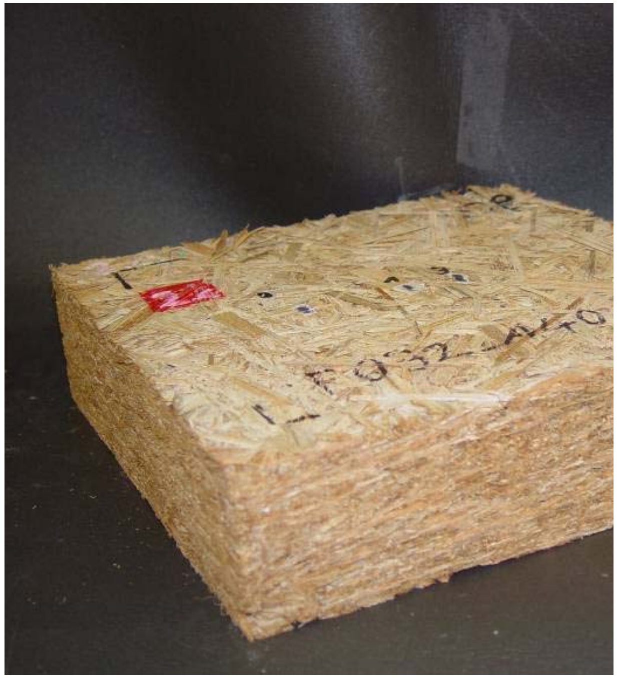
Introduction

Department of Hygrothermics – Product Development and Optimization



Renewable materials development: Cavity insulation made from mould resistant bulrush (cattail). Excellent carbon footprint if wetlands are renaturated for cultivation

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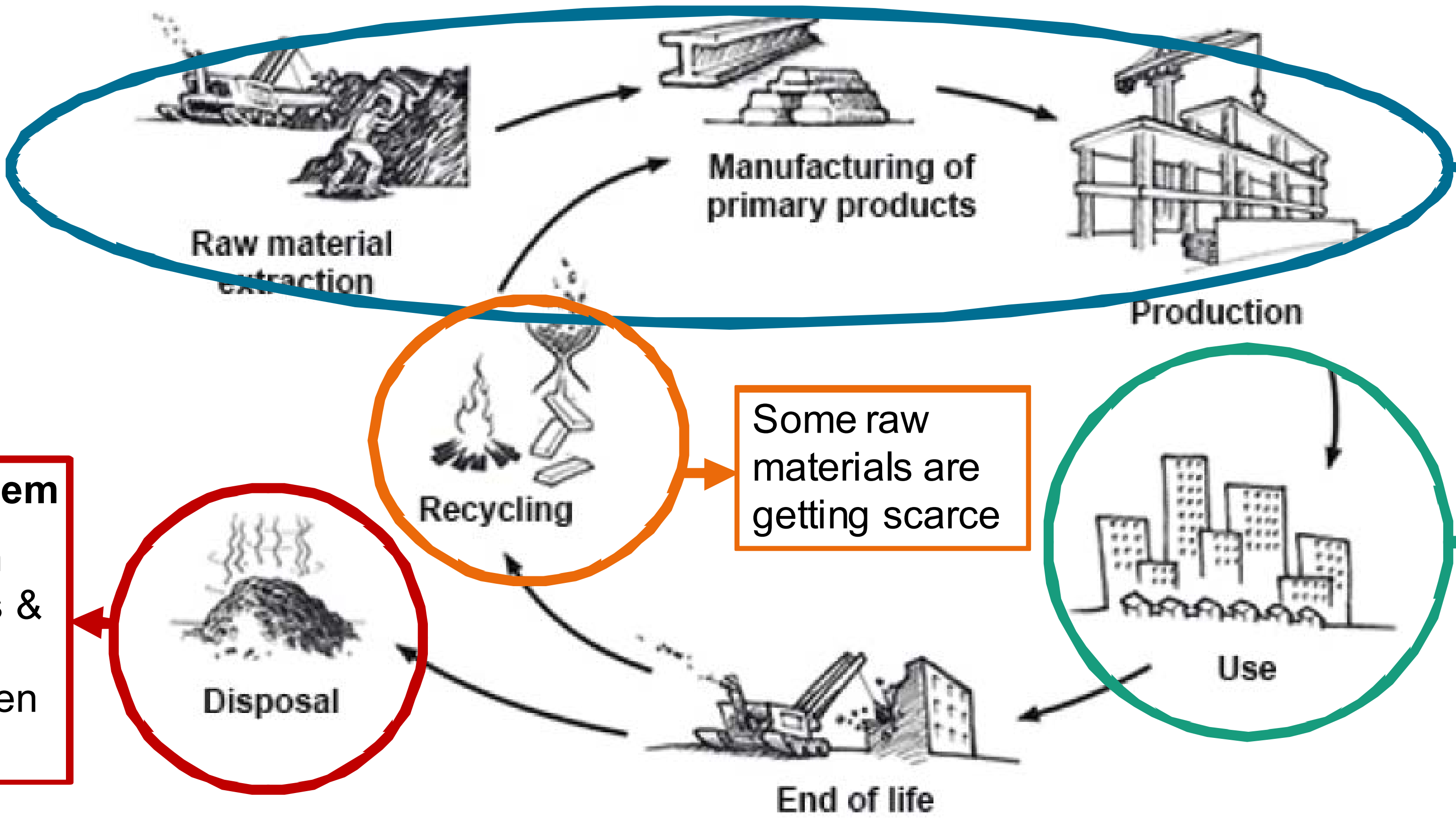
Challenges – Reduce environmental impacts by sustainable constructions

Life cycle engineering is the basis for Sustainable Buildings



Embodied energy

Advantage renewable materials & lightweight structures

Some raw materials are getting scarce

Good progress achieved (Net-zero energy)

Durability important

Urgent problem

Materials with fire retardants & and treated timber are often **toxic waste**

Challenges – Reduce environmental impacts by sustainable constructions

Avoiding timber treatment – DIN 68800-2: **Constructive measures to replace chemistry**

DEUTSCHE NORM | Februar 2012

DIN 68800-2 | DIN

ICS 71.100.50; 91.080.20

Ersatz für
DIN 68800-2:1996-05

Holzschutz –
Teil 2: Vorbeugende bauliche Maßnahmen im Hochbau

Wood preservation –
Part 2: Preventive constructional measures in buildings

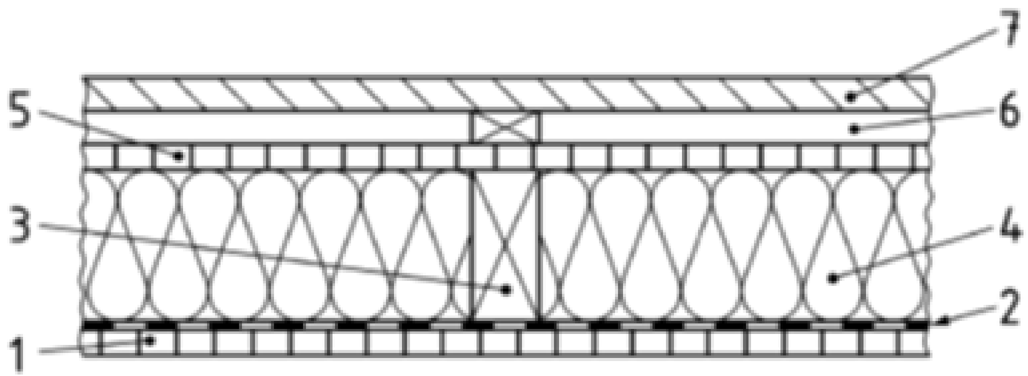
DIN 68800-2 was first introduced in 1996 to overcome timber treatment requirements

Ventilated cavities within the load bearing structure **must** be replaced by vapor open ($s_d \leq 2$ m) exterior envelope layers (e.g. breather membranes) and interior vapor barriers by vapor control layers

Challenges – Reduce environmental impacts by sustainable constructions

Avoiding timber treatment – DIN 68800-2: **Constructive measures to replace chemistry**

Examples: **Wall**



1/2 Interior lining + vapor retarder $s_d \geq 2$ m

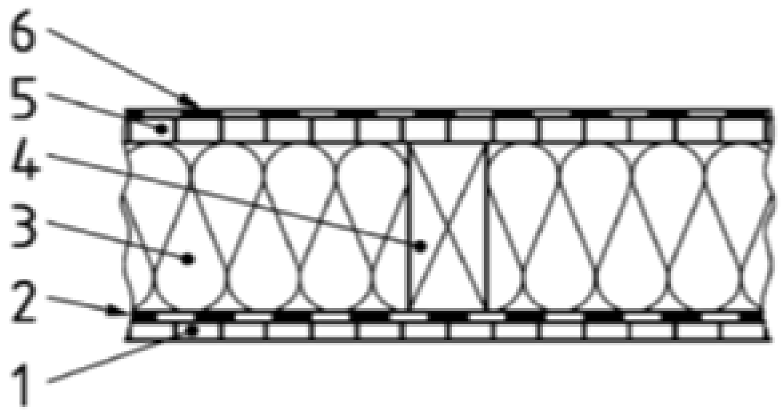
3/4 Fibrous insulation / dry timber

5 Exterior sheathing $s_d \leq 0.3$ m

6 Ventilated cavity thickness ≥ 20 mm

7 Weather resistant cladding on vertical furring

Flat roof



1 Interior lining $s_d \leq 0.5$ m

2 Smart vapor retarder $s_d = f(RH)$

3/4 Fibrous insulation / timber u ≤ 15%

5 Dry wood or wood based sheathing

6 Dark roofing membrane (a ≥ 80%)

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Challenges – ASHRAE

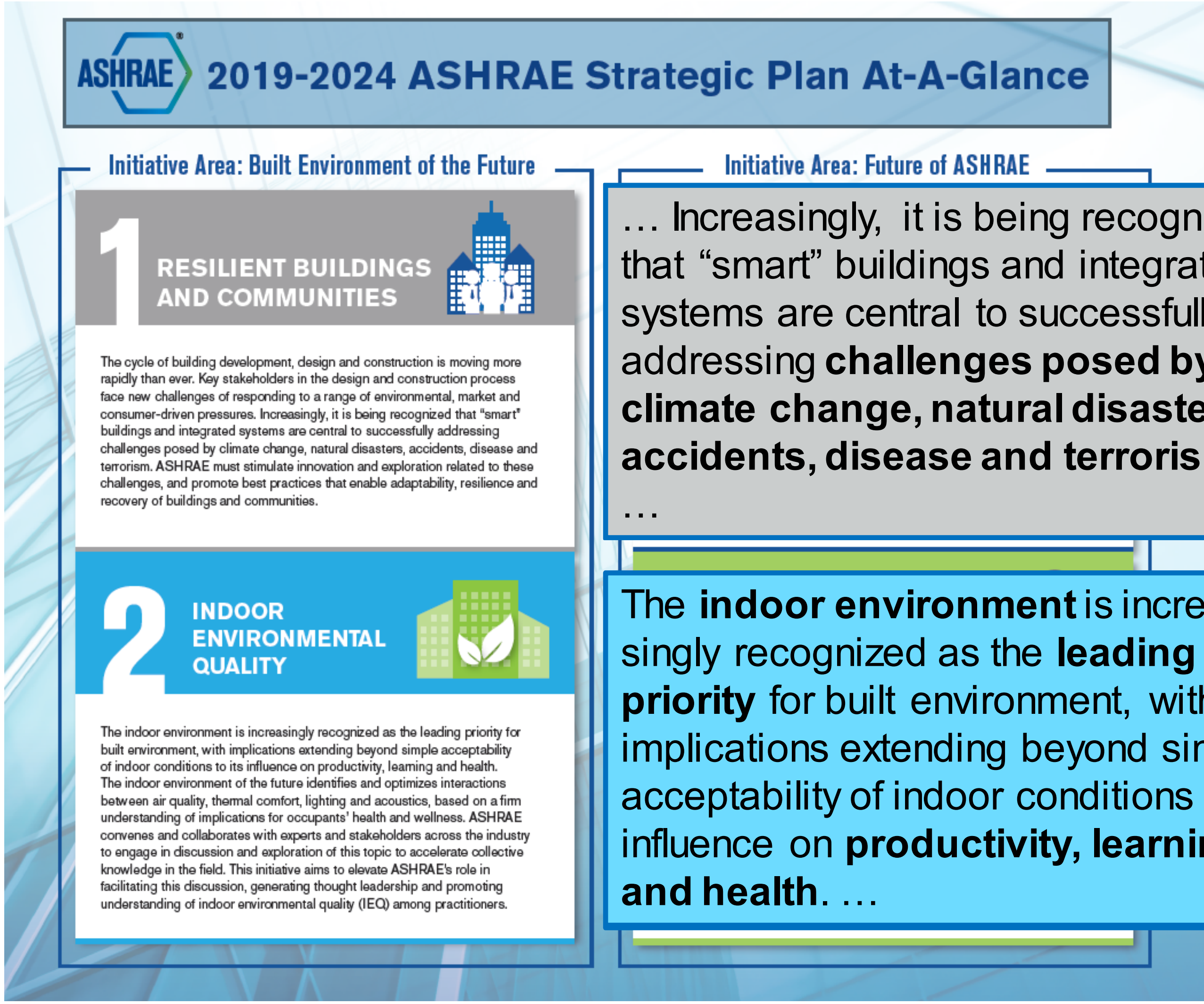
ASHRAE Strategic Plan
2019-2024

Main focus for the built environment:

Building Resilience &

Indoor Environmental Quality

Building Resilience and IEQ have a lot to do with the **building envelope** especially with **heat, air & moisture control**



… Increasingly, it is being recognized that "smart" buildings and integrated systems are central to successfully addressing **challenges posed by climate change, natural disasters, accidents, disease and terrorism**. …

The **indoor environment** is increasingly recognized as the **leading priority** for built environment, with implications extending beyond simple acceptability of indoor conditions to its influence on **productivity, learning and health**. …

Challenges – ASHRAE

ASHRAE Strategic Plan

Building resilience implies:

- Air-tight envelope to protects occupants from polluted outdoor air following accident, fire or terrorist attack
- Energy efficient building envelope and onsite energy generation to protect occupants from uncomfortable indoor conditions and/or prevent building damage in case of power outage
- Moisture resistive envelope components and cost effective restoration possibility

Indoor environmental quality suggests

- Low VOC emissions and no MVOC release
- Sufficient ventilation (air purification) and 35% < RH < 60%, low fine particle concentration
- Thermal, lighting and acoustic comfort ► **ageing population**

Challenges – Climate change

Tasmania's Climate Change Action Plan 2017 – 2021

Building Climate Resilience

enhances our capacity to withstand and recover from extreme weather events,

and better understand and manage the risks of changing climate

You cannot always prevent moisture from getting in

but you can make sure that it is getting out fast by **sufficient drainage and drying potential**

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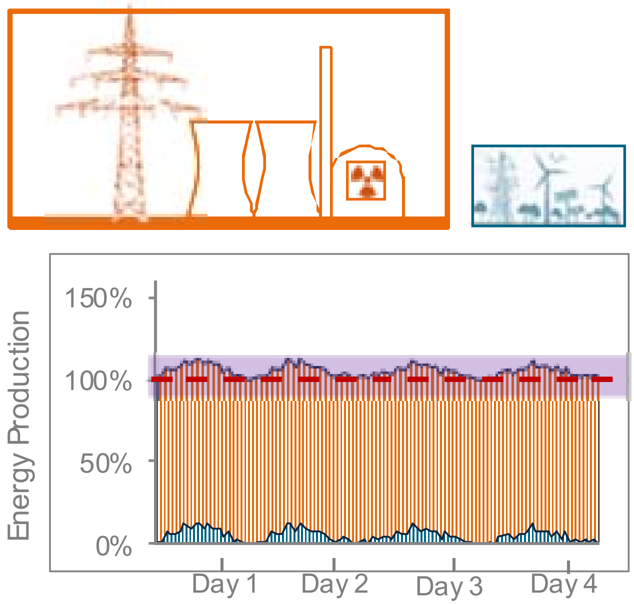
Challenges – Renewable energy, grid compatible buildings

Buildings as energy storage systems – Compensating fluctuating energy supply

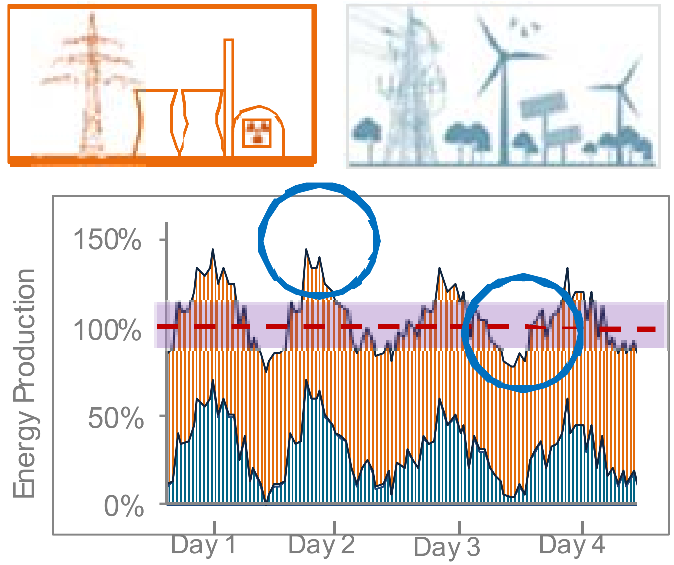
Year 2000

Renewables: 6 %



Year 2020

Renewables: 35 %



Conventional Energy

Renewable Energy

Energy Demand

Grid flexibility

Save energy in times of **low** energy supply
Consume and store when supply is **high**

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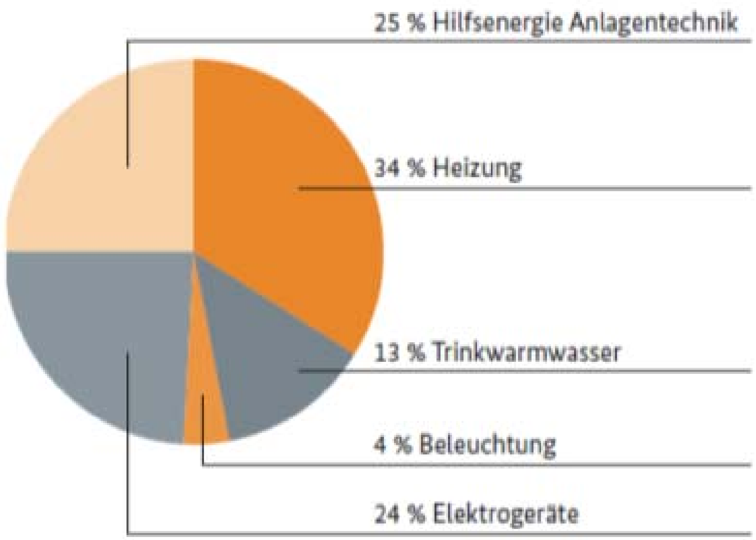
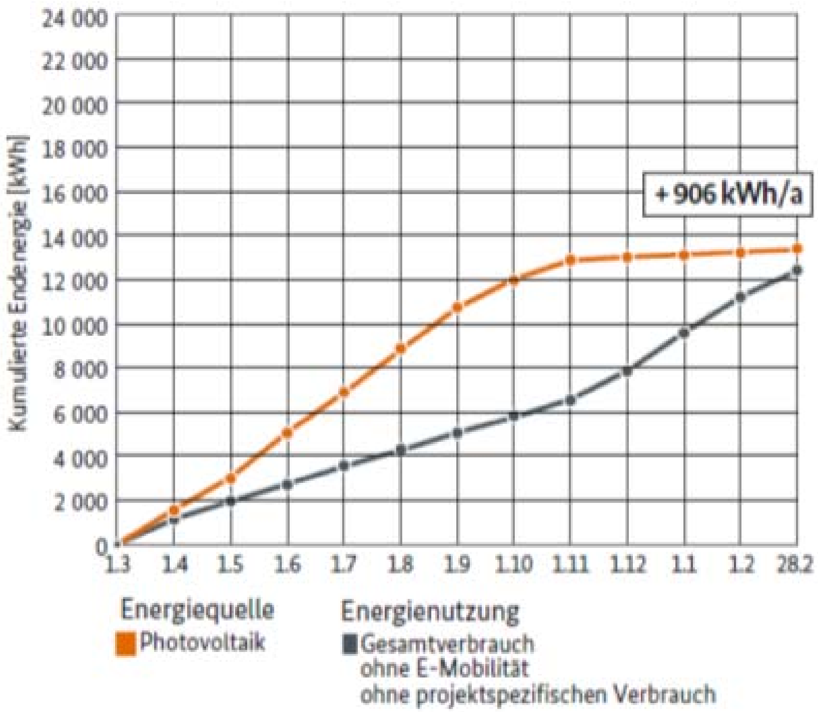
Challenges – Renewable energy, grid compatible buildings

Solar energy generation (PV) is very dynamic – **diurnal and seasonal pattern**





PV and net-zero

Buildings switch from energy consumer to energy producer

Challenge: Time-shift between energy generation and demand

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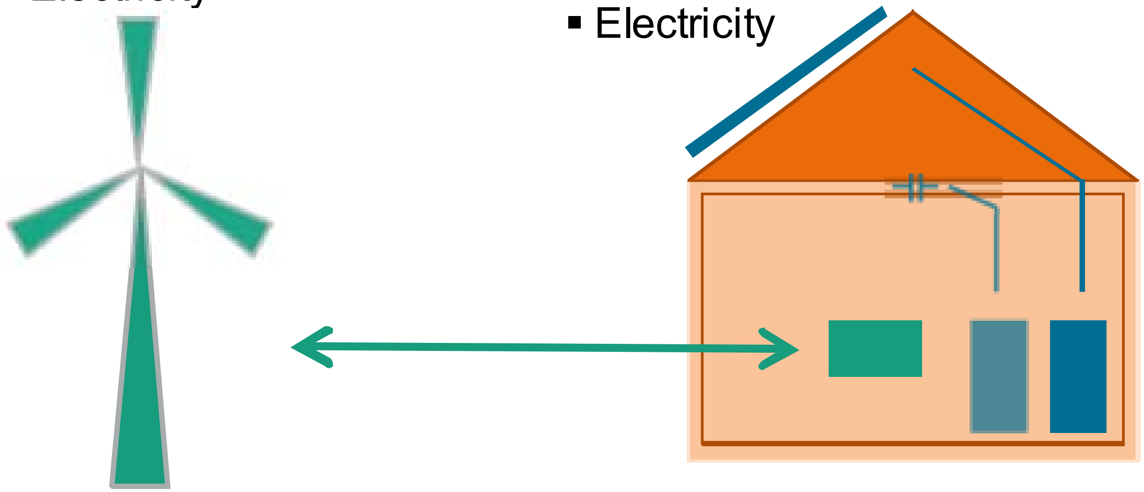
Challenges – Renewable energy, grid compatible buildings

Wind energy generation, less cyclic but with unused production peaks

Grid
- Electricity

Production
- Heat
- Electricity

Demand
- Heat
- Electricity



Storage
- Heat
- Electricity

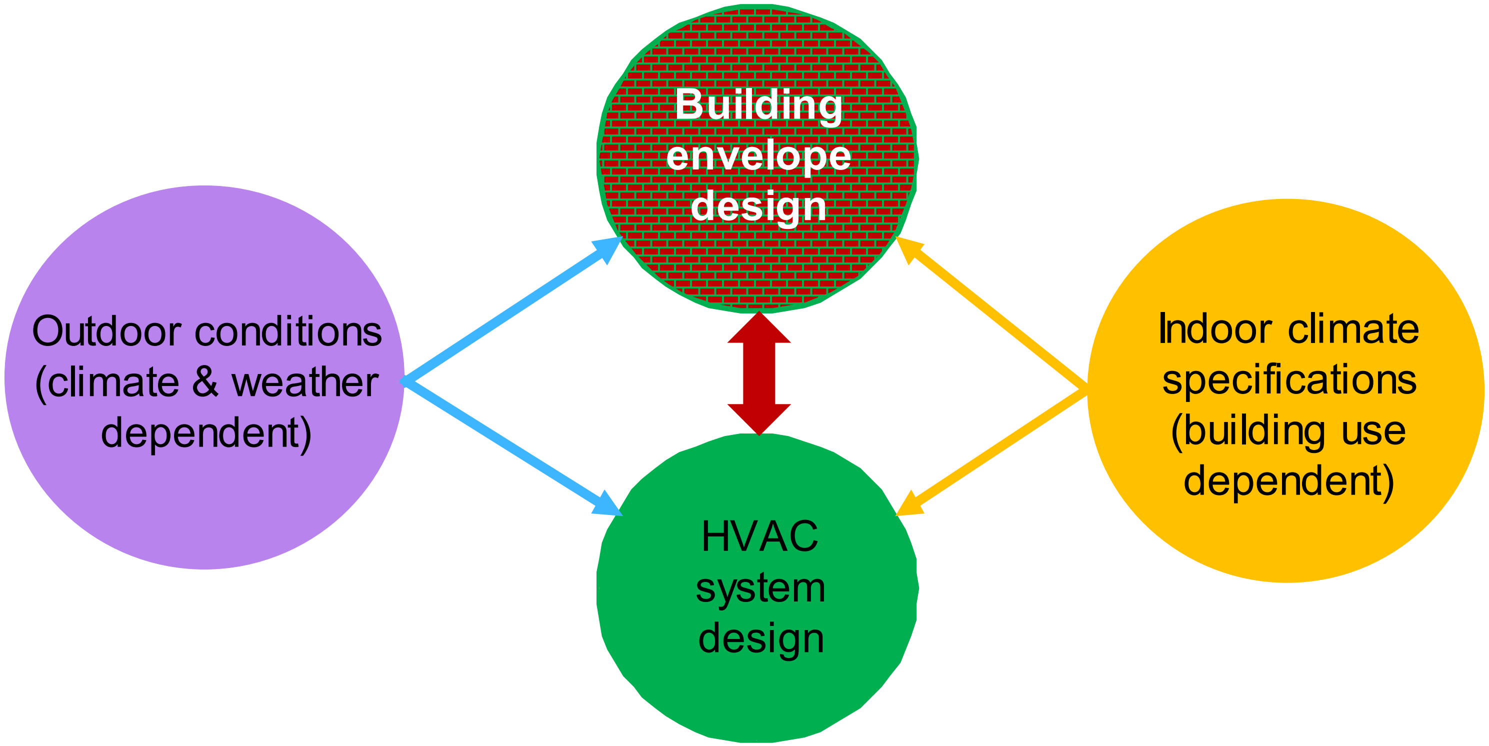
Wind energy production peaks during the heating season (in Germany).

Potential for heating buildings has not been fully exploited yet.

Storage capacity must respond to typical weather cycles that effect wind electricity production (e.g. 10 days in Central Europe)

Hygrothermal design principles

Building envelope and HVAC systems design must respond to local climate and building operation



Combined systems (envelope component = HVAC), e.g.:

- Radiant wall heating and cooling - **fast** response time
- Thermally activated components - **slow** response time but **favourable** energy demand **time shift**
- Façade (window) integrated ventilation systems

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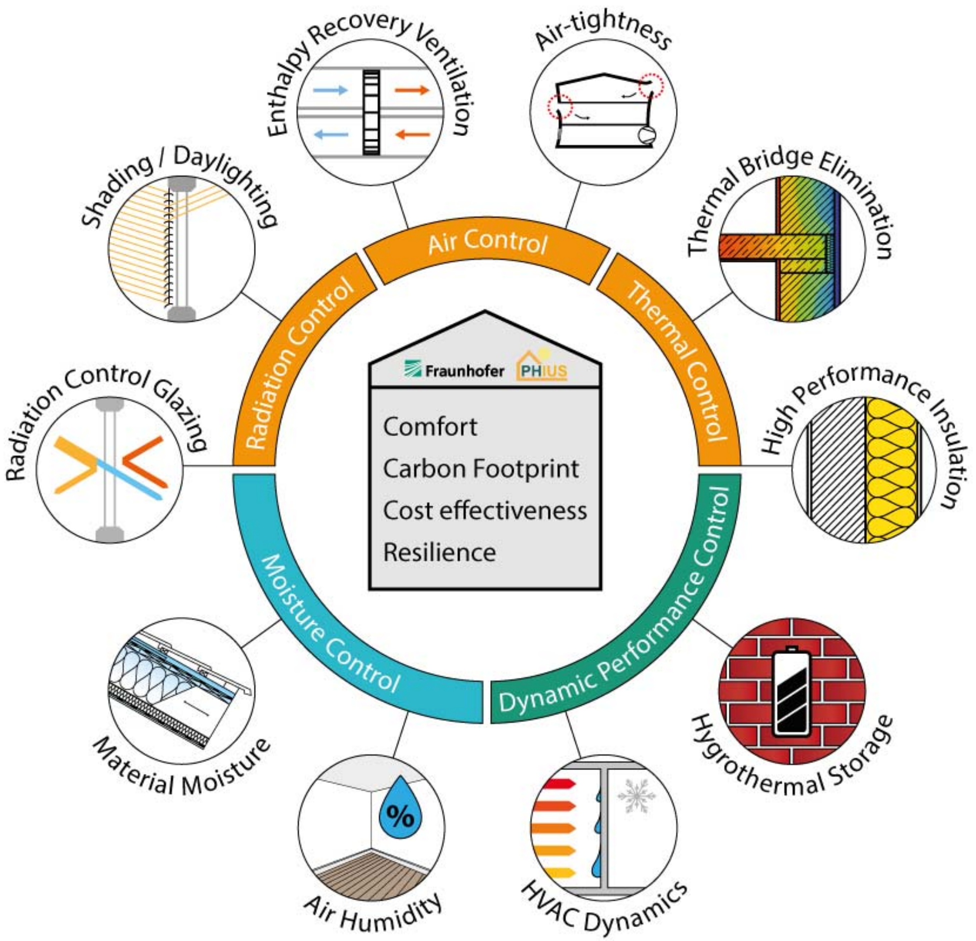
Hygrothermal design principles



Best solution: small window-to-wall ratio

Air-flow control is the most important issue in all climate zones for many reasons!

Best solution: small window-to-wall ratio

Moisture problems may occur if moisture control analysis is not part of the design process or installation is not best practice

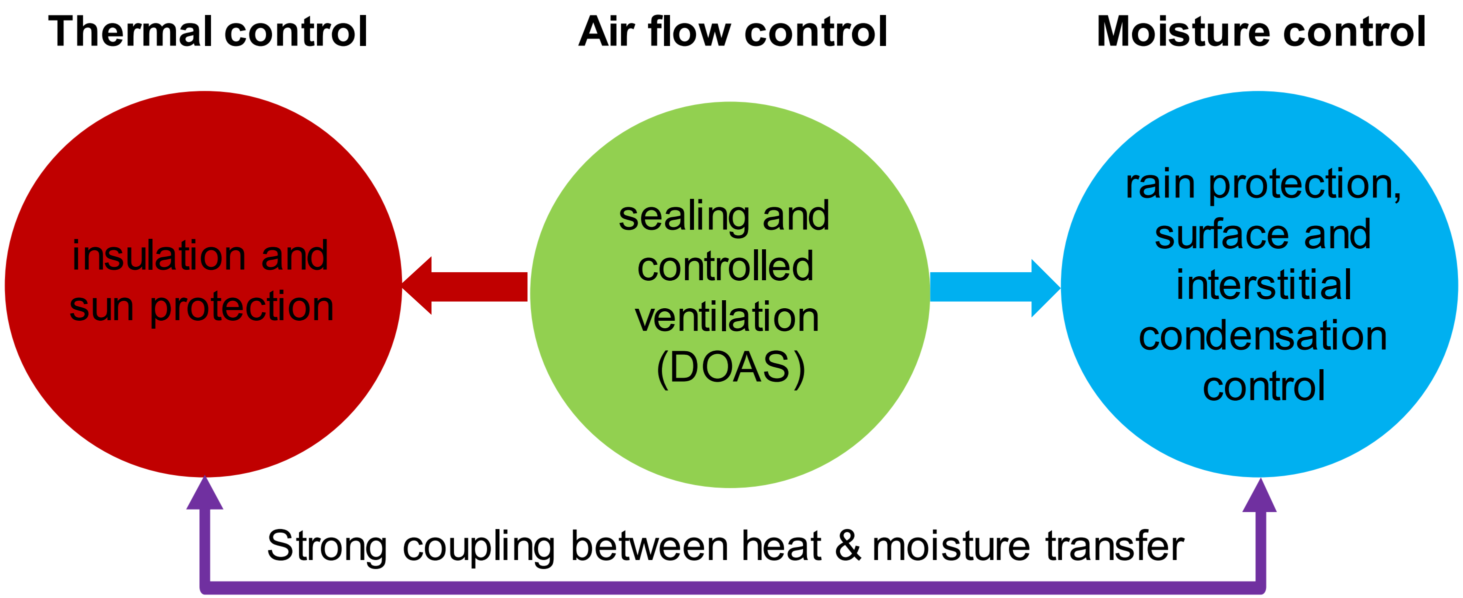
Outdoor conditions and HVAC operation are very dynamic

Renewable energy supply and occupation may vary significantly

► Consider impact of heat and moisture storage

Hygrothermal design principles

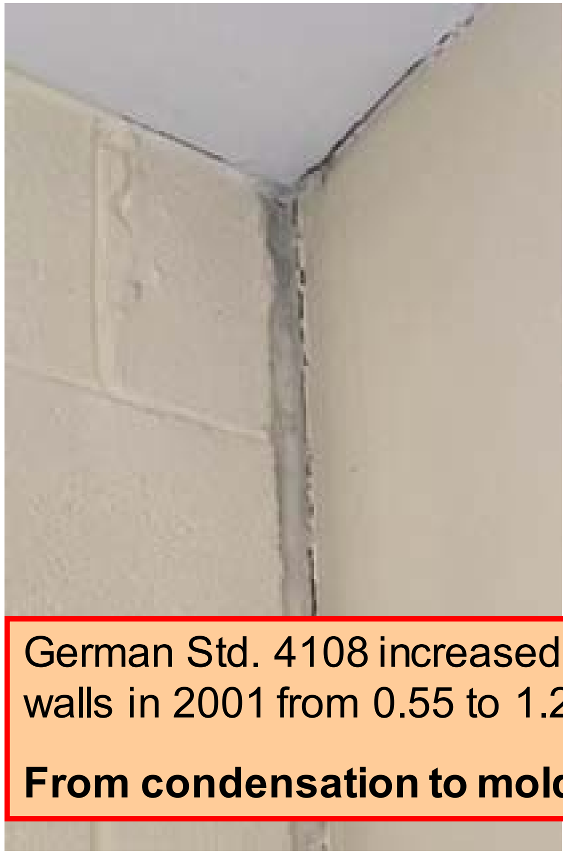
Design **continuous** thermal, air flow and moisture control layers and **check their installation**

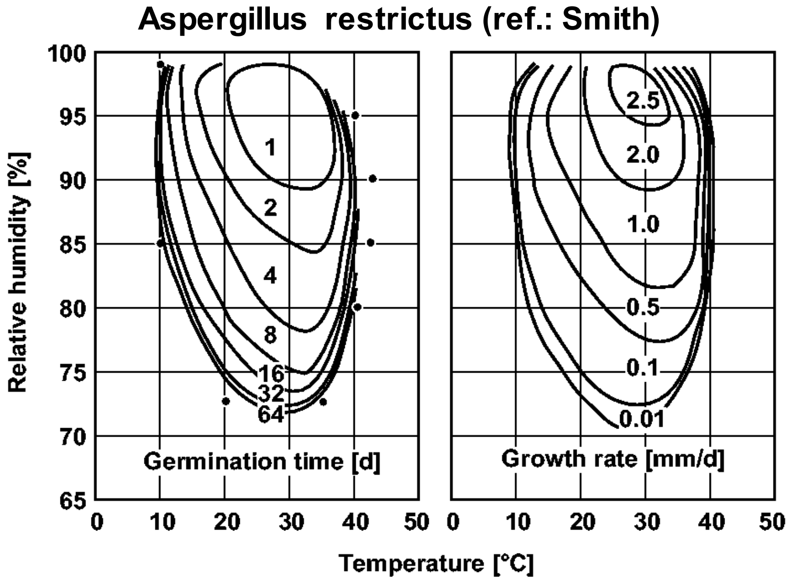


Control layers are required when indoor conditions ≠ outdoor conditions

Hygrothermal design principles – Thermal control

Building envelope insulation ensures **hygienic indoor conditions**, comfort and energy efficiency





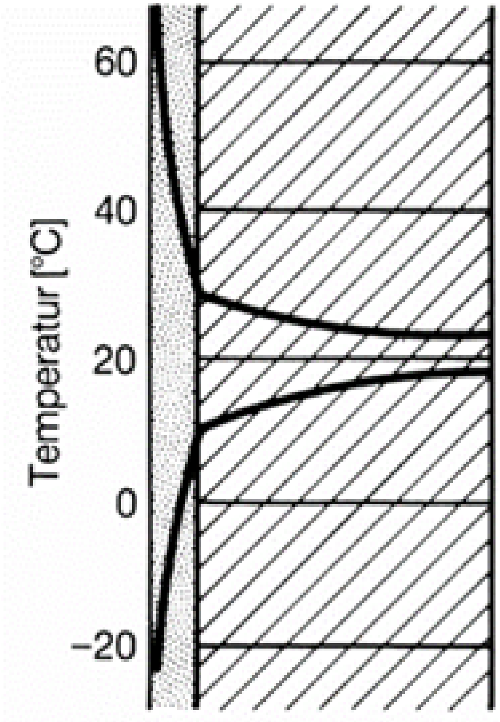
German Std. 4108 increased R-value for walls in 2001 from 0.55 to 1.2 m²K/W

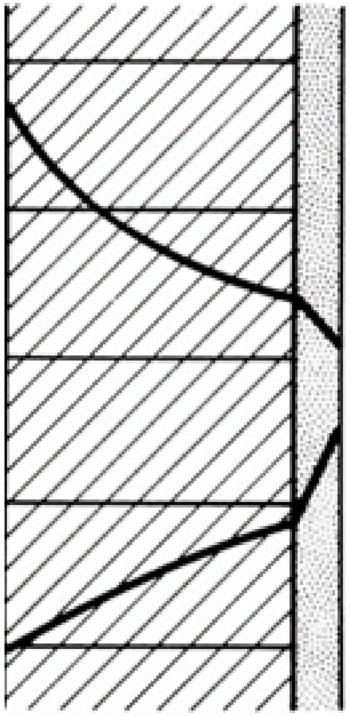
From condensation to mold prevention

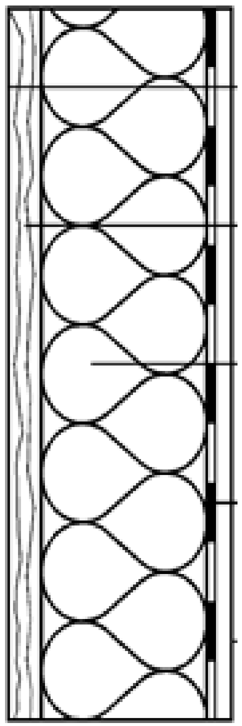
Mould can start to grow at 75% RH at 25°C and at 80% RH around 10 °C

Thermal Control

Insulation is a game changer for the building envelope







Exterior insulation **Interior insulation** **Cavity insulation**

Thermal insulation raises interior surface temp. & prevents mold.

The outdoor surface temp. may drop below ambient conditions. This increases the risk of façade staining & interstitial condensation

Cavity and interior insulation are often not really continuous (e.g. steel or concrete framing / ceiling)

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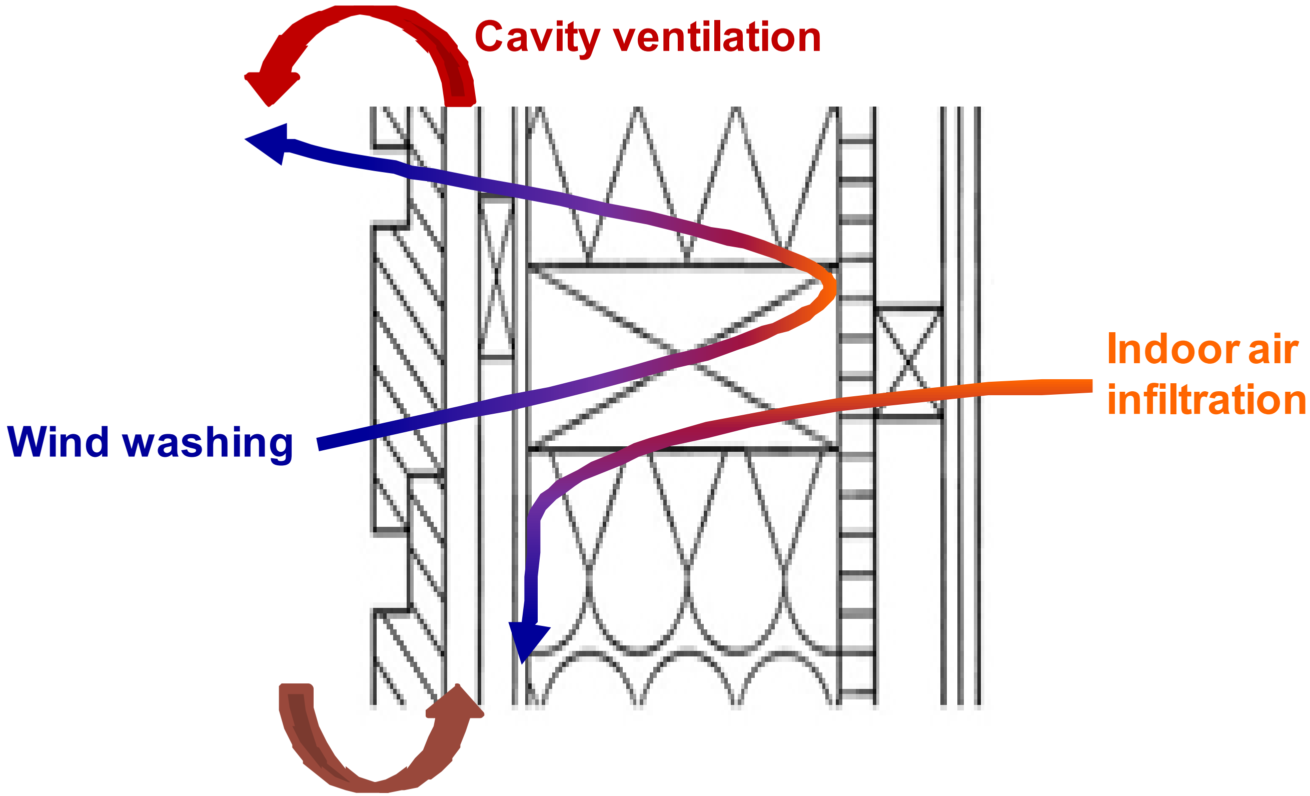
Airflow control

Air convection effects occurring in light-weight construction assemblies



Critical if indoor dewpoint exceeds exterior sheathing temperature

Helps to dry the assembly but may cause high interior surface RH

Impairs thermal envelope performance

Day-time drying

Night-time wetting

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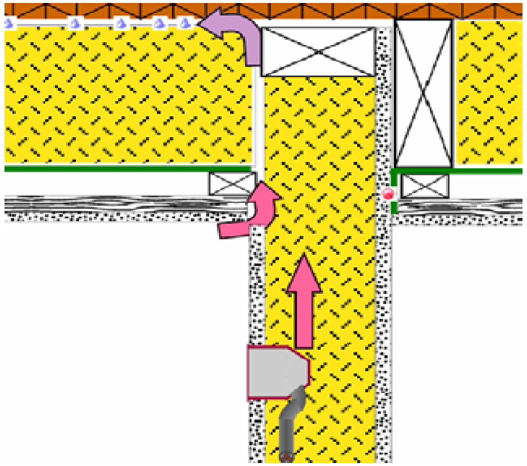
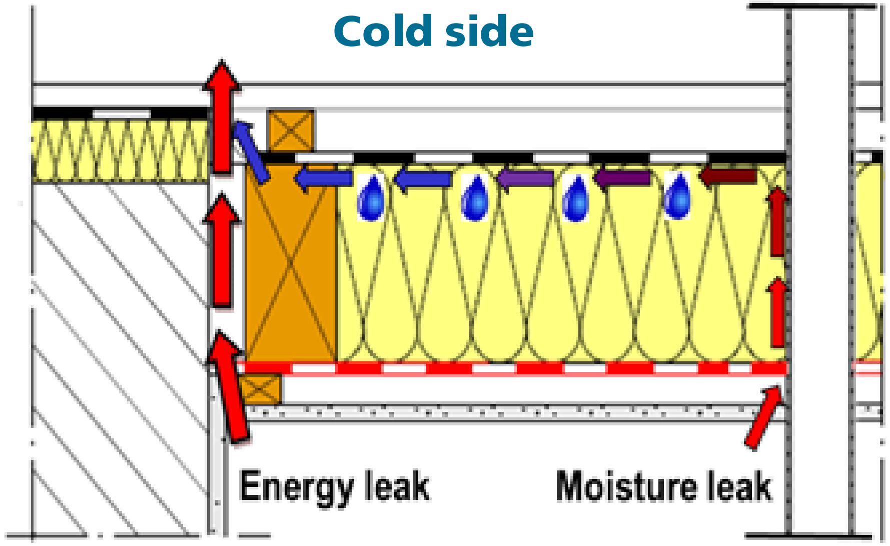
Airflow control

Flaws in the air barrier (better: air control layer) my cause excessive condensation





Airflow driven by buoyancy, wind or mechanical ventilation pressure differentials may cause interstitial condensation and mold growth

► Air sealing is essential especially in **cold** or **hot and humid climates**

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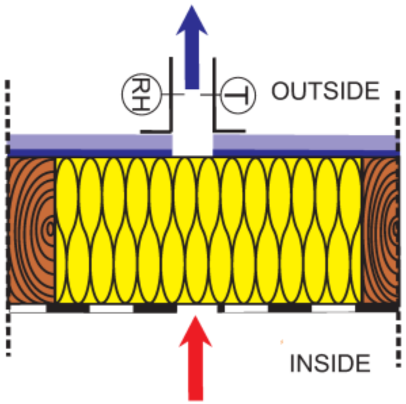
Airflow control

Impact of small leaks on condensation in walls

Hot-box / cold-box tests



Warm Side

Cold Side

One 5 mm hole in the middle of the warm side, air extraction at the bottom of cold side (5 Pa)

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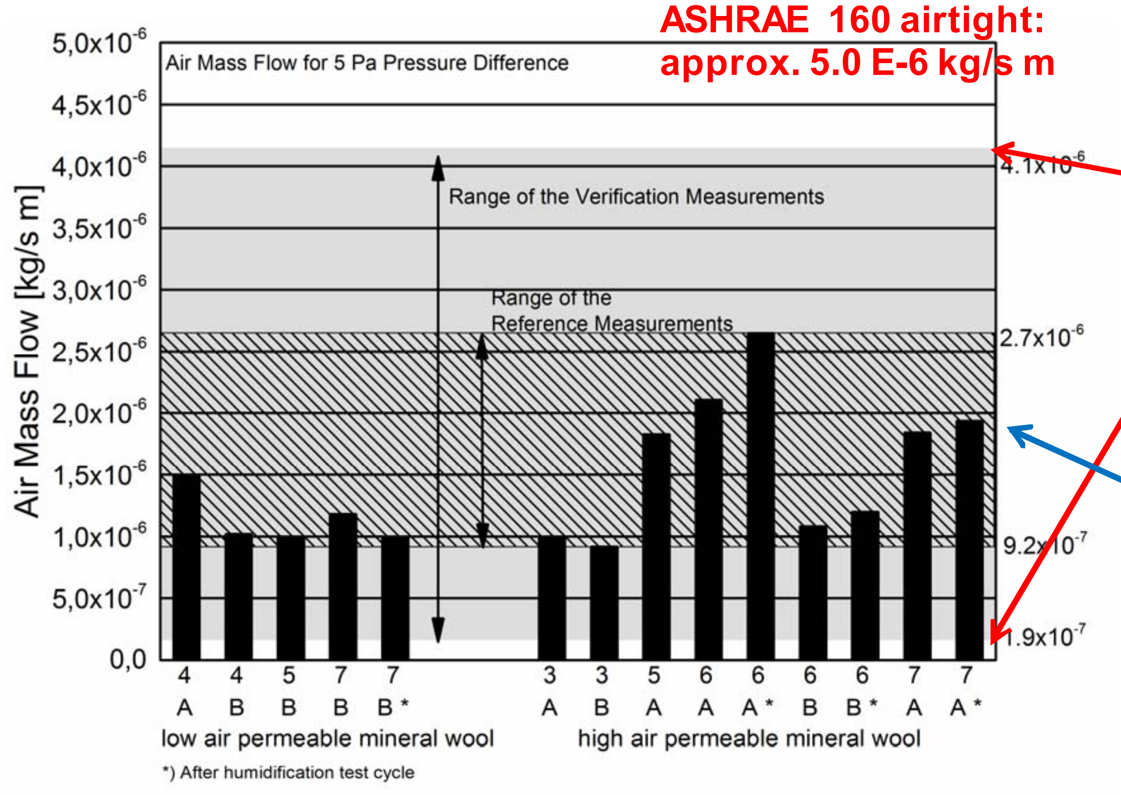
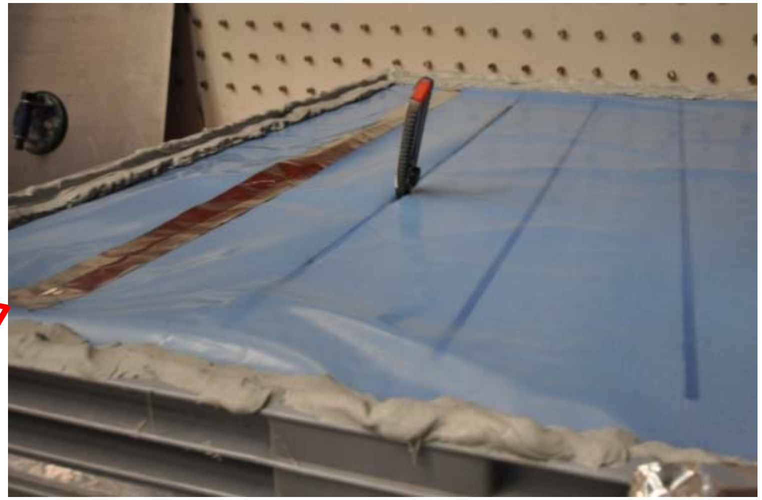
Airflow control

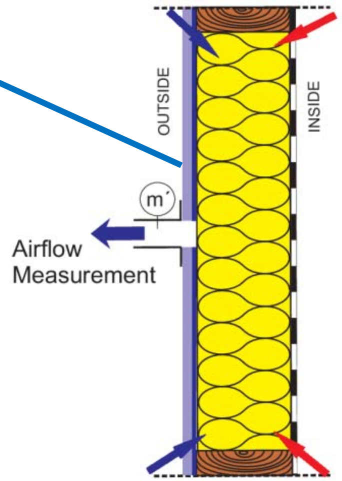
Impact of small leaks on condensation in walls



Measured air flow rates per meter adhesive tape under nearly perfect lab conditions for 5 Pa

Independent verification tests





Reference: tests with closed leakages

A significant fraction of the total air flow rate can be assigned to the adhesive tape connections.

Airflow control

Major findings during hot-box/cold-box test with air pressure differentials

- Condensation occurs in MW and in sheathing – it is 50/50 with high density MW and 30/70 with lower density MW
- Under the test conditions all excess moisture between warm and cold side condensed in the assembly >> air flow seems too slow to heat up flow path significantly
- Lateral flow situations with leakages near the studs show the highest moisture accumulation
- Leakage through the adhesive tape joints amounts to almost half of leakage rate given in ASHRAE Std. 160 for airtight structures. 10 m of taped joints have a similar leakage rate as one Ø 5 mm hole.
- Despite 2 distinct inlet and outlet openings, condensate at the exterior sheathing is **evenly distributed**
  >> 1D model appropriate to account for convective moisture sources in HM simulations

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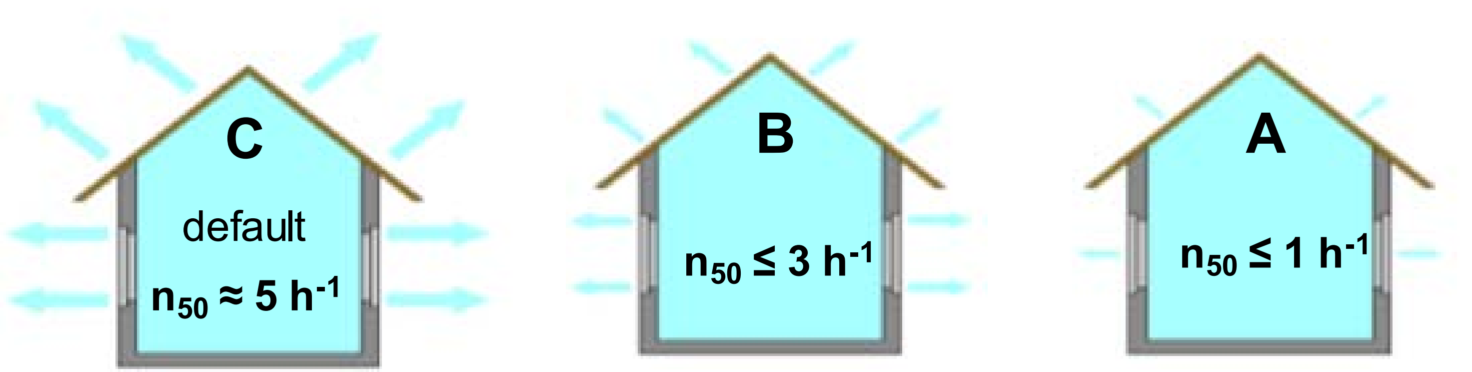
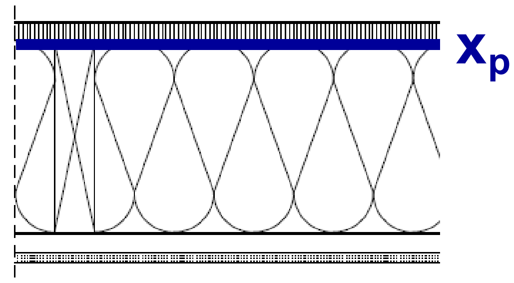
Airflow control

Component leak rate to consider in HT roof simulation according to DIN 68800-2 and WTA 6-2





$$q_{CL} = k_{CL} \cdot (P_i - P_e)$$

CL = Component Leakage

Air-tightness class	Envelope leak rate q_{50} [m³/m²h@50Pa]	Component leak rate k_{CL} [m³/(m²h·Pa)]
A	≲ 1,0	0,0015
B	≲ 3,0	0,004
C	≈ 5,0	0,007

$$S_{CL} = q_{CL} \cdot \left(c_i - c_{sat,\,x_p}\right)$$

c_i [kg/m³] indoor vapor con.

$c_{sat,xp}$ [kg/m³] sat. vap. con. at position x_p

ASHRAE Std. 160: Standard case: k_{CL} = 0,060 m³/(m²h·Pa)
Air-tight case: k_{CL} = 0,010 m³/(m²h·Pa)

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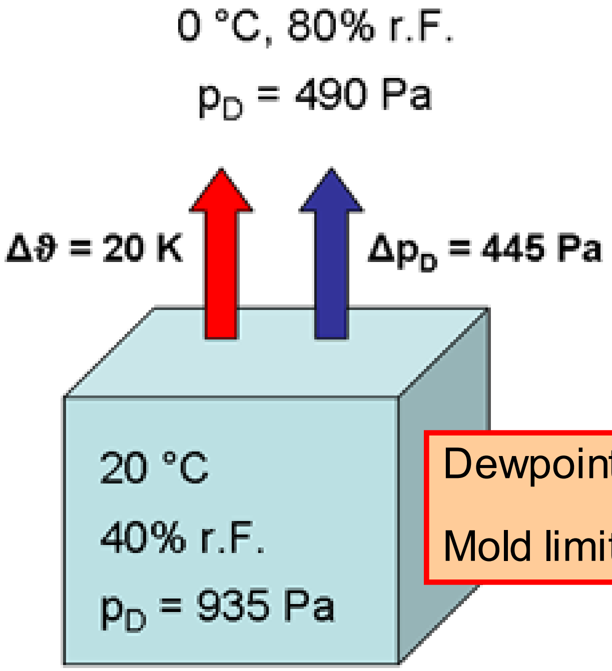
Moisture control

Climate dependent vapor diffusion from warm to cold

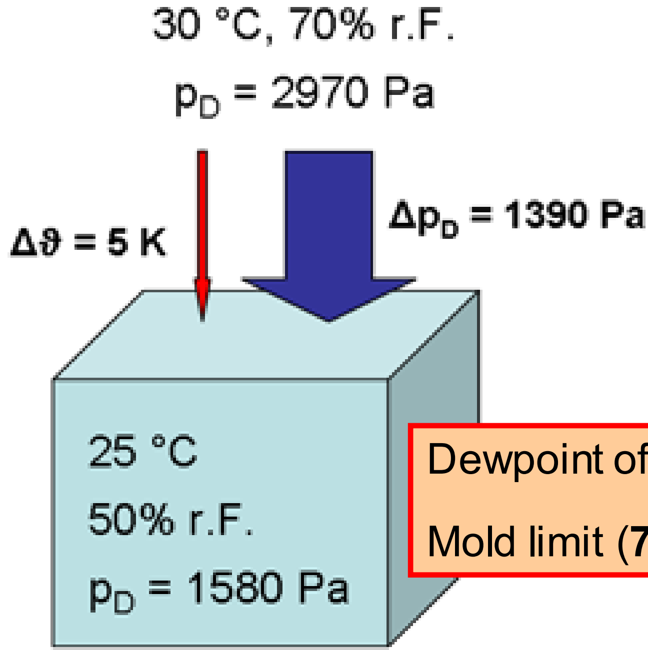
Heating period: outdoor temp. 0 °C



Dewpoint of indoor air: **6°C**

Mold limit (**80%** RH): **10°C**

Cooling period: outdoor temp. 30 °C



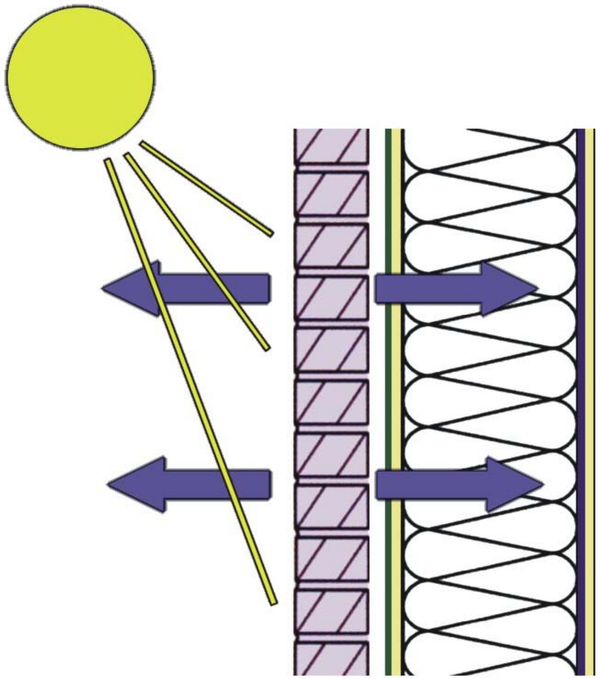
Dewpoint of outdoor air: **24°C**

Mold limit (**75%** RH): **29°C**

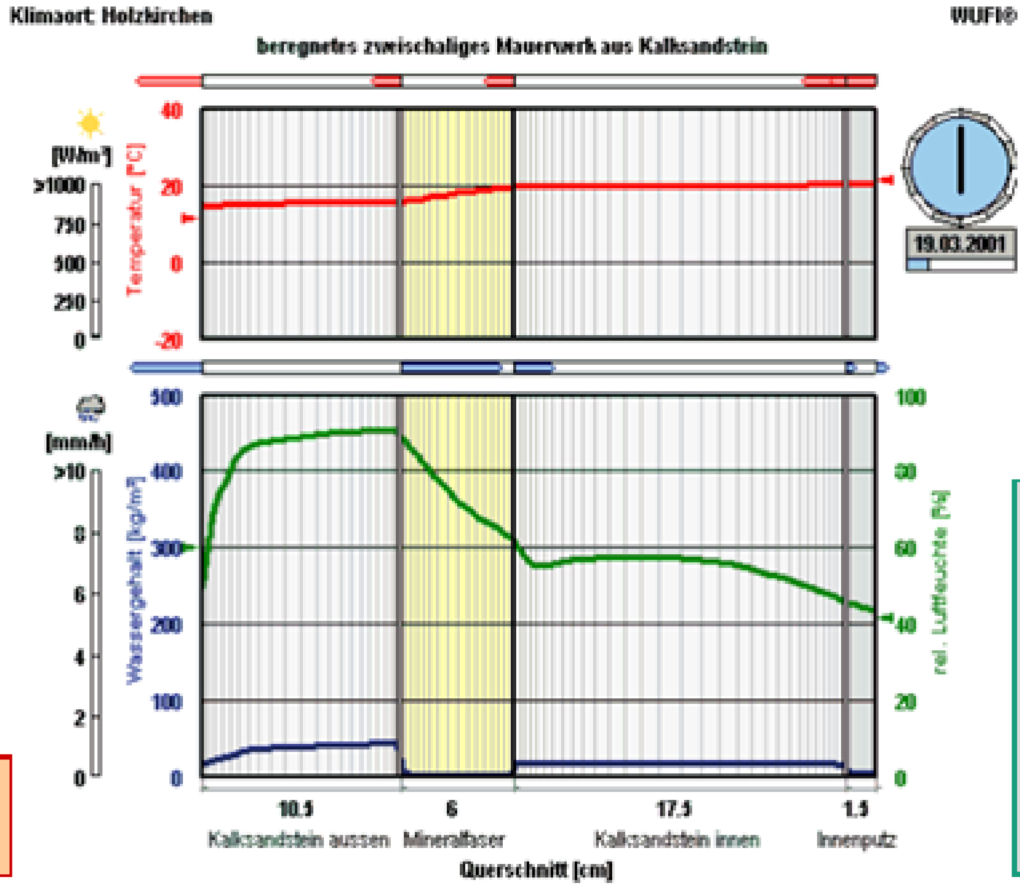
Vapor retarder should be placed at the side with the highest vapor pressure

Moisture control

Weather dependent vapor diffusion from warm to cold



Solar vapor drive when the sun heats up wet reservoir wall cladding

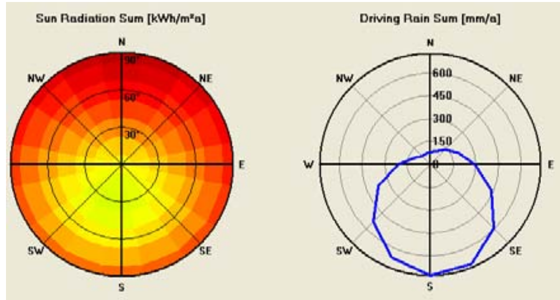


Double brick walls can easily handle solar vapor drive

Timber structures may be at risk

Moisture control

Weather dependent vapor diffusion from warm to cold

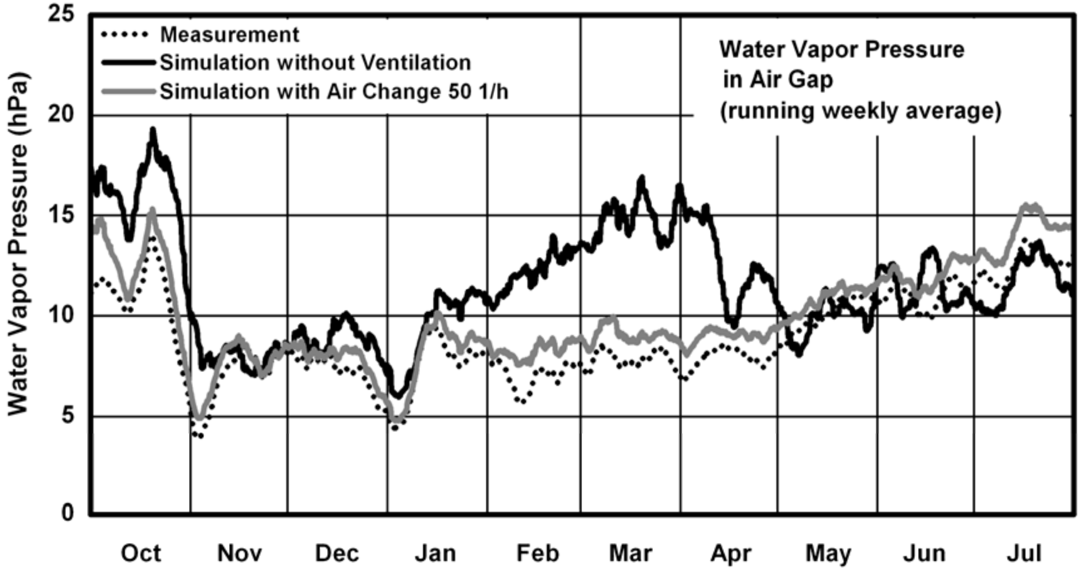


Test buidling at Wash. State University (USA) in Puyallup (near Seattle)

Wall orientation: South

Wall composition

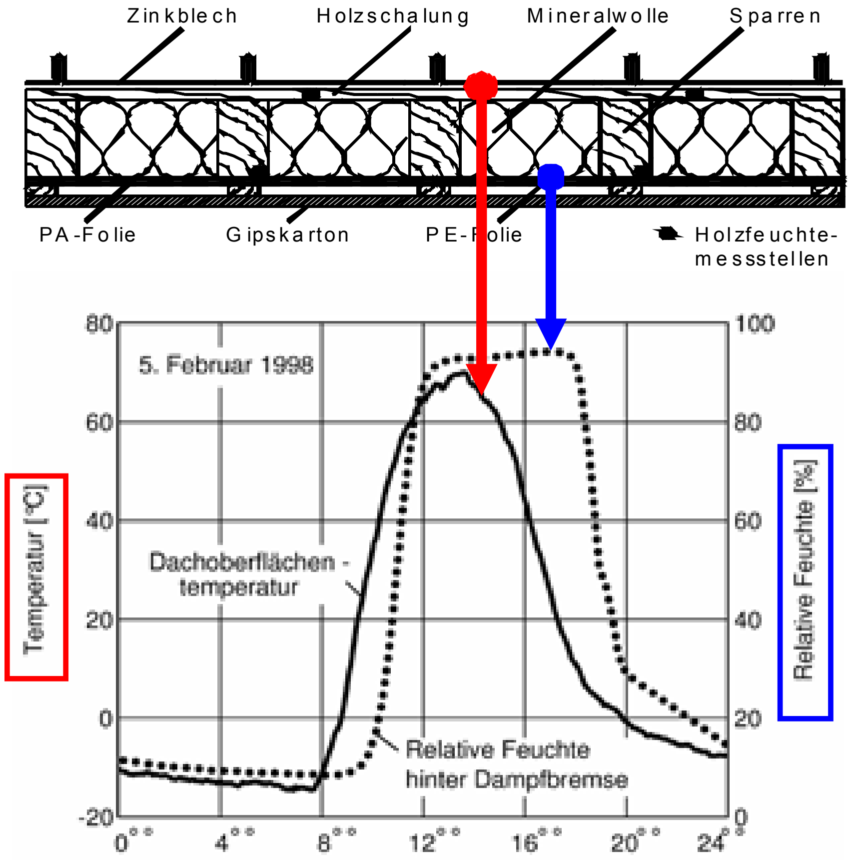
- 3-coat cement stucco (22 mm)
- ventilated cavity (19 mm)
- weather resistive barrier (2 x 60 min. building paper)
- OSB sheathing (11 mm)
- glass fibre insulation between wooden studs (150 mm)
- vapour retarder (PE film)
- gypsum board (13 mm)

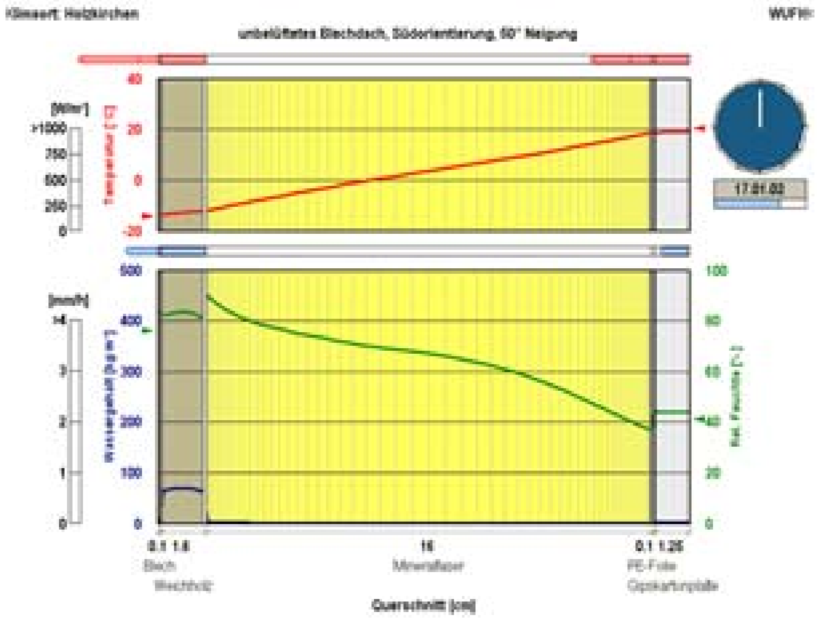


Ventilated cavities can alleviate wetting by solar vapor drive

Moisture control

Weather dependent vapor diffusion from warm to cold





Surface temperatures up to 80°C may degrade materials underneath and push vapor into the structure

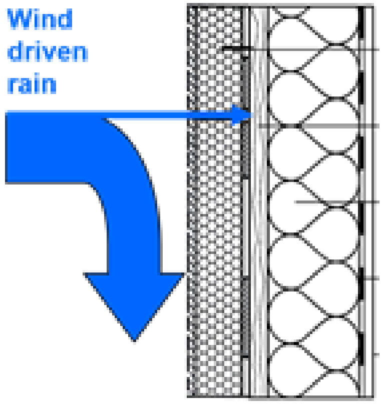
Hygrothermal simulation helps to select appropriate vapor control layers for any type of construction

Moisture Control

Risk of damage due to rainwater penetration

1990s: damaged stud walls with EIFS in North America, later also in Sweden

Reason: water penetration at window joints and other wall connections



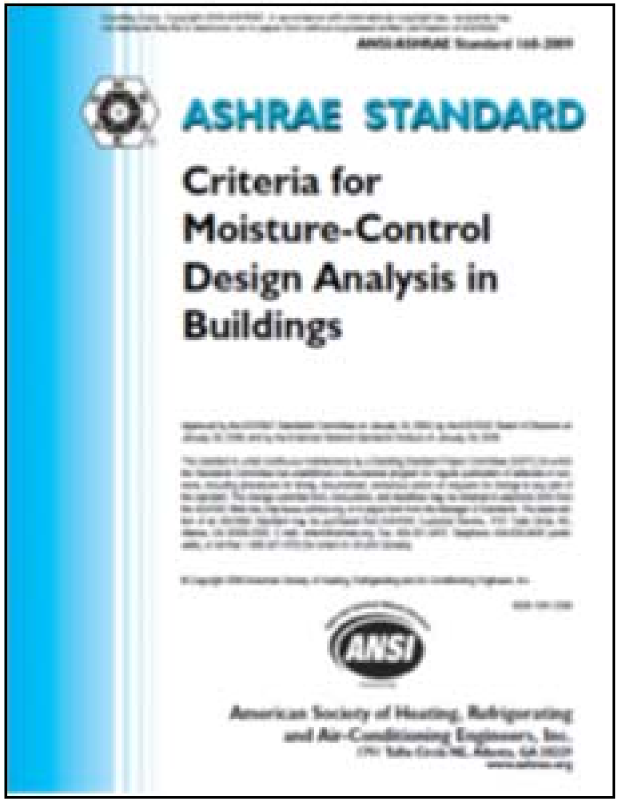
Rainwater entry at the window sill

Visible structural damage occurred only at the stud wall because of its higher moisture susceptibility

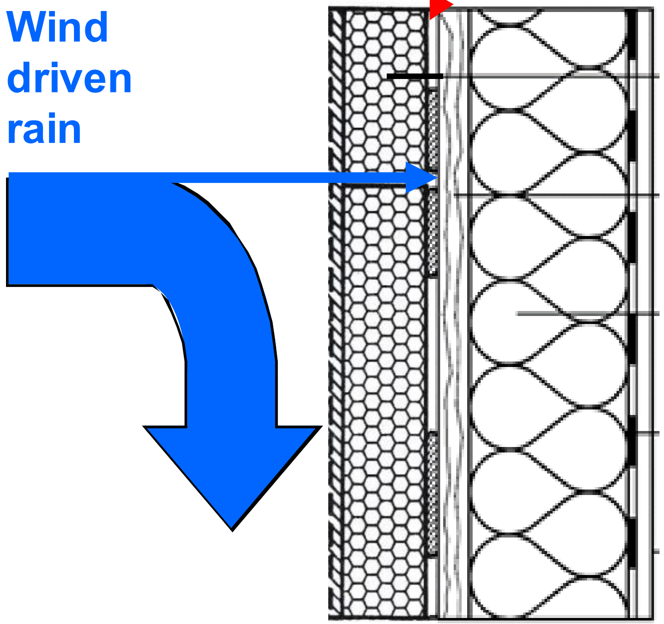
Probing of wall with EPS external insulation system at IBP field test site

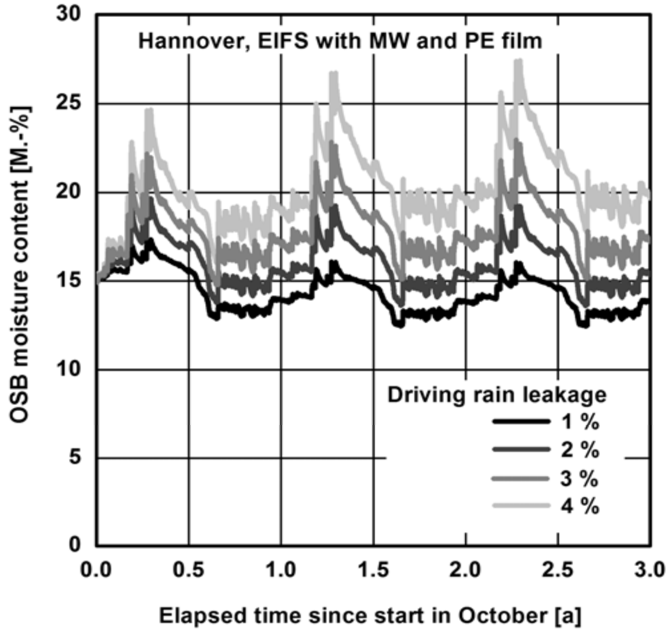
Moisture Control

Risk of damage due to rainwater penetration



WRB (water resistive barrier) missing





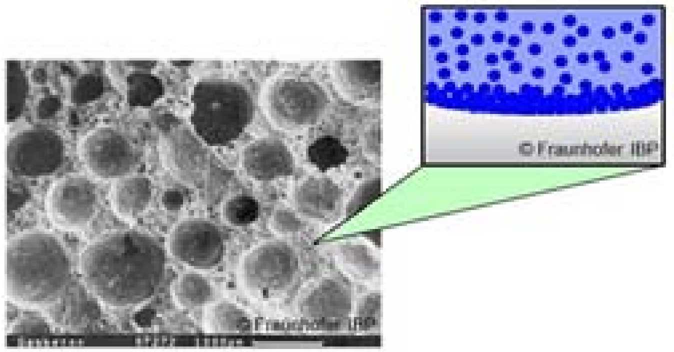
ASHRAE Std. 160 proposes that **1%** of driving rain hitting the façade be introduced on WRB (or other layer) behind exterior cladding

ETICS with EPS fail

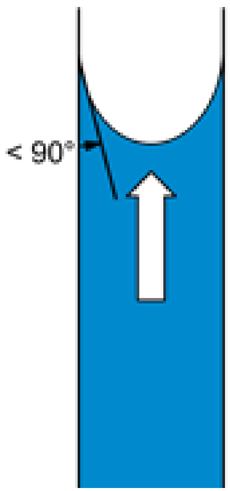
ETICS with MW pass if leakage rate ≤ 2 %

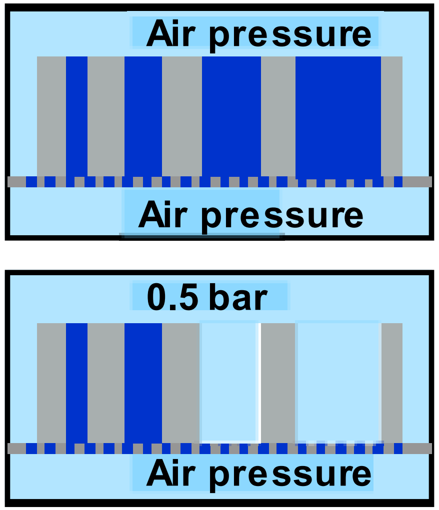
Moisture control design by hygrothermal simulation

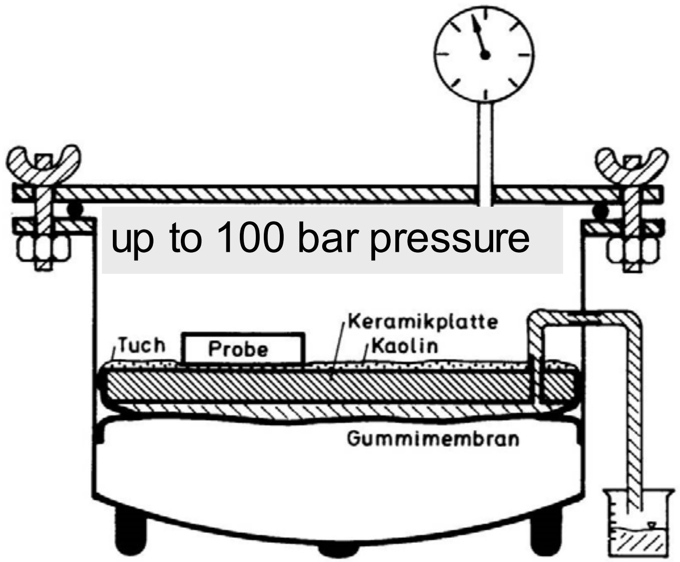
Moisture transport phenomena: vapour & liquid absorption & transport

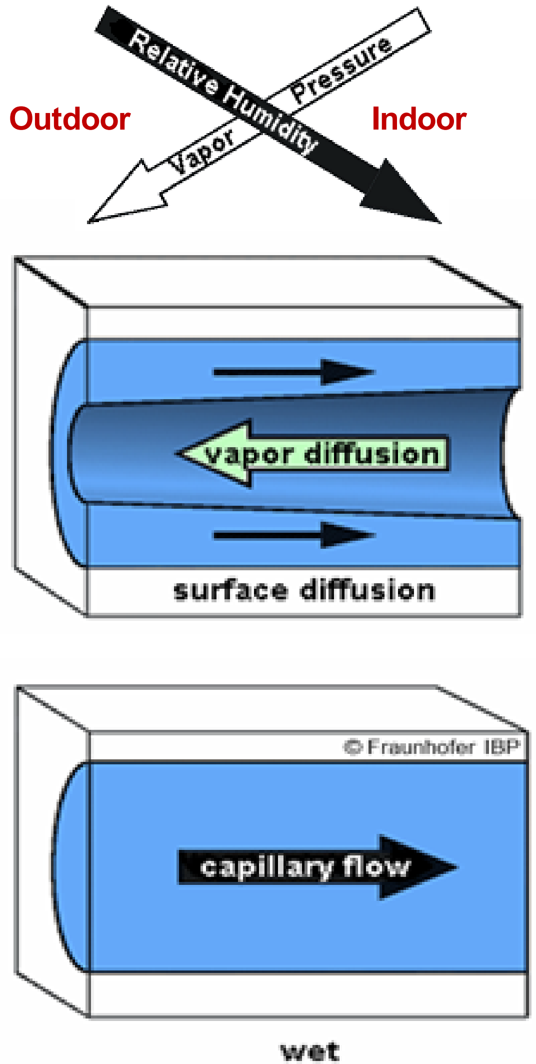


Extending moisture control to account for moisture storage and liquid transport



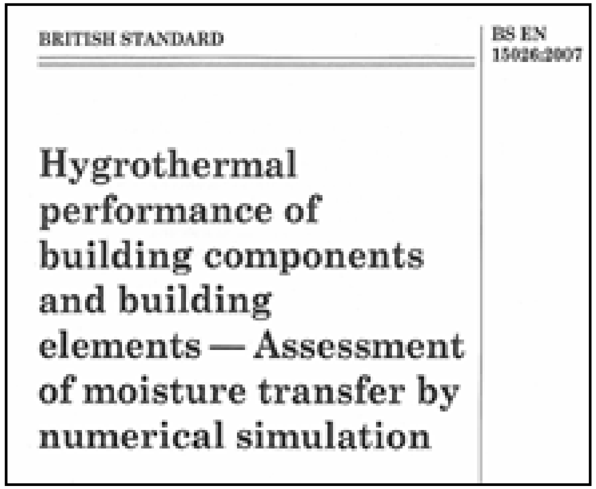






Moisture control design by hygrothermal simulation

International application standards and guidelines


BRITISH STANDARD

BS EN 15026:2007

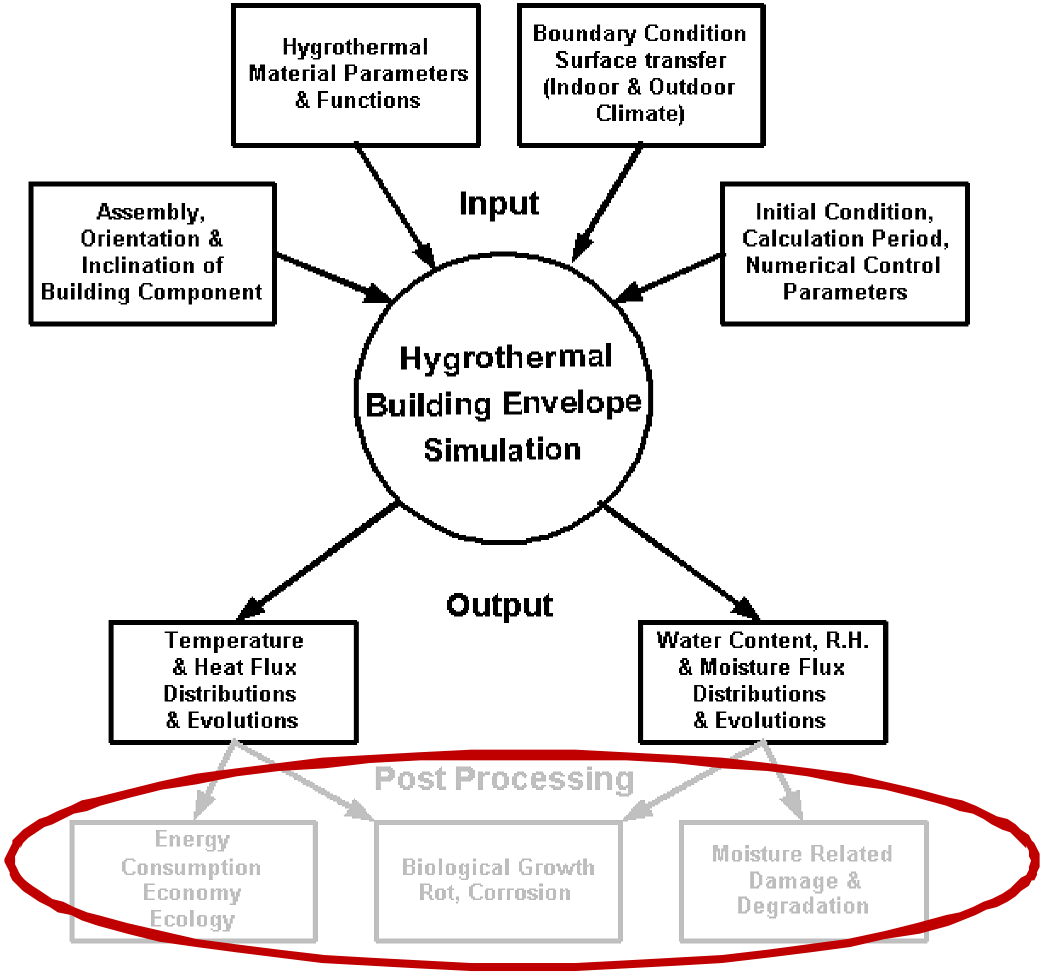
Hygrothermal performance of building components and building elements — Assessment of moisture transfer by numerical simulation


ASHRAE STANDARD

Criteria for Moisture-Control Design Analysis in Buildings

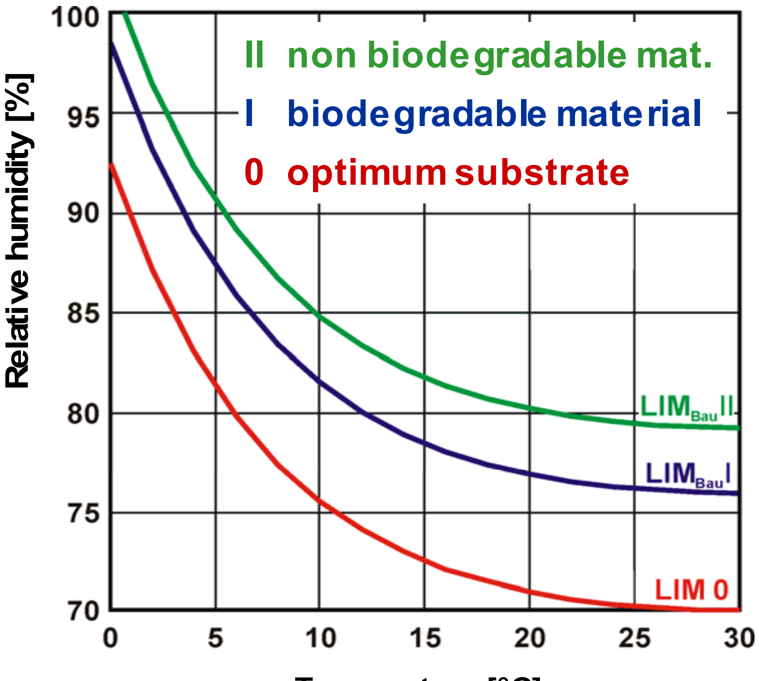
Hygrothermal analysis based on validated simulation models ref. to EN 15026 or ASHRAE Std 160 & ASTM E3054/E3054M−16

Result Evaluation

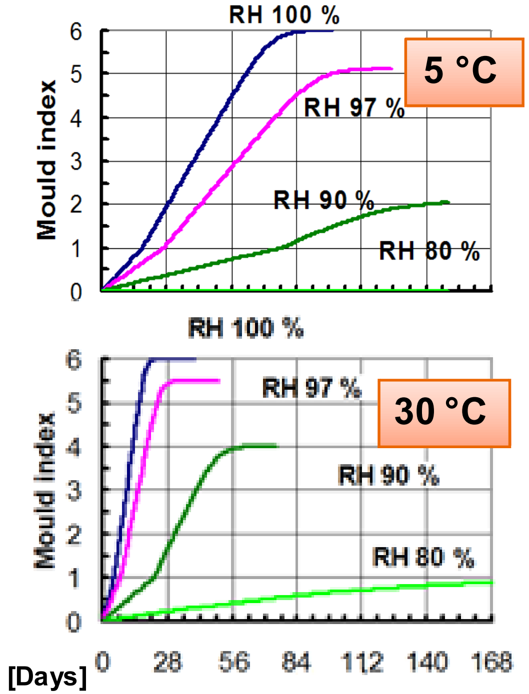


Moisture control design by hygrothermal simulation

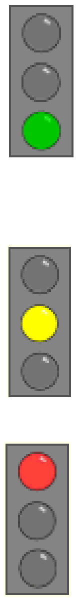
Determine the risk of mold growth by post process models from IBP or VTT (ASHRAE Std. 160)



Ref.: Sedlbauer



Ref.: Viitanen



MI	Mold index description
0	no growth
1	some growth visible under microscope
2	moderate growth visible under microscope, coverage more than 10%
3	some growth detected visually
4	visual coverage >10%
5	coverage more than 50%
6	complete coverage, 100%

Mold growth criteria change for internal surfaces in ASHRAE Std. 160 from 80% RH (30-day av.) to MI ≤ 3

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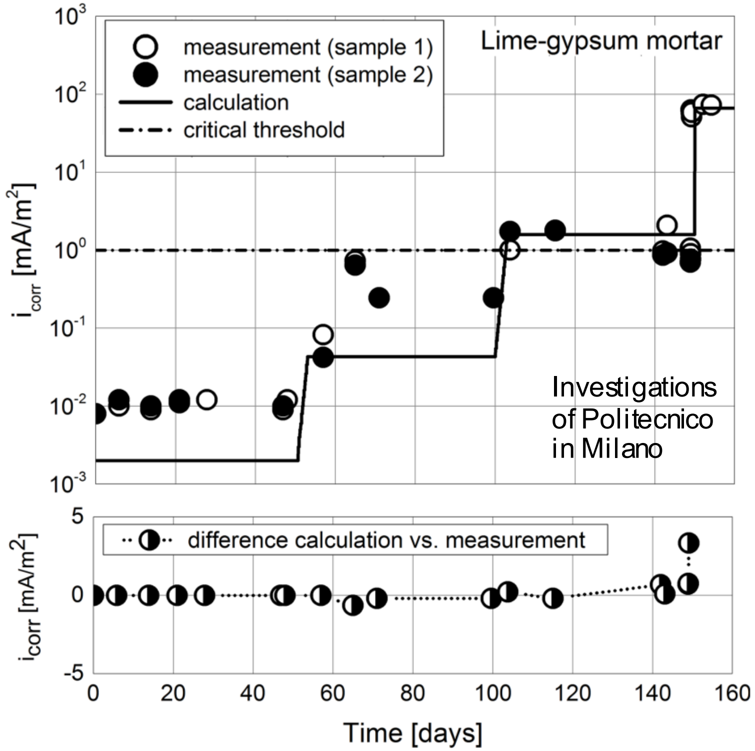
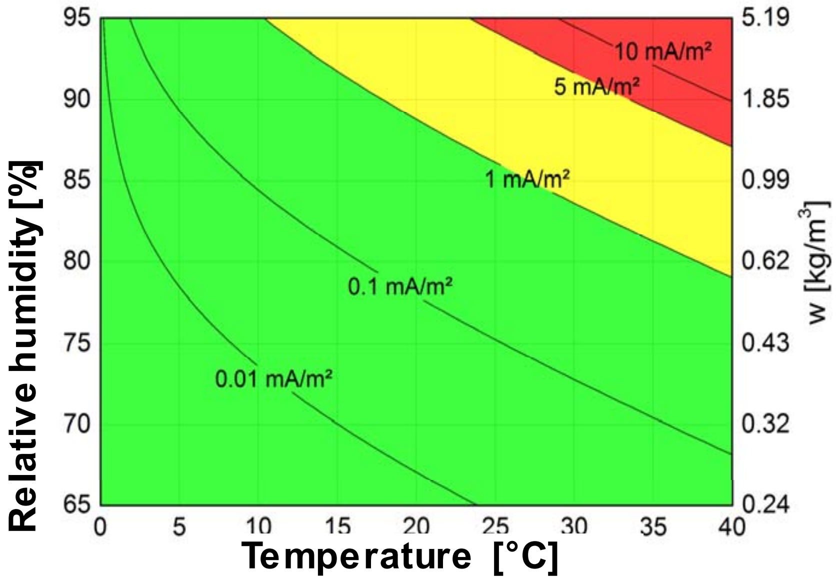
Moisture control design by hygrothermal simulation

Determine the risk and rate of corrosion (WUFI Corr)

Corrosion rates of steal in mortar as function of temp. & RH





Models estimating the corrosion rate of iron and steel are still under development

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Summary Hygrothermal Design

Appropriate moisture control measures depend on several parameters

- Outdoor climate, exposure and indoor conditions
- Continuous control layers for heat, air and moisture
- Damage prevention caused by small flaws and imperfections

Benefits of hygrothermal simulation

- Hygrothermal simulation results are reliable if input data are sufficiently accurate
- Simulation results have been extensively experimentally validated
- Hygrothermal simulation may help to assess the impact of imperfections

Improved hygrothermal design should

- Emphasize the drying potential and detail best practice installation
- Strive for resilient building envelope components

Thank you!