SUSTAINABLE BUILDING DESIGN AND RETROFIT FOR ENERGY EFFICIENT AND DURABLE HOUSES – STATE-OF-THE-ART IN GERMANY

Healthy Homes for a Sustainable Future: A German-NZ Collaboration for Energy Efficiency Retrofitting – Conference Wellington May 22, 2023

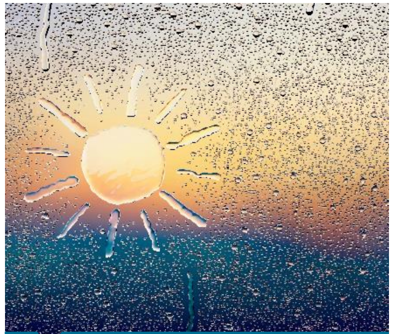
Hartwig M. Künzel, Fraunhofer-Institute for Building Physics

Auf Wissen bauen


ACOUSTICS


ENERGY EFFICIENCY AND INDOOR CLIMATE


LIFE CYCLE ENGINEERING


HYGROTHERMIK


INORGANIC MATERIALS AND RECYCLING


ENVIRONMENT, HYGIENE AND SENSOR TECHNOLOGY

Fraunhofer IBP

Introduction

Fraunhofer-Institute for Building Physics is a member of the Fraunhofer-Gesellschaft

The Fraunhofer-Gesellschaft undertakes applied research of direct utility to private and public enterprise and of wide benefit to society.

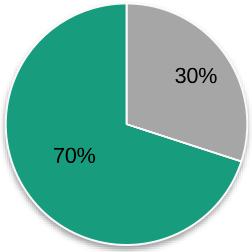
29,000 staff

75 institutes and research units

€ 2.8 billion Finance Volume

€ 2.4 billion Contract research

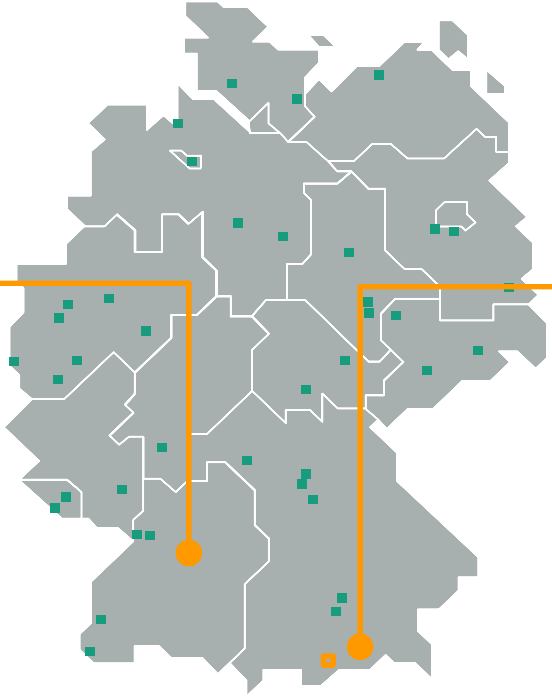
Contracts with industry and publicly financed research projects



Basic financing by the federation and the states

Introduction

Location and specifics of Fraunhofer IBP



Institute Stuttgart

- Founded in 1929
- Became Fraunhofer Institute in 1959

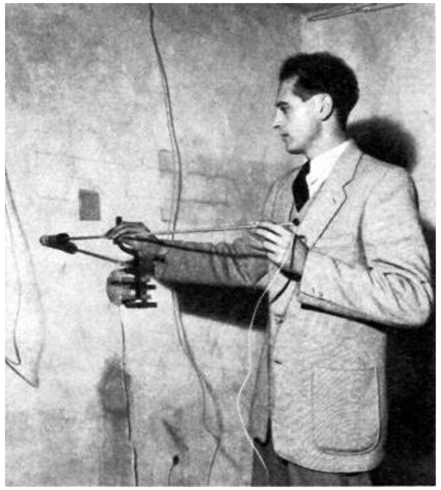
Holzkirchen Branch

- Budget ~30 Mio. €
- Industrial research ~36%
- ~420 employees

Fraunhofer IBP

Introduction

Fraunhofer IBP field test site



70 years of field tests to investigate long-term building performance & material durability

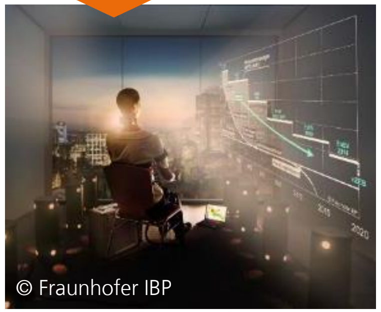
More information on IBP field tests: [Building Science Outdoor Testing (fraunhofer.de)]

Introduction
Core Competencies of Fraunhofer IBP

ACOUSTICS

- Building acoustics
- Room acoustics
- Noise control and vehicle acoustics
- Human-Centered Acoustic Design and User Research
- Musical acoustics / photo acoustics

ENERGY EFFICIENCY AND INDOOR CLIMATE



- Buildings, Districts, Cities
- Evaluation and demonstration
- Lighting technology and passive solar systems
- Vehicle climate control systems
- Design tools
- Thermal comfort, models, simulation

LIFE CYCLE ENGINEERING

- Energy and mobility
- Materials and product systems
- Sustainable construction
- Sustainable aviation
- Data-Science enhanced Product Stewardship

HYGROTHERMICS

- Hygrothermal materials and system testing
- Climate simulation and field studies
- Hygrothermal system analyses
- Market implementation
- Urban Physics Modeling

INORGANIC MATERIALS AND RECYCLING

- Building materials technology
- Inorganic raw materials and material cycles
- Testing and analysis
- Processing methods

ENVIRONMENT, HYGIENE AND SENSOR TECHNOLOGY

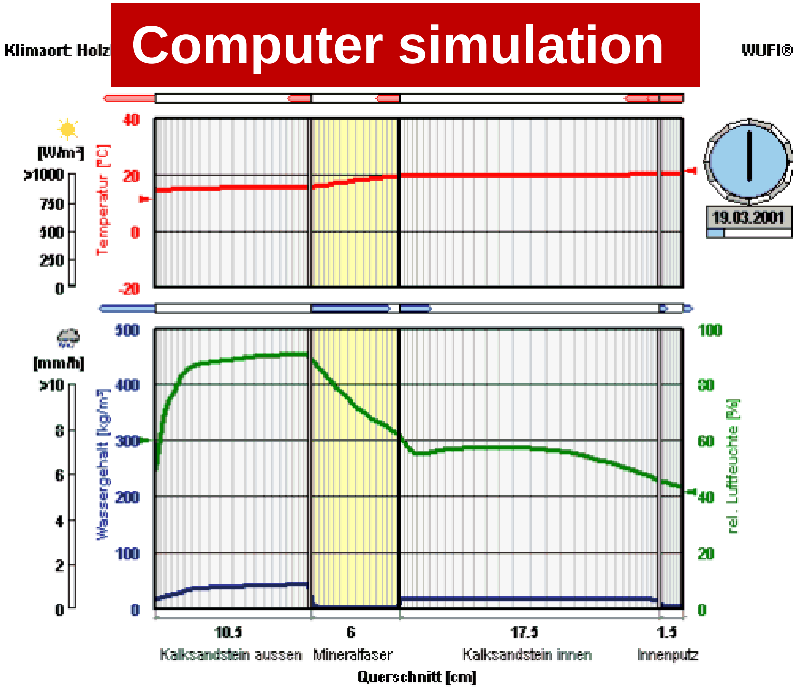
- Emissions, trace analysis
- Applied sensor technology
- Materials and causes of damage
- Ecology and microbiology
- Combustion / environ-mental technology
- Hygiene

Introduction – Building Physics Testing and Analysis

The laws of physics are the same all over the world, but the climatic impacts differ

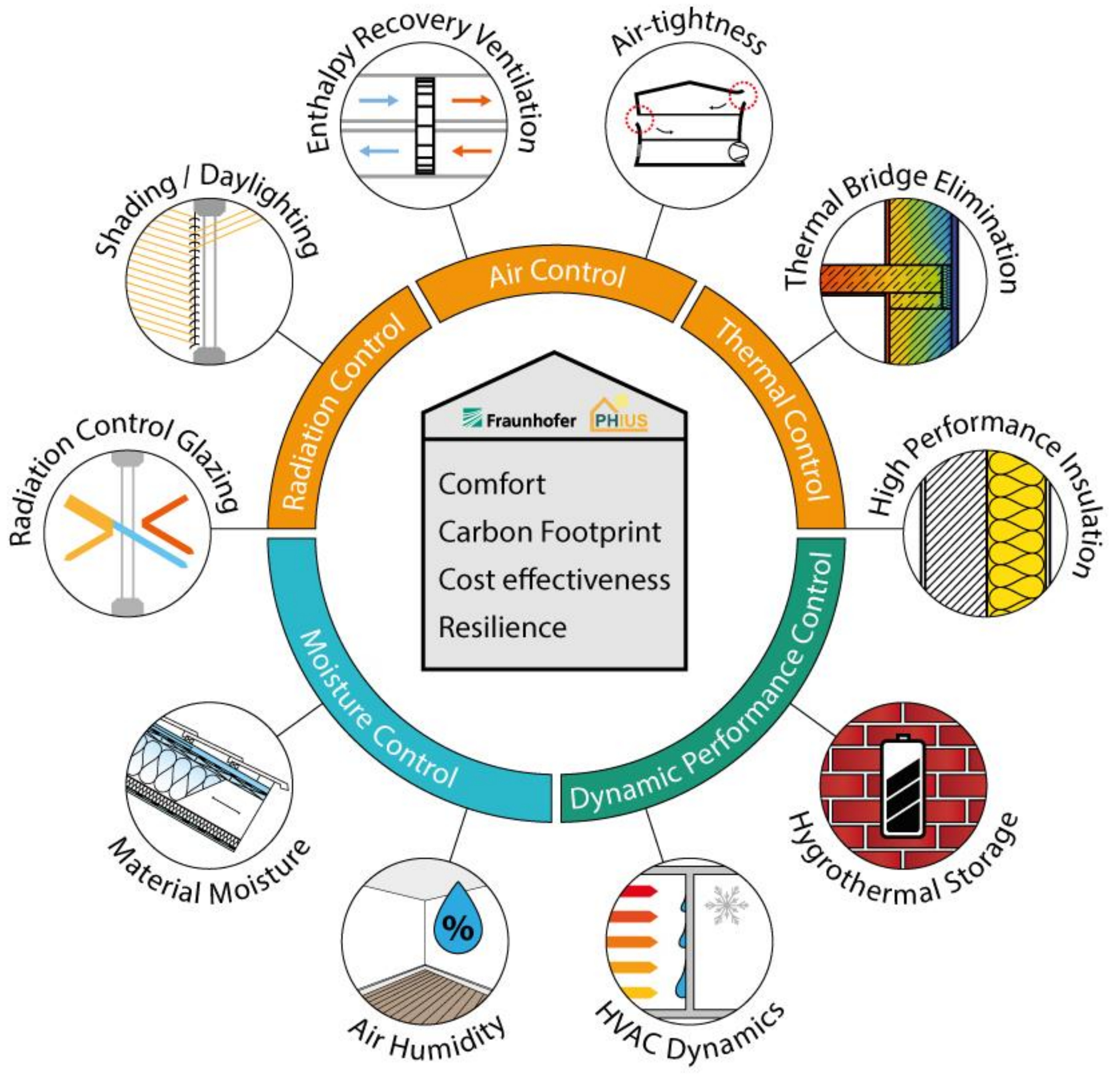
Investigations of integral building performance focusing on heat, air and moisture transfer in building materials, systems and components (hygrothermal performance).

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



https://wufi.de/de/wp-content/uploads/sites/9/IBP-Report-546.pdf

Envelope design and retrofit aspects for energy efficient and durable houses



Large windows in energy efficient homes may lead to overheating without shading systems and/or radiation control glazing

Damage or accelerated ageing may occur if **moisture control** is not an integral part of the design process

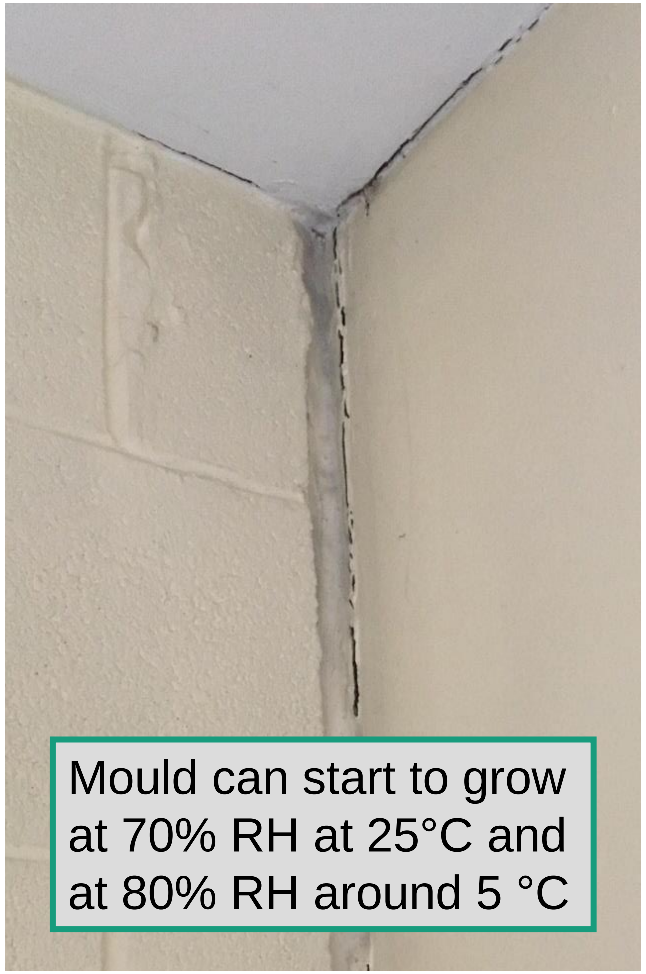
Outdoor conditions and building operation may vary significantly (dynamic behavior)

Energy supply will become more unstable due to higher share of renewable energy

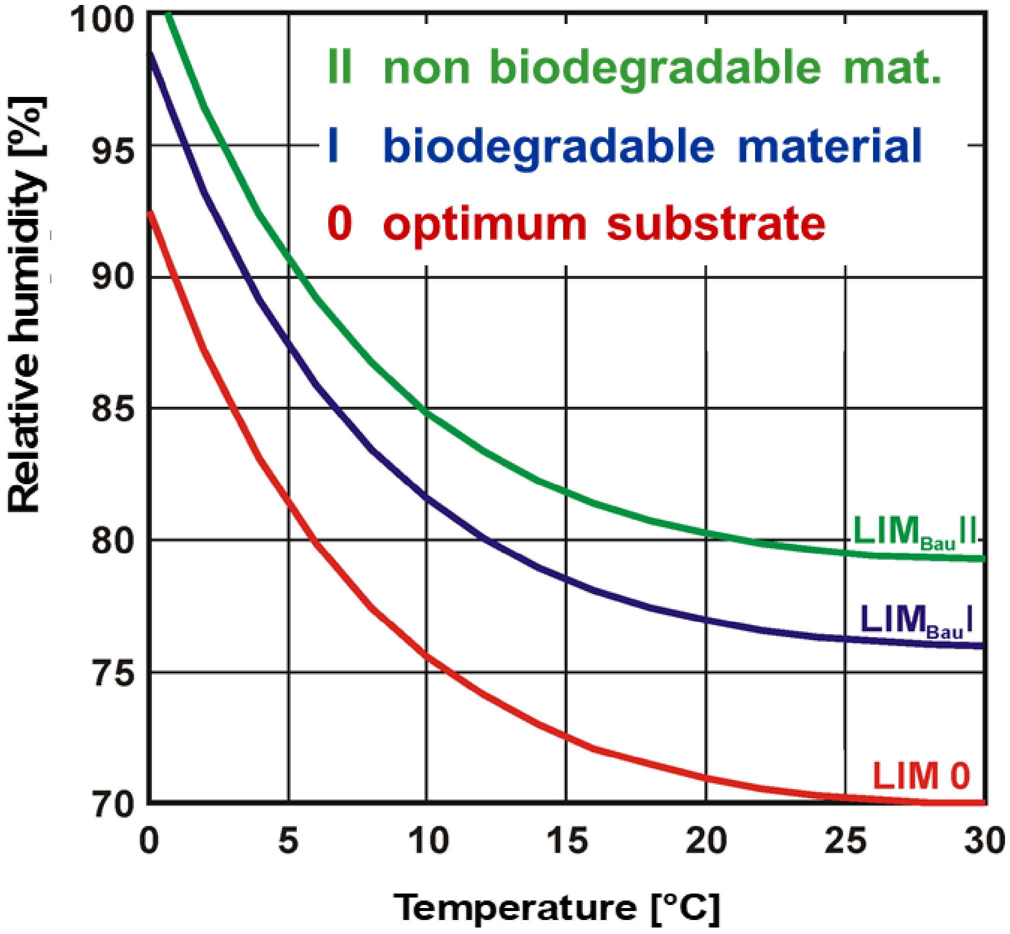
► Impact of **heat and moisture storage** (inertia) on indoor climate conditions becomes more relevant (e.g. overheating)

Envelope design – Thermal control

Insulation to ensure **hygienic conditions**



Mould can start to grow at 70% RH at 25°C and at 80% RH around 5 °C

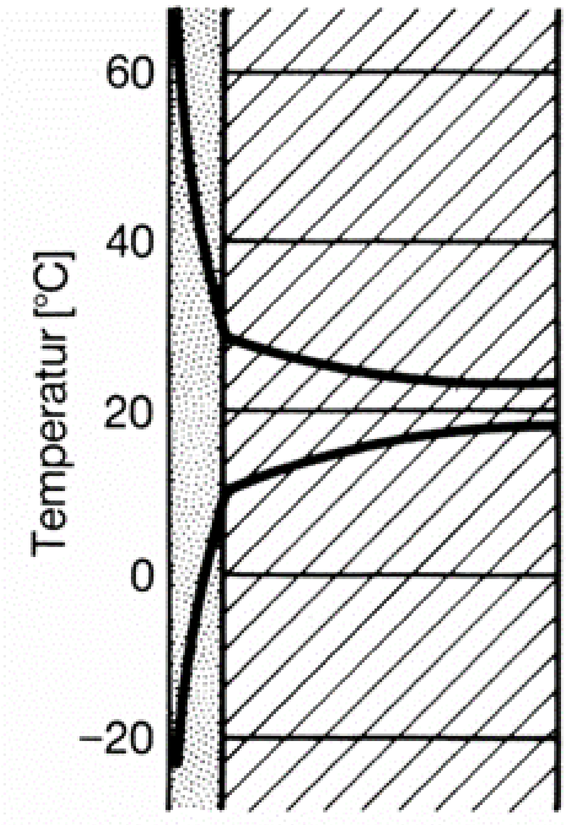


German Std. 4108 increased R-value for walls in 2001 from 0.55 to 1.2 m²K/W

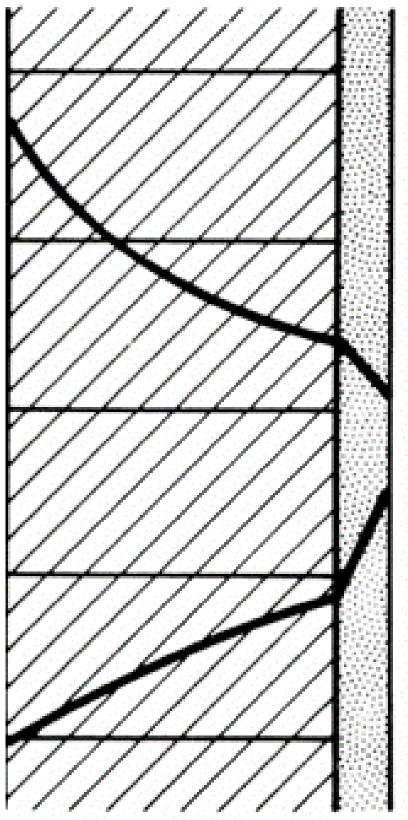
From condensation to mould prevention

Envelope design – Thermal control

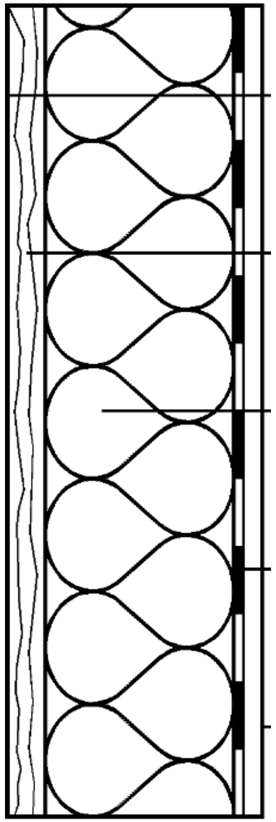
Insulation to ensure comfort and energy efficiency



Exterior insulation



Interior insulation



Cavity insulation

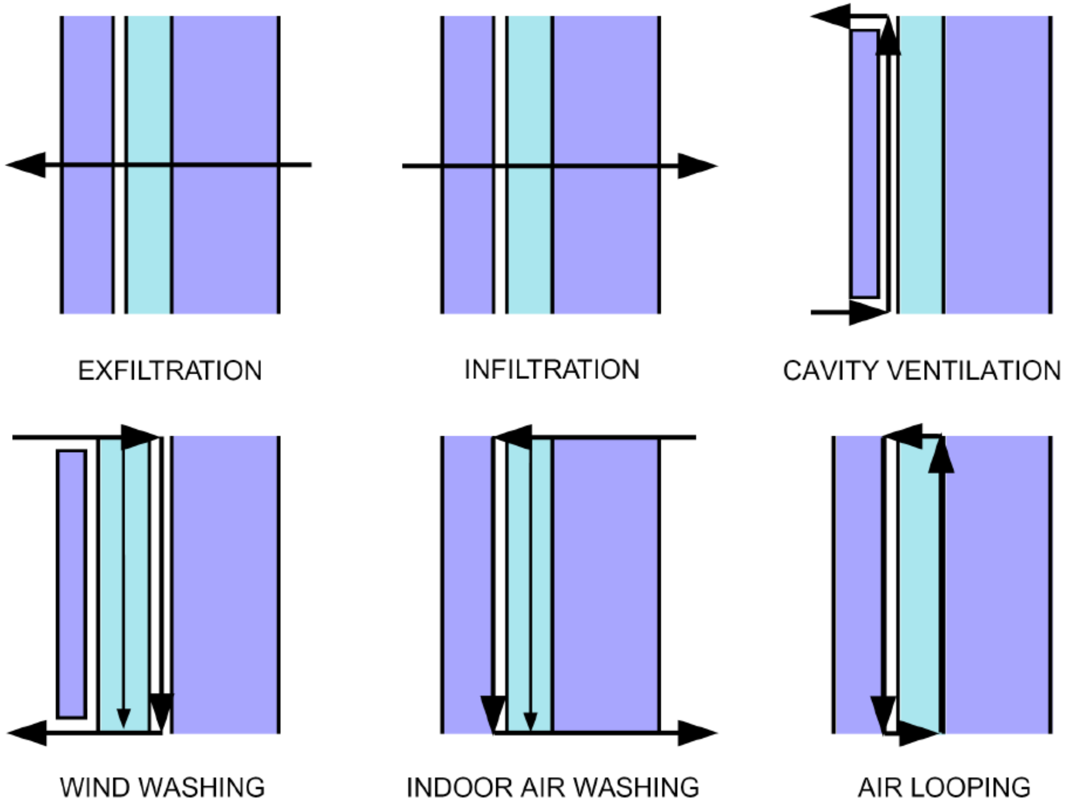
Cavity insulation is often not continuous (e.g. interrupted by steel ties or framing)

Thermal insulation brings the interior surface temp. closer to the indoor temp. This reduces the risk of mould growth.

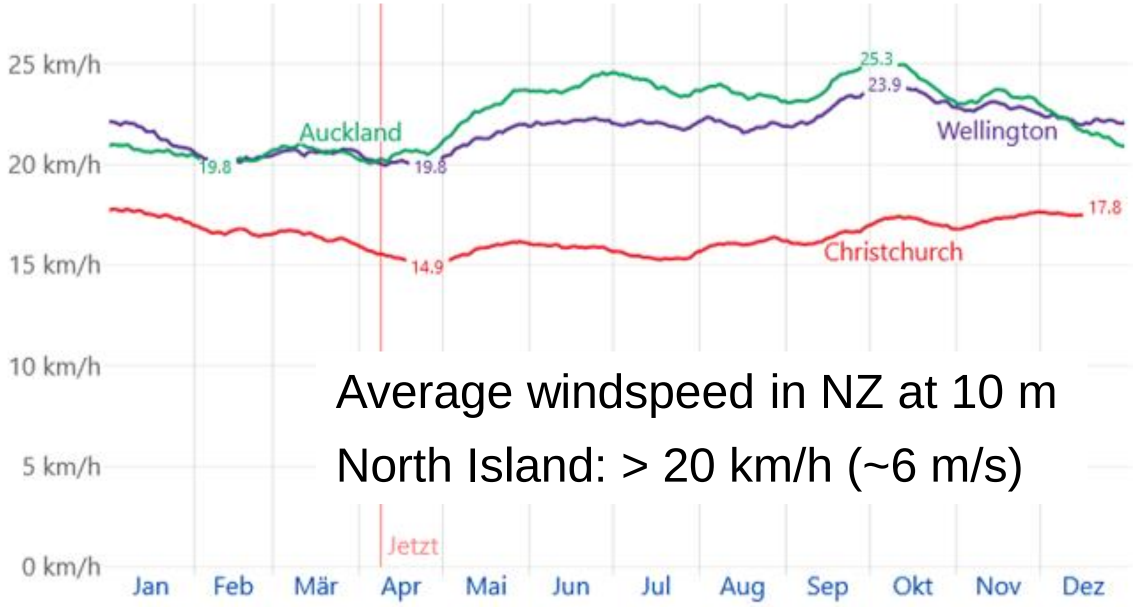
The outdoor surface temp. may drop below ambient conditions. This may increase the risk of façade staining (microbial growth)

Envelope design – Airflow control

Air-tightness to ensure hygienic conditions, comfort and **energy efficiency**



Convection effects degrade the performance of bulk insulation (ASHRAE HoF)



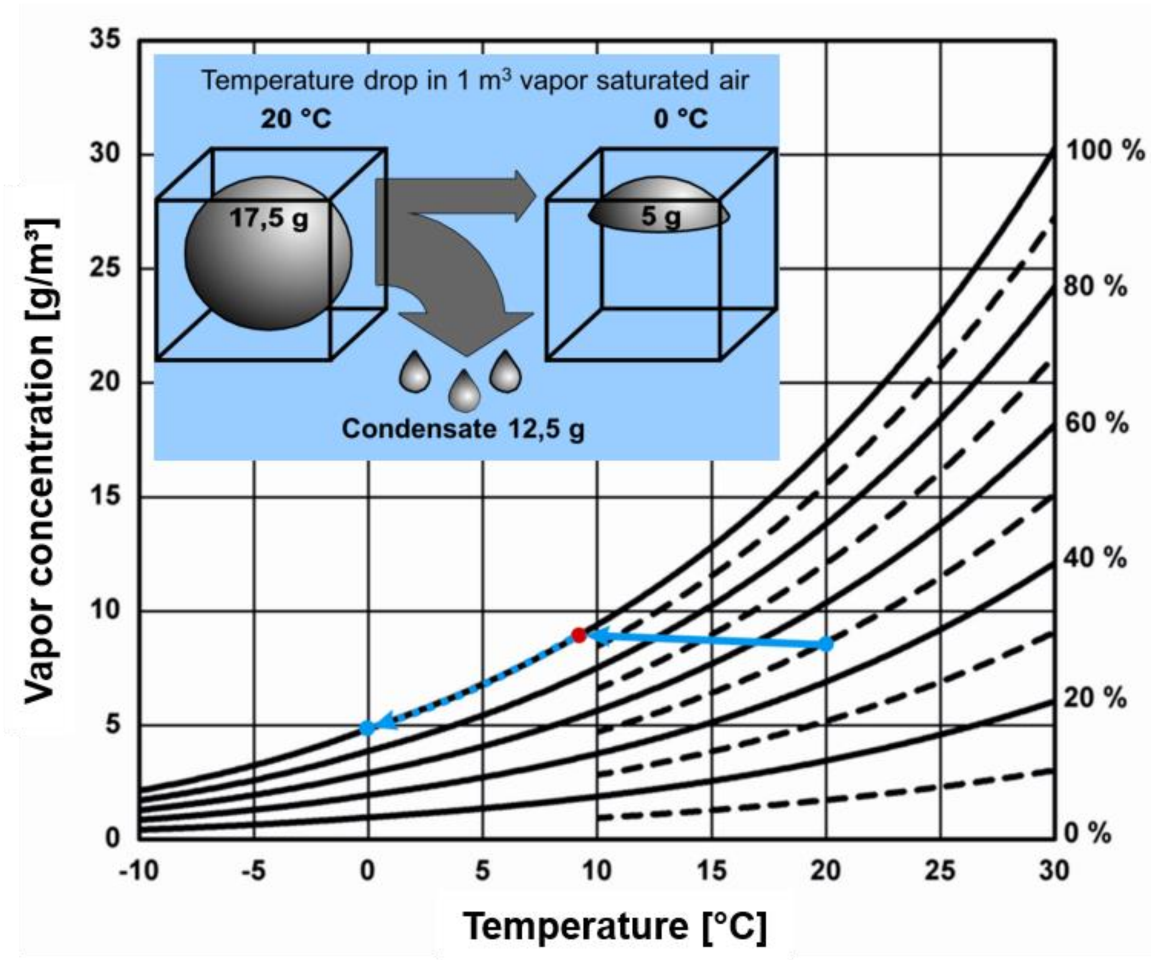
Average windspeed in NZ at 10 m

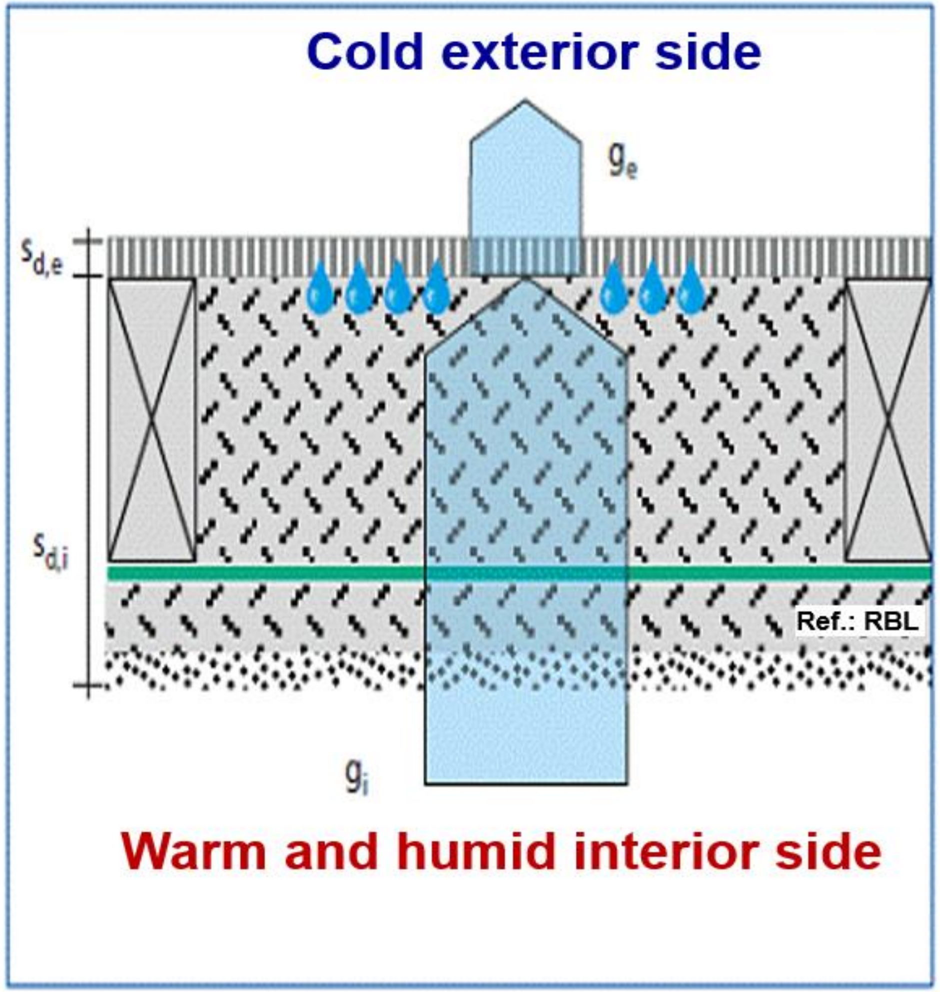
North Island: > 20 km/h (~6 m/s)

- Bulk insulation should be protected by **two** (ext. & int.) airflow control layers
- **Mechanical ventilation** (preferably with heat recovery) must guarantee indoor air quality

Envelope design – Moisture control

Condensation control of **insulated** assemblies by interior vapour control layers



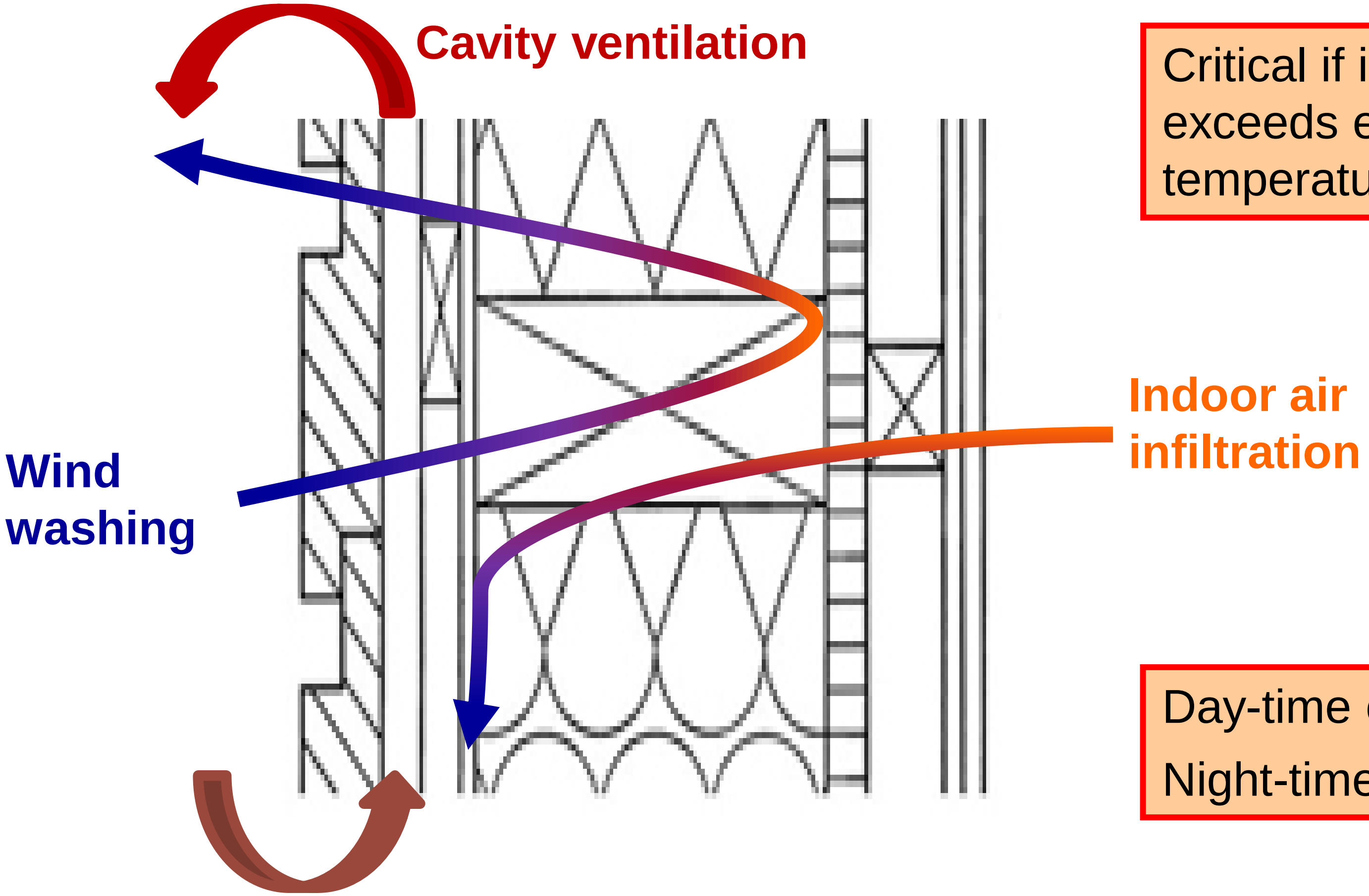


Envelope design – Vapour convection control

Air convection effects occurring in light-weight construction assemblies

WTA	Simulation of Heat and Moisture Transfer	Merkblatt 6-2 Ausgabe: 12.2014/E

5 Auxiliary models for the simplified inclusion of special effects
5.1 Rear ventilation and venting of building components
5.2 Condensation caused by air flow
5.3 Wind driven rain penetration



Critical if indoor dewpoint exceeds exterior sheathing temperature

To be included in EN 15026

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

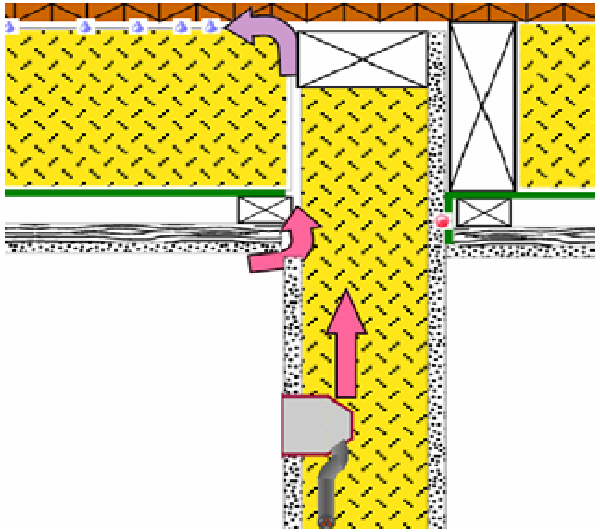
Impairs thermal envelope performance

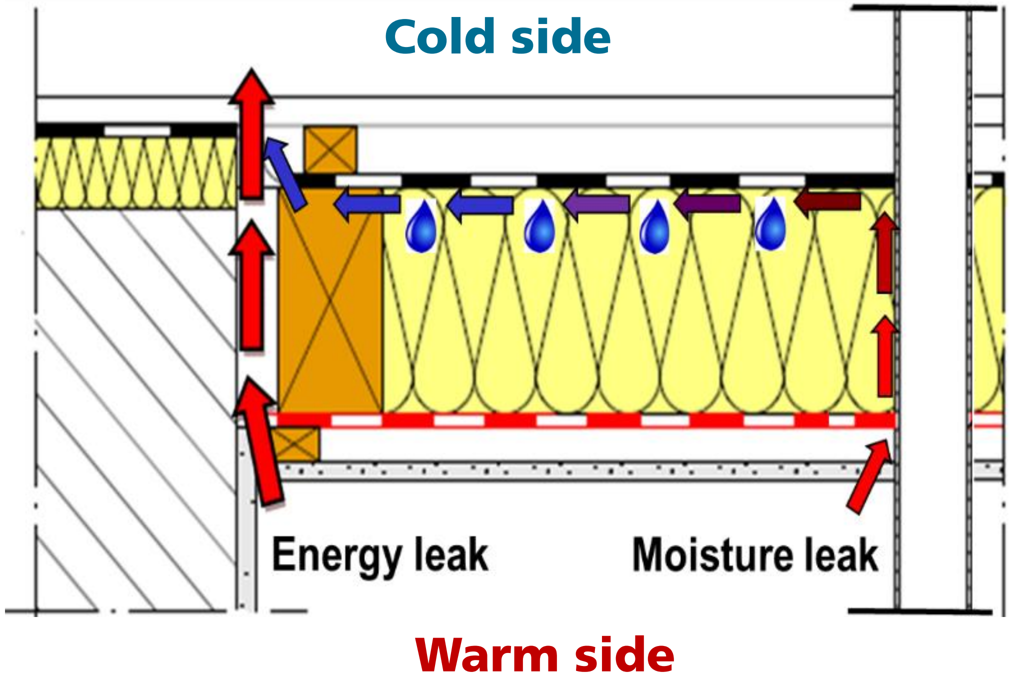
Day-time or summer-time **drying**

Night-time or winter-time **wetting**

Envelope design – Vapour convection control

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





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

► Therefore, air sealing is essential especially in **cold** or **warm and humid climates**

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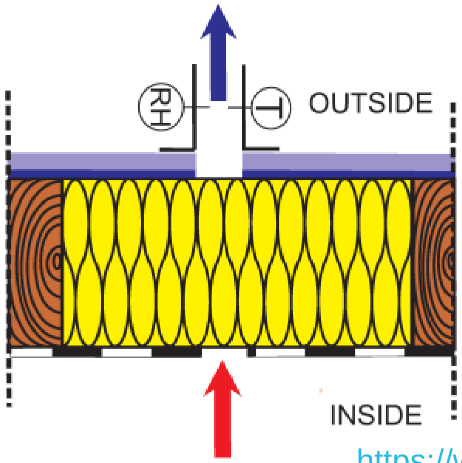
Envelope design – Vapour convection control

Impact of small leaks on condensation in walls

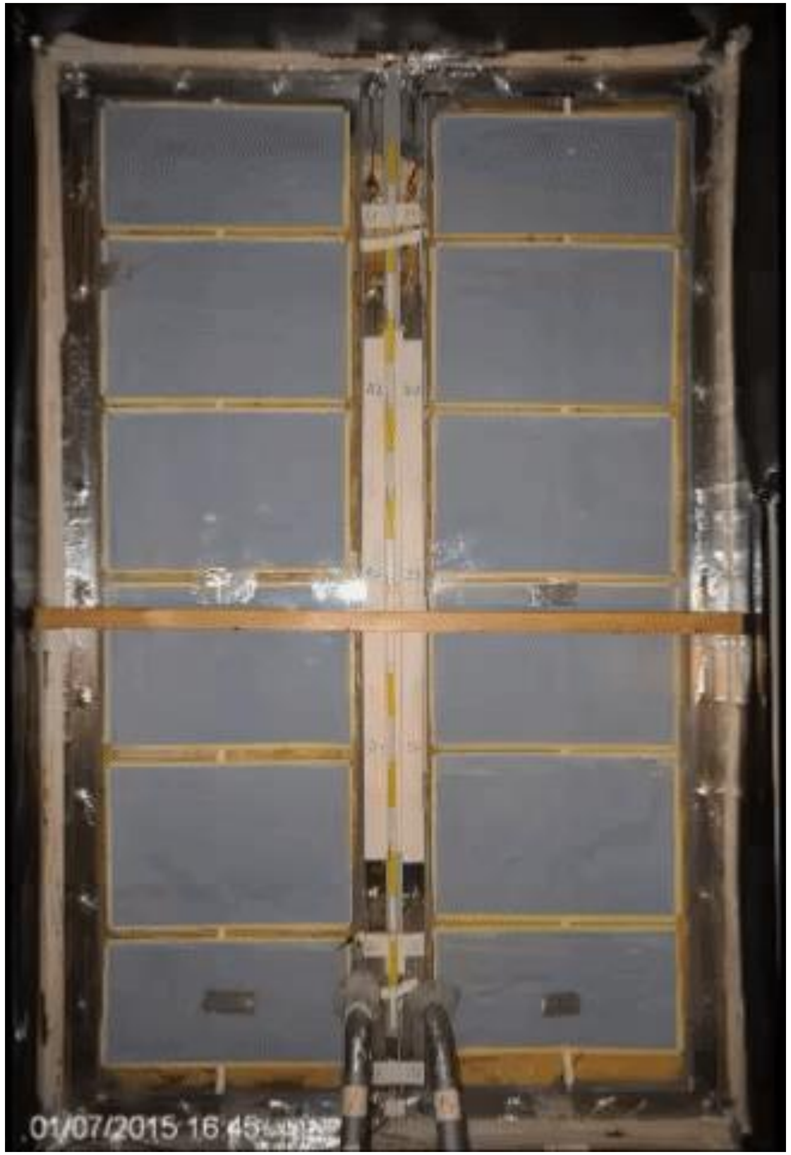
Since it is impossible to achieve complete and durable air-tightness in practice, envelope design must ensure a sufficient **drying potential** of all assemblies. This is most relevant for timber structures (DIN 68800-2)

Hot-box / cold-box laboratory tests



Warm Side

Cold Side



Leakage through taped joints around the wall section equals that of a 5 mm hole

https://www.researchgate.net/publication/311846004_Airflow_through_Lightweight_Wall_Assemblies_-_Influence_of_Size_and_Location_of_Leakages

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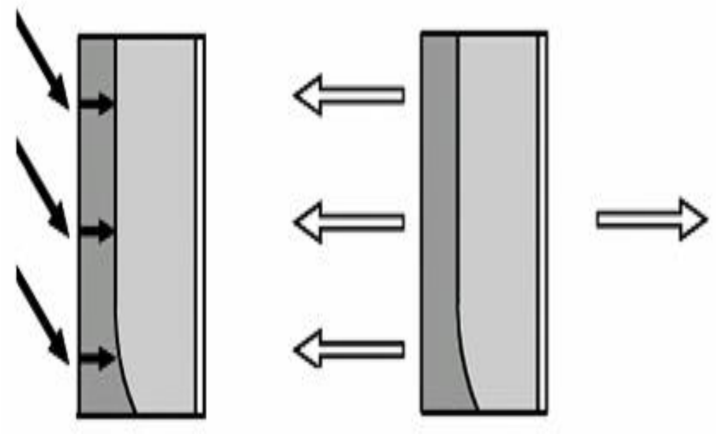
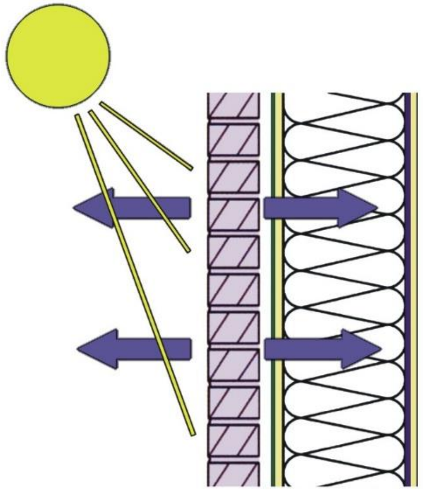
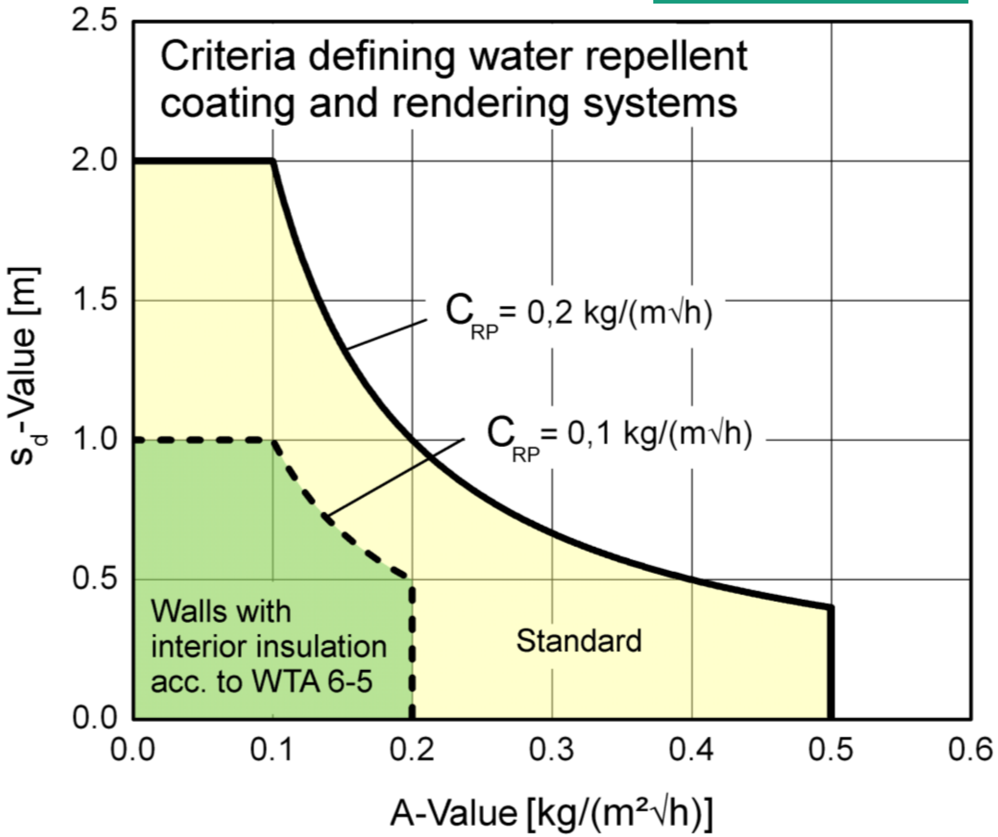
Driving rain control – rainwater absorption

Rainwater absorption and drying of walls with external rendering systems

DIN 4108-3







Frost damage, solar vapour drive, corrosion or rot may occur if there is an imbalance between wetting and drying

Therefore, external finishing systems should not absorb much water (small A-value) and should be as vapour permeable as possible (small s_d-value)

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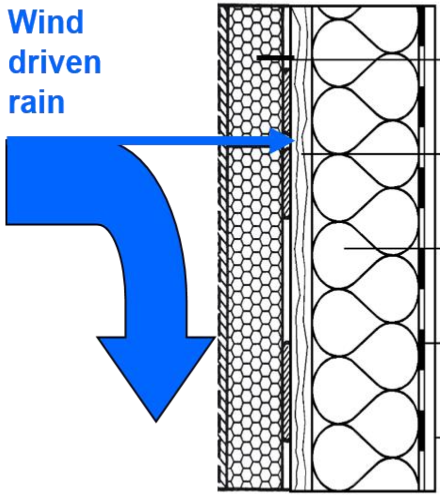
Driving rain control – rainwater penetration

Risk of damage due to driving rain leakage

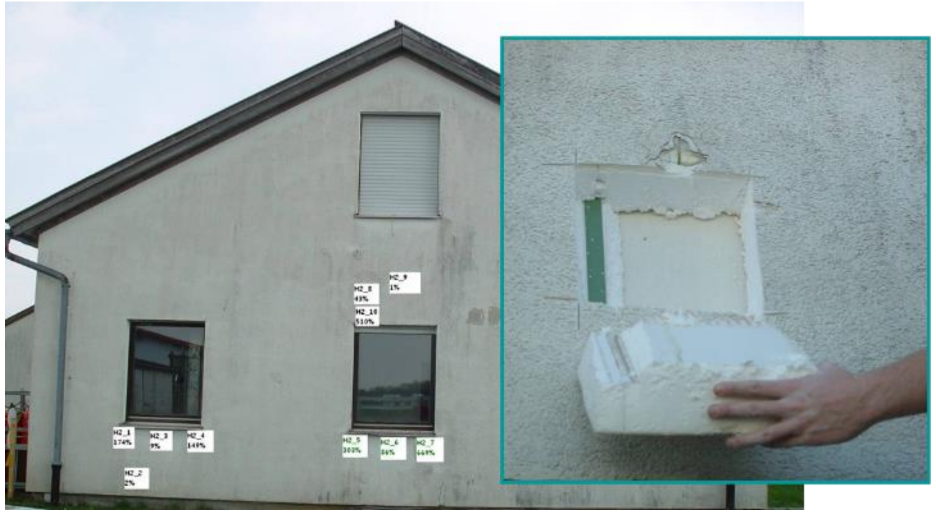
1990s: damaged stud walls with EIFS in North America, later also in Sweden

Reason: water penetration at window joints and other wall connections



Rainwater entry behind the insulation must be dealt with!

EWIS (External Wall Insulation Systems) on timber structures require a technical approval in Germany



Probing of wall with rendered EPS as external insulation system (IBP field test)

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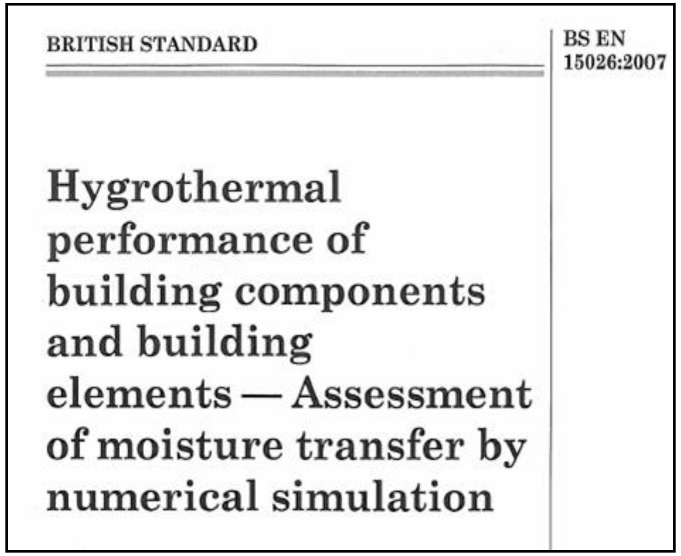
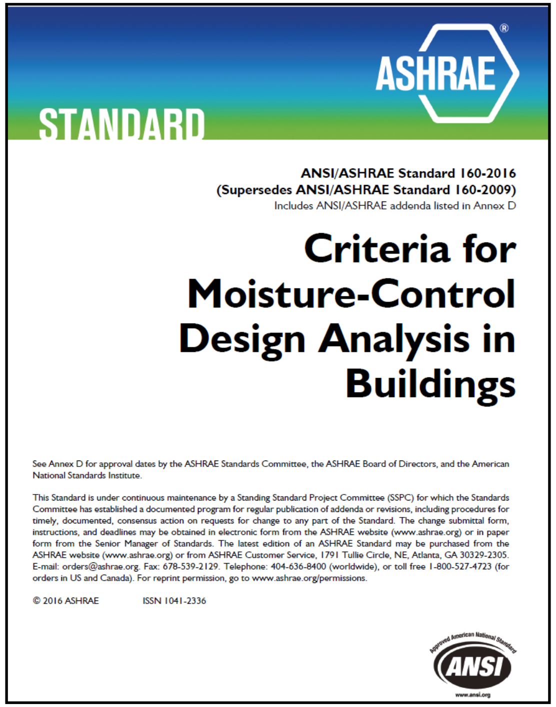
Preventing damage by moisture control

International hygrothermal simulation 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

ANSI/ASHRAE Standard 160-2016
(Supersedes ANSI/ASHRAE Standard 160-2009)
Includes ANSI/ASHRAE addenda listed in Annex D

Criteria for Moisture-Control Design Analysis in Buildings

See Annex D for approval dates by the ASHRAE Standards Committee, the ASHRAE Board of Directors, and the American National Standards Institute.

This Standard is under continuous maintenance by a Standing Standard Project Committee (SSPC) for which the Standards Committee has established a documented program for regular publication of addenda or revisions, including procedures for timely, documented, consensus action on requests for change to any part of the Standard. The change submittal form, instructions, and deadlines may be obtained in electronic form from the ASHRAE website (www.ashrae.org) or in paper form from the Senior Manager of Standards. The latest edition of an ASHRAE Standard may be purchased from the ASHRAE website (www.ashrae.org) or from ASHRAE Customer Service, 1791 Tullie Circle, NE, Atlanta, GA 30329-2305. E-mail: orders@ashrae.org. Fax: 678-539-2129. Telephone: 404-636-8400 (worldwide), or toll free 1-800-527-4723 (for orders in US and Canada). For reprint permission, go to www.ashrae.org/permissions.

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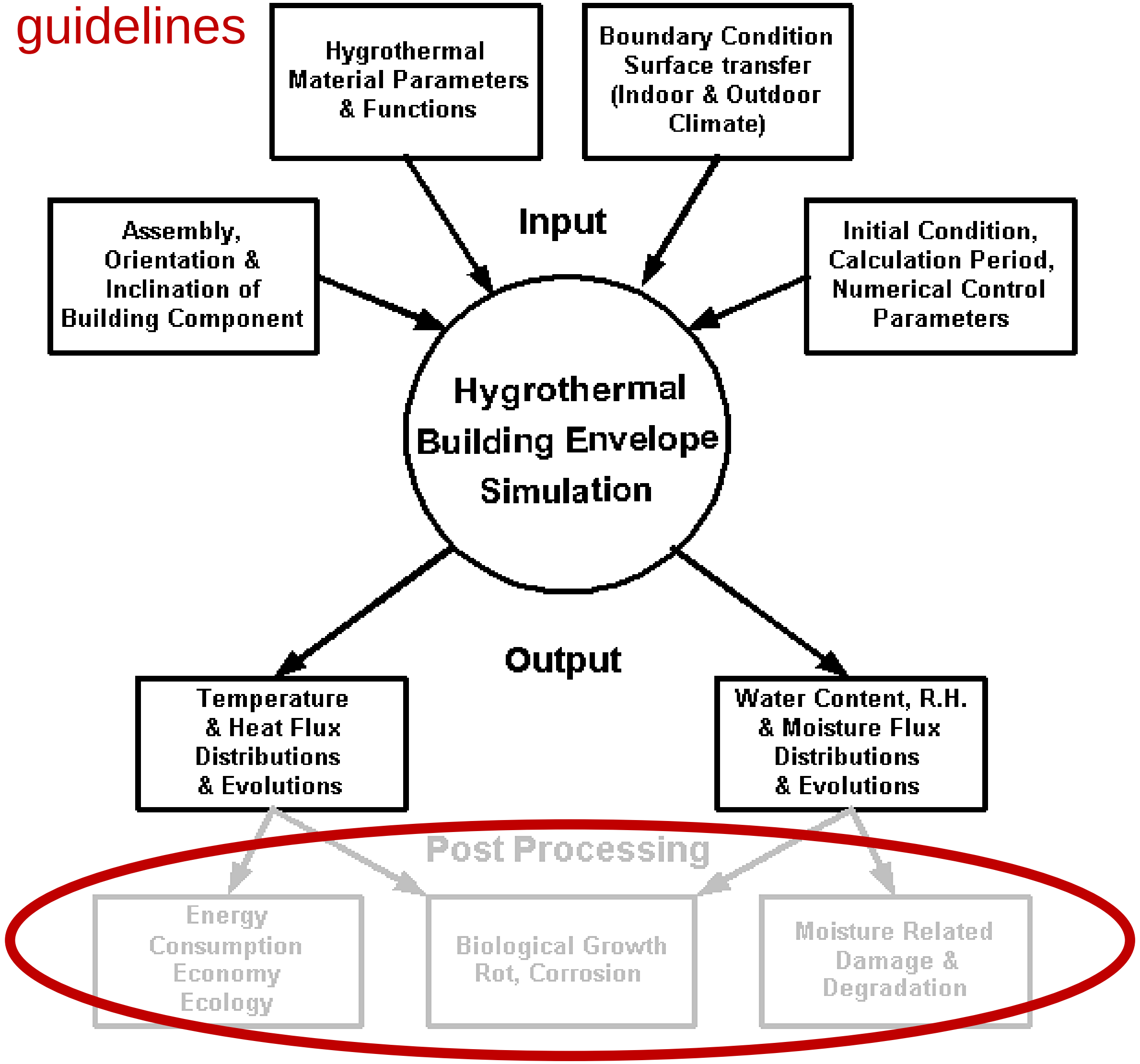
Approved American National Standard ANSI

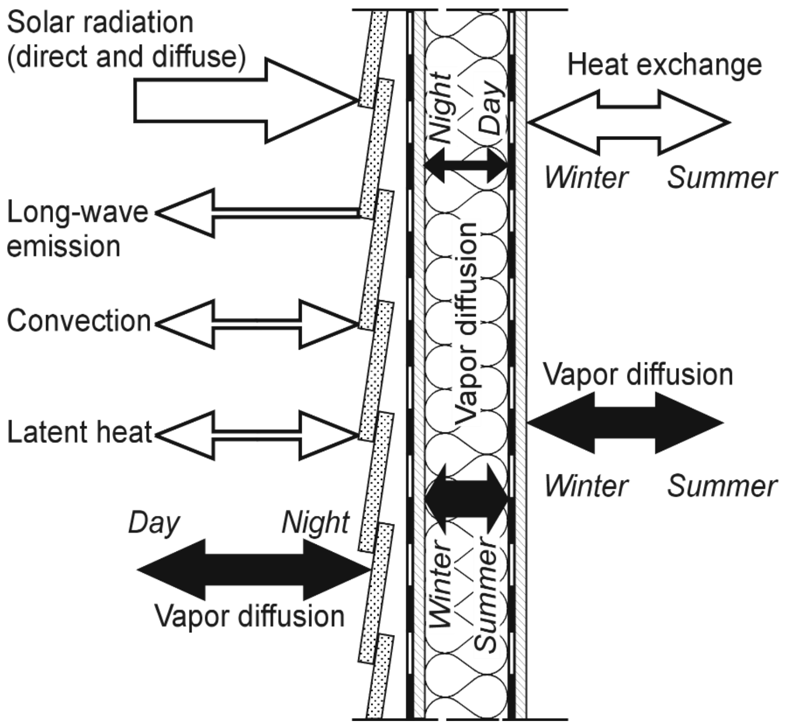
Hygrothermal analysis based on validated simulation models ref. to **EN 15026** or ASHRAE Std. 160 (2021) & ASTM E3054/E3054M−16

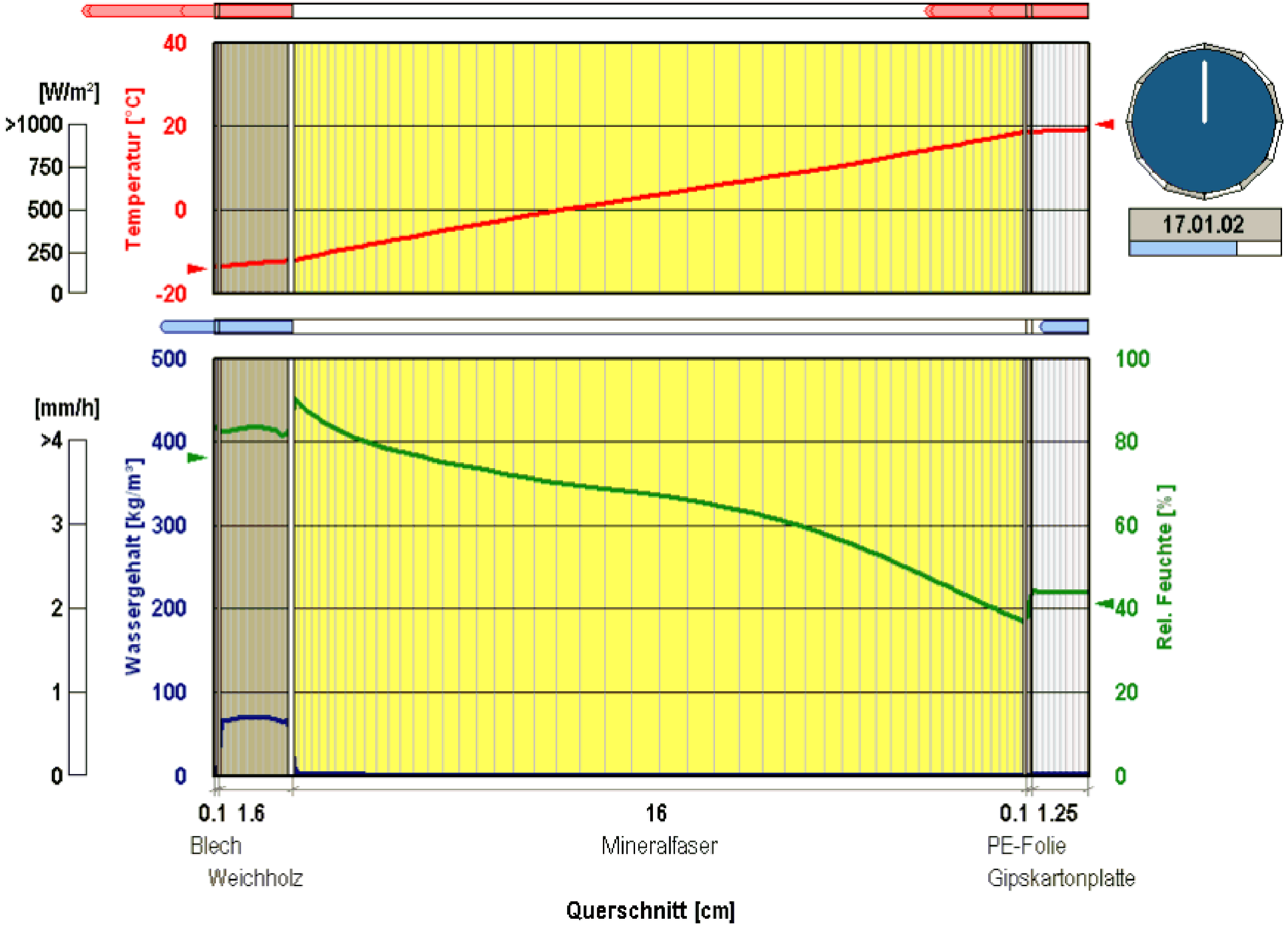
Result Evaluation



Hygrothermal simulation according to EN 15026 – Results

Looking inside: Dynamic temperature (top) and moisture (bottom) distributions in a timber frame wall





Hygrothermal simulation helps to select appropriate vapour control layers for any type of construction and climate

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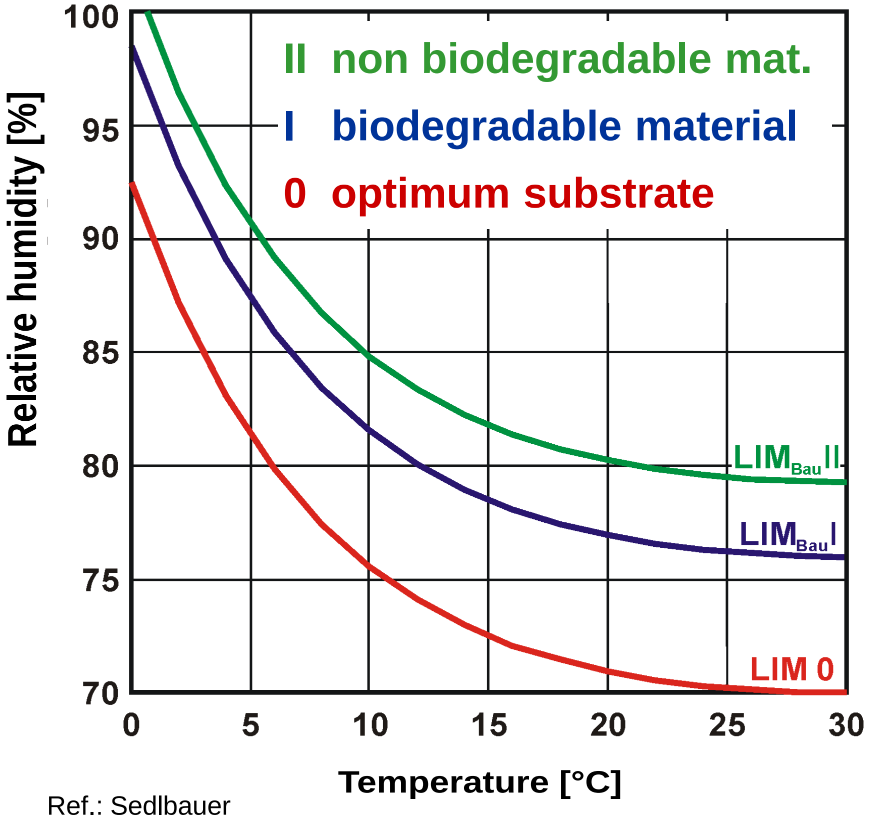
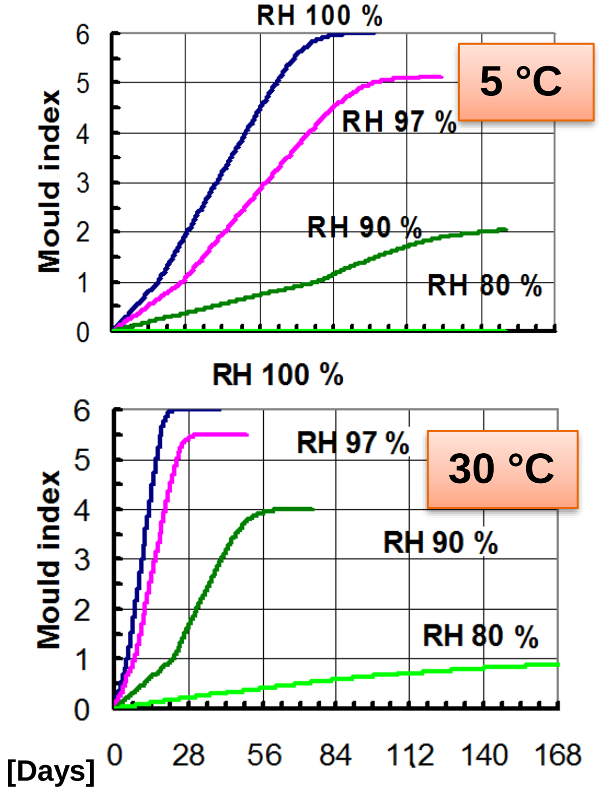
Post-process models to evaluate hygrothermal simulation results

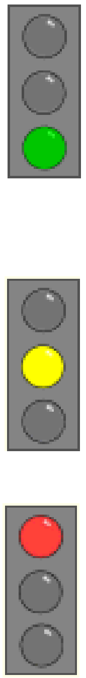
Determine the risk of mould growth models from IBP or VTT (ASHRAE Std. 160)



Ref.: Sedlbauer



Ref.: Viitanen



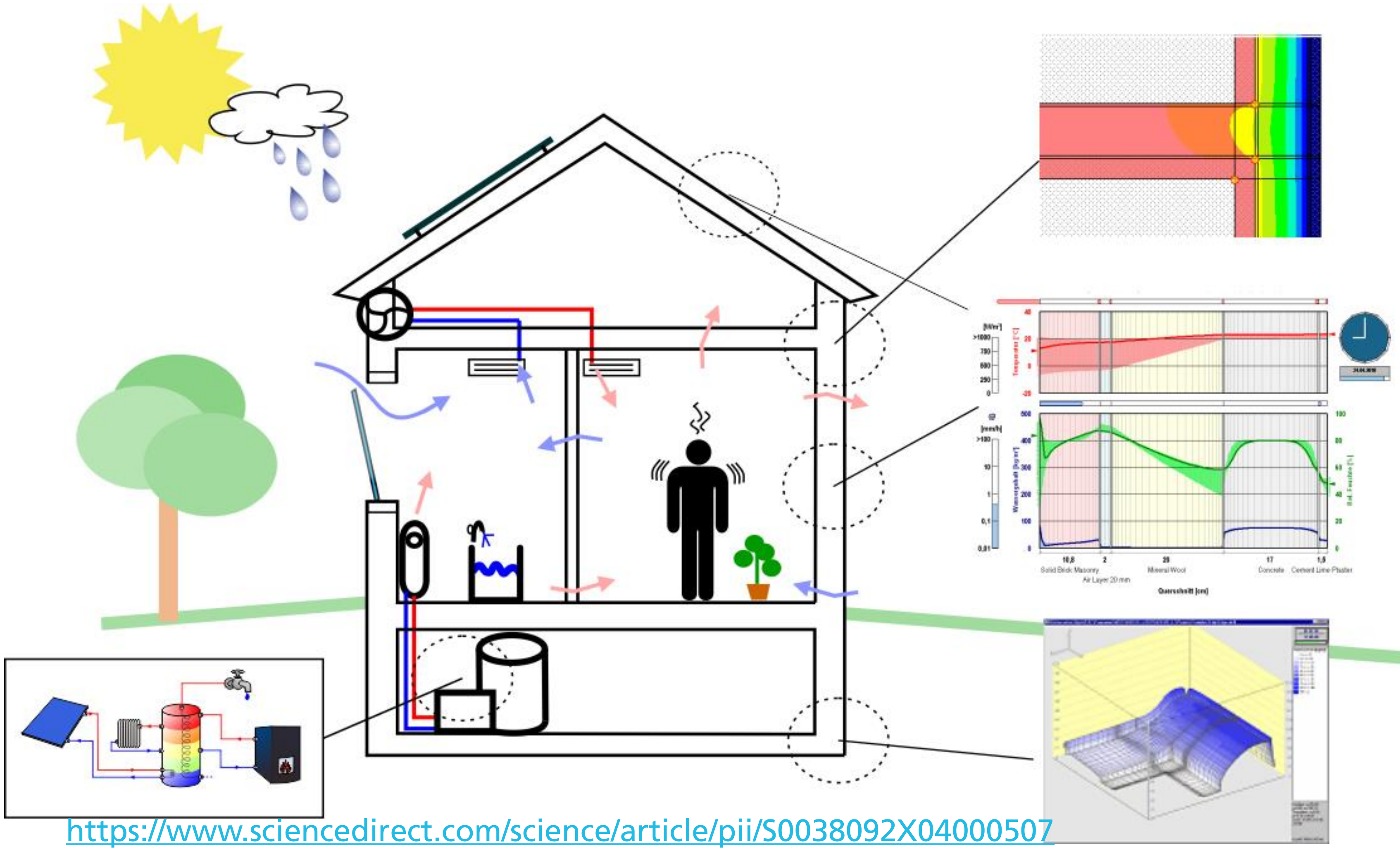
MI	Mold index description
0	no growth
1	some growth visible under microscope
2	moderate growth visible under microscope, coverage more than 10%
3	some growth detected visually
4	visual coverage >10%
5	coverage more than 50%
6	complete coverage, 100%

Mould criteria for material interfaces in ASHRAE Std. 160: **MI ≤ 3** ▌ after 80% RH (30-day av.) in 2007

https://www.sciencedirect.com/science/article/pii/S1876610215018974/pdf?md5=efe3b23062dd123db235de0d896bc805&pid=1-s2.0-S1876610215018974-main.pdf

Conclusions – Energy efficiency, ventilation and indoor environment

Hygrothermal **building simulation** tools predict the combined impacts of heat and moisture transfer



WUFI ® Plus and Passive developed by Fraunhofer IBP and used worldwide for **dynamic** hygrothermal building design on **hourly** basis

Applicable to simulate the hygrothermal performance of:

- Heritage buildings
- Moisture buffering finishings
- HVAC systems
- Thermally activated building structures (TABS)

https://www.sciencedirect.com/science/article/pii/S0038092X04000507

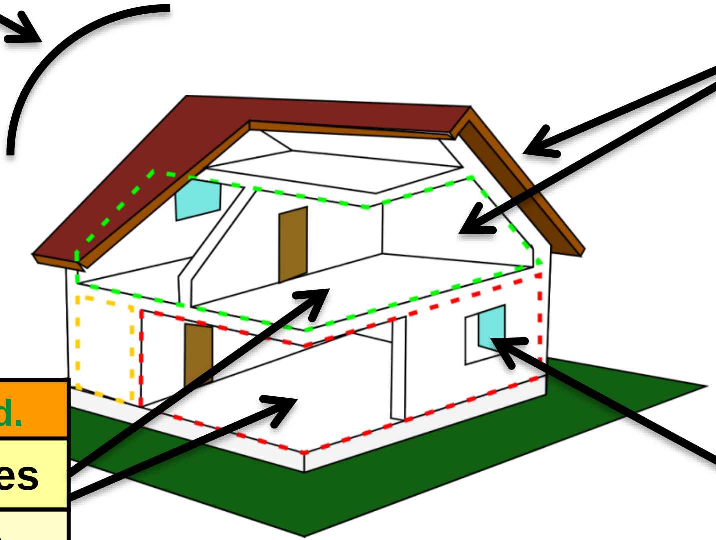
https://wufi.de/de/wp-content/uploads/sites/9/Hygrothermal-whole-building-simulation.pdf

Conclusions – Energy efficiency, ventilation and indoor environment

Boundaryond.

Outdoor climate

- temperature
- humidity
- radiation
- rain
- wind

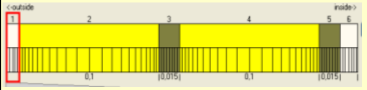


Building envelope

Opaque

layer definition

material data



Boundary cond.

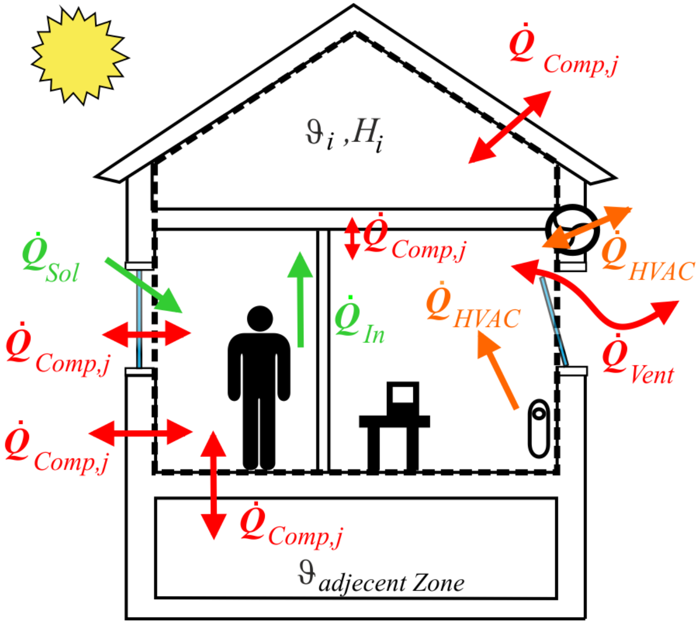
Indoor climates

- internal sources
- ventilation
- set-points
- HVAC system

Building envelope

Transparent

U-value, SHGC, blinds



Hygrothermal conditions in the building envelope ⟵ **Hygrothermal simulations with WUFI®-Plus** ⟶ **Indoor climate**
Energy demand

Simulation results:

- Indoor temp., RH & CO_2
- Energy consumption
- Performance of envelope and HVAC systems

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Summary – Relevance of heat, air and moisture control design

Indoor air quality depends on adequate envelope and ventilation design

- Mould and other microorganisms need damp surfaces to thrive
- Products treated for moisture protection may cause health problems ► see expl of DIN 68800-2

Building durability depends on effective moisture control

- Adding **insulation is a game changer** because condensation risks increase
- Installing **new windows** with high airtightness and thermal resistance may increase indoor RH
- Bio-based materials are very sustainable but may be moisture susceptible

Benefits of hygrothermal simulation

- Hygrothermal simulation enables innovations and improved design
- If damage occurred hygrothermal simulations help to determine the cause and the **liable party**

Moisture protection measures must be implemented and **maintained** from the design until the end of life of a building **with special focus on the construction phase**