



# **Energetic Refurbishment of Brick Buildings**

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## 1. Building physical research laboratory



Multi chamber climate test facility

## 2. Modeling and simulation



 DELPHIN / COND / CHAMPS / ...

## 3. Application and test buildings

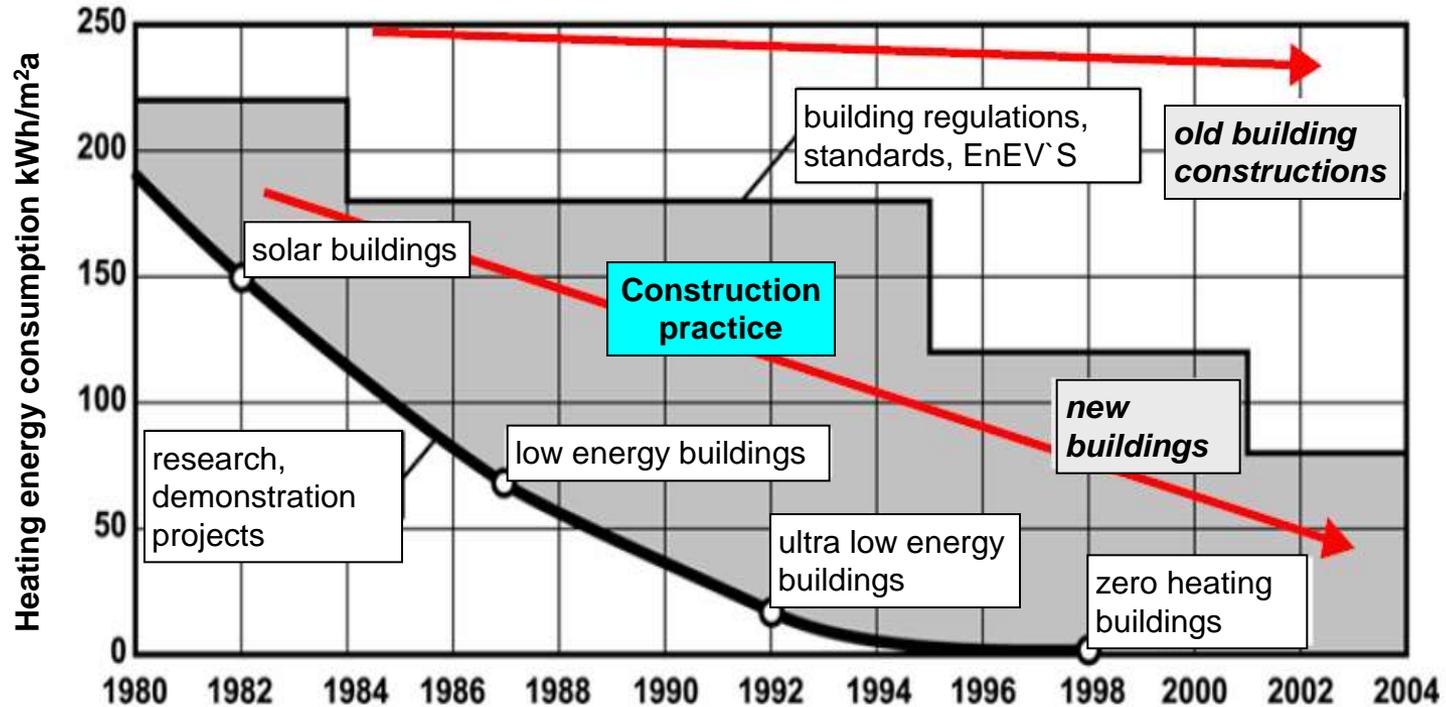


Herrenschiesshaus Nuremberg

- **Rehabilitation Engineering projects:** Elbe- Philharmony in Hamburg; Historic Storage magazines in Potsdam; Red Barracks in Potsdam; Red Town Hall in Berlin; Rijksmuseum in Amsterdam, NL; Palace Gueterfelde, Tivoli in Berlin Kreuzberg; several town quarters „Am Urban“ in Berlin, “Zöllnerviertel” in Weimar, ...
- **International cultural heritage projects:** “Humayun Tomb” in Delhi, India; Museum village of Sapiro in Japan; Ayasofia in Istanbul, Turkey; Takamatzusuka Tomb in Japan; ...
- **Modern construction projects:** Saxonian State and University Library, National competition award „Plus energy building & e-Mobility“; ...

# Why insulation?

Energy saving  
Environmental protection, CO<sub>2</sub>-reduction  
Reduction of cost of operation



# Why insulation?

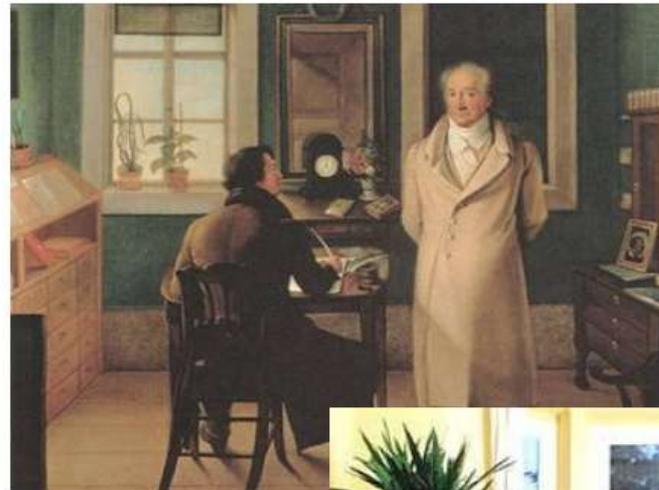
## Protection against condensation and mould



Ref: Straube



## Enhancement of thermal comfort



## Distribution of existing net dwelling area of age classes (Germany) <sup>[1]</sup>

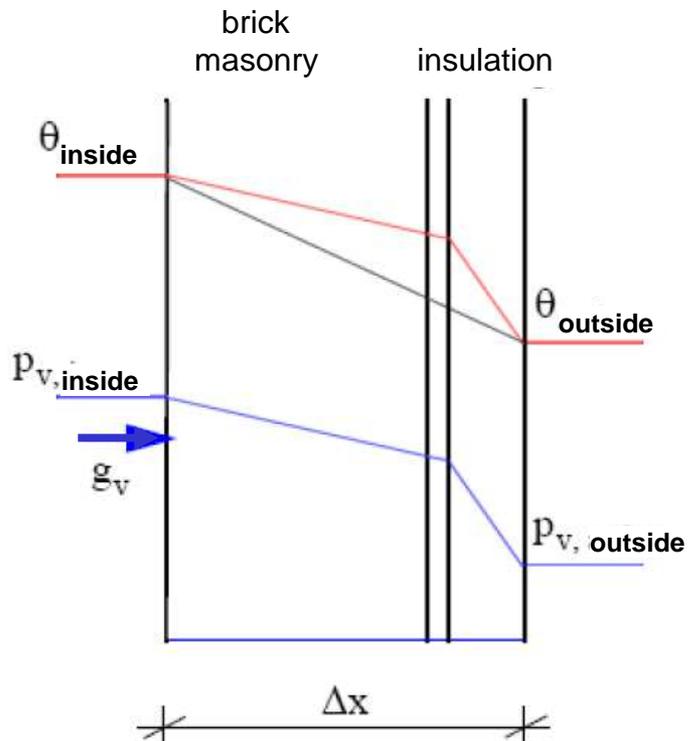
year of construction	Fraction of living space [%]
<b>before 1918</b>	<b>12</b>
<b>1919-1948</b>	<b>10</b>
<b>1949-1978</b>	<b>42</b>
<b>1979-1994</b>	<b>19</b>
<b>1995-2006</b>	<b>17</b>
<b>Sum:</b>	<b>100</b>

<sup>[1]</sup> <http://www.iwu.de>, 15.10.09

# Behavior of buildings in winter

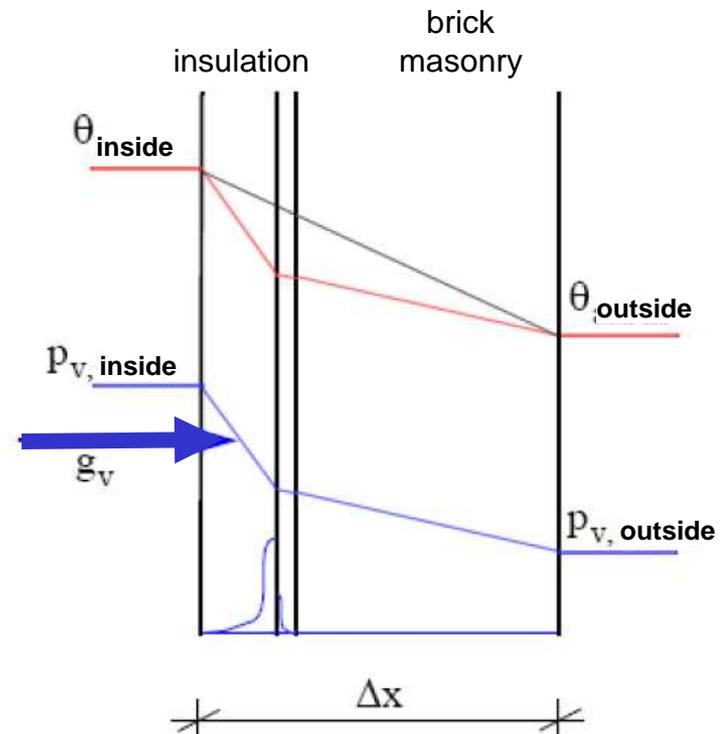
## outside insulation

*small vapor flow into the construction*



## interior insulation

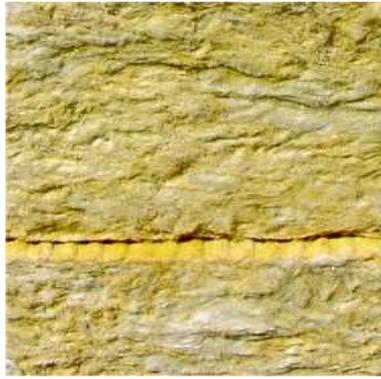
*large vapor flow into the construction*



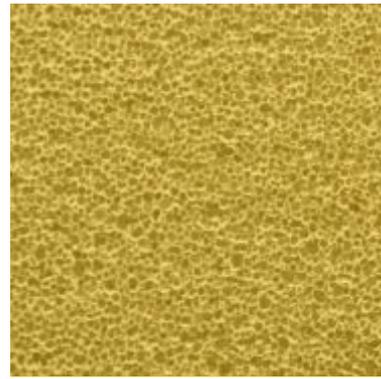
## Insulation system basing on materials...



perlite



mineral fiber



mineral foam



calcium silicate



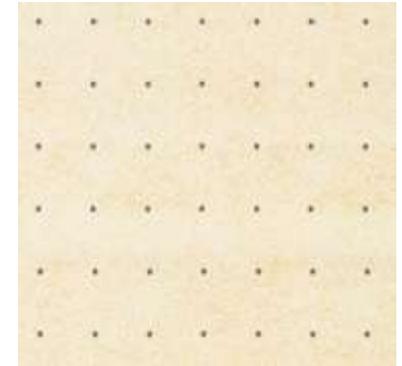
foam glass



wooden fiber  
boards

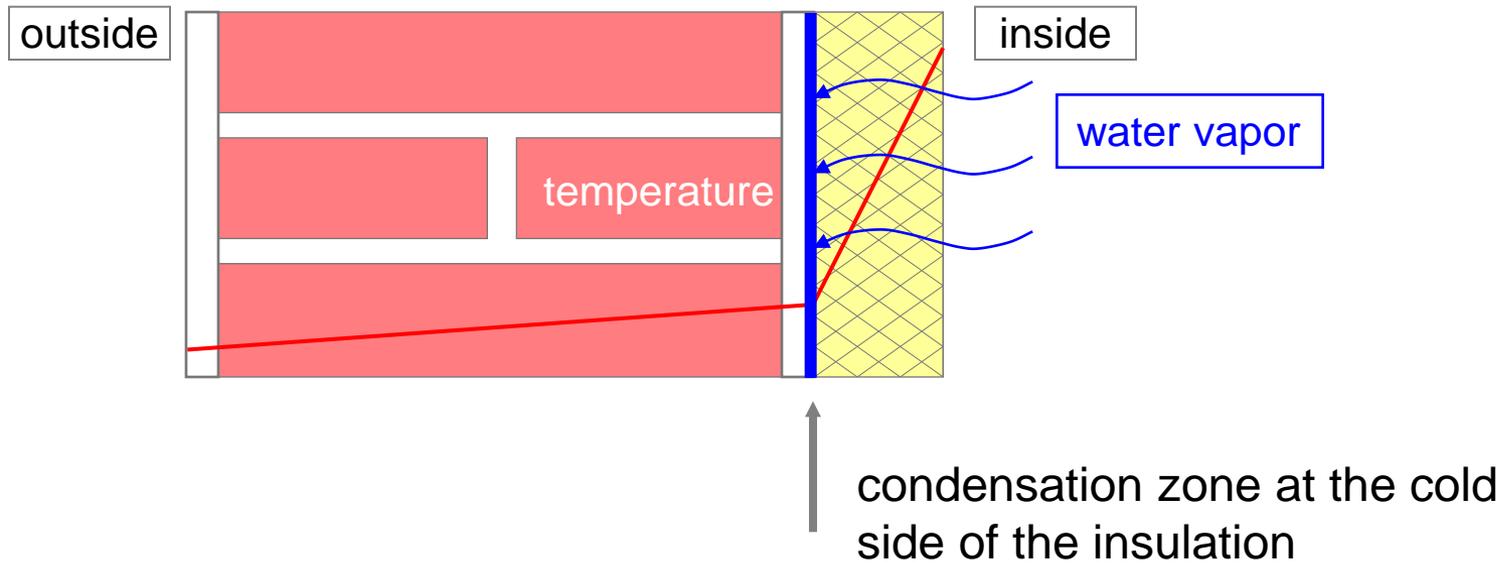


cellulose



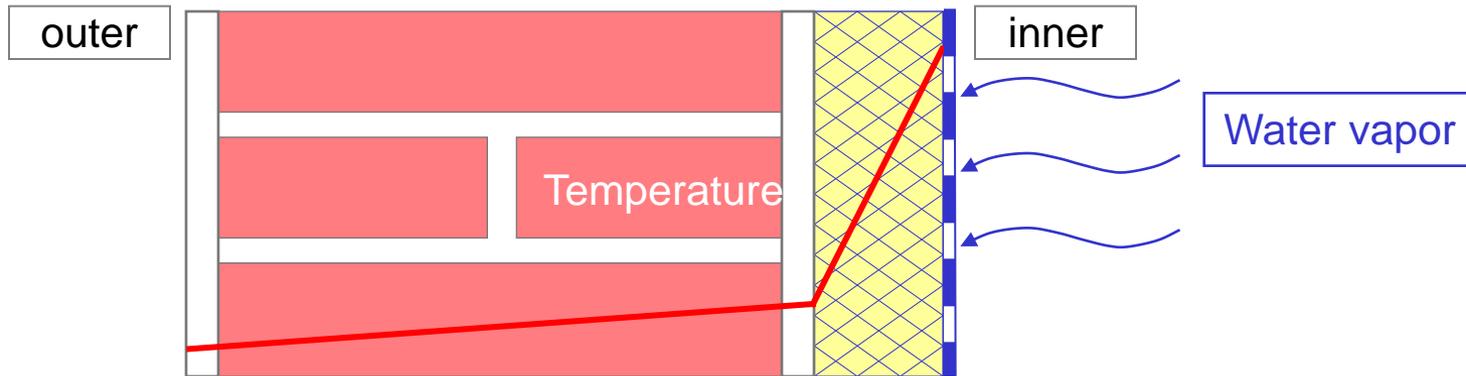
PUR

# Condensation caused by inside insulation



**2 different solutions**

## Inside insulation vapor tight



No condensation, if membrane is tight  
(long life functioning required)

### Example for tight systems:

#### Mineral composed having foil or tight

- Mineral wool  $\lambda \sim 0.04$  W/mK
- foam glass  $\lambda \sim 0.045$  W/mK

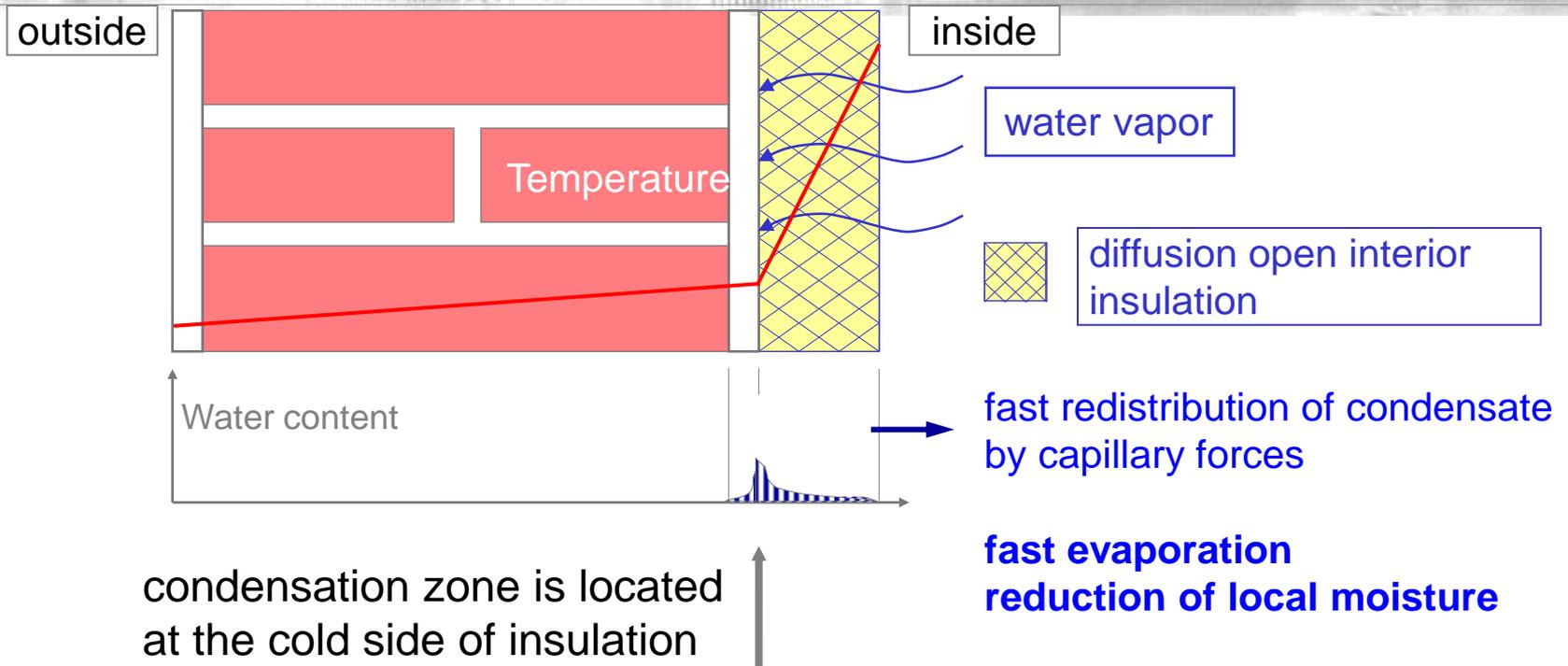
#### Organic composed having foil

- styrofoam  $\lambda \sim 0.04$  W/mK
- Cellulose, wooden fibers  $\lambda \sim 0.04$  W/mK

#### Design Systems

- Vacuum pannel  $\lambda \sim 0.008$  W/mK
- Mineral wool + pyrogen silicat acid  $\lambda \sim 0.02$  W/mK

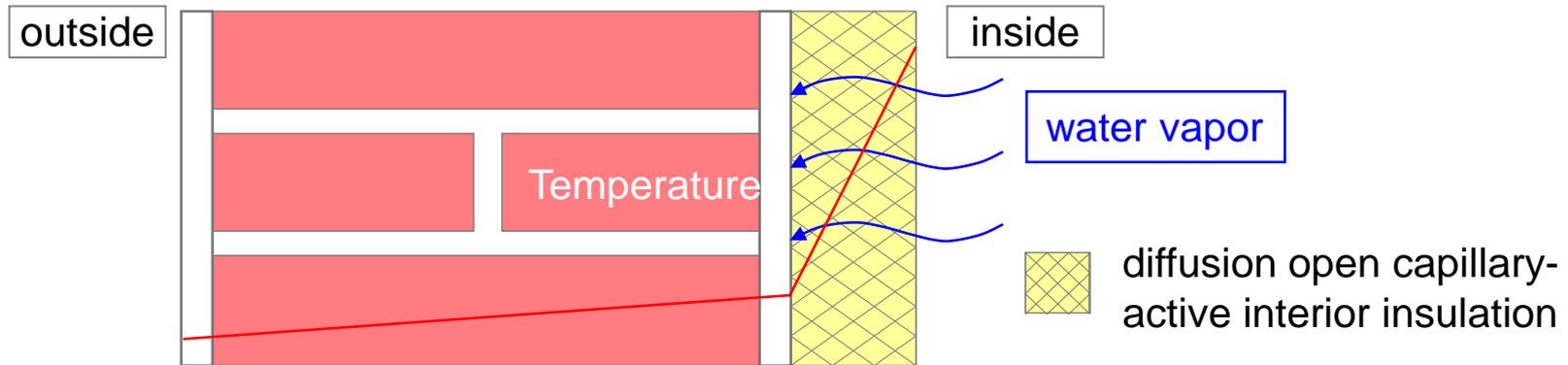
# Diffusion open inside insulation with capillary distribution



## multi functional material properties

- + good insulation
- + proper moisture buffer, room climatisation
- + large drying potential,  
reduction of freezing damages
- + resistance against mould
- + fire protection, noise transmission reduction, ...

# Diffusion open inside insulation with capillary distribution



## Mineral composed

- calcium silicate climate board  $\lambda \sim 0.06 - 0.09 \text{ W/mK}$
- mineral foam  $\lambda \sim 0.04 - 0.045 \text{ W/mK}$
- perlite board  $\lambda \sim 0.045 - 0.055 \text{ W/mK}$

## composits

- insulation plaster  $\lambda = 0.06 - 0.1 \text{ W/mK}$

## Organic composed

- insulation loam -cork  $\lambda \sim 0.08 \text{ W/mK}$
- wooden fiber board  $\lambda \sim 0.05 \text{ W/mK}$
- cellulose insulation plaster  $\lambda \sim 0.055 \text{ W/mK}$

## Design Systems

- PUR based iQ- Therm  $\lambda \sim 0.03 \text{ W/mK}$
- calcium silicate + pyrogen silicat acid  $\lambda \sim 0.03 \text{ W/mK}$

# Design and development of capillary active interior insulation

During the last 20 years ...

- 1990 → Idea and research approach
- 1995 → Application and test houses
- 2000 → Research projects material optimization
- since 2002 → Application at cultural heritage buildings



Rijksmuseum Amsterdam

mediation plaster, iQ-Therm  
board, iQ-Therm system, on-spray  
cellulose plaster, ...

# Test house management: Wilhelminian style building in Dresden Calcium silicate climate board (Calsitherm)



**interior insulation**

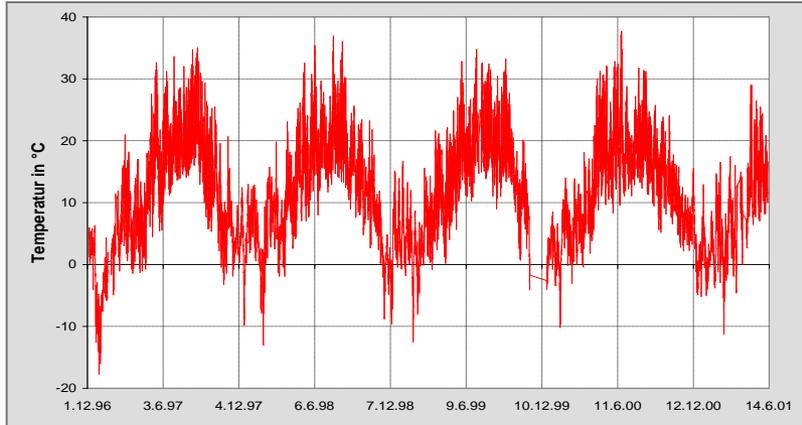


**meteriological station**

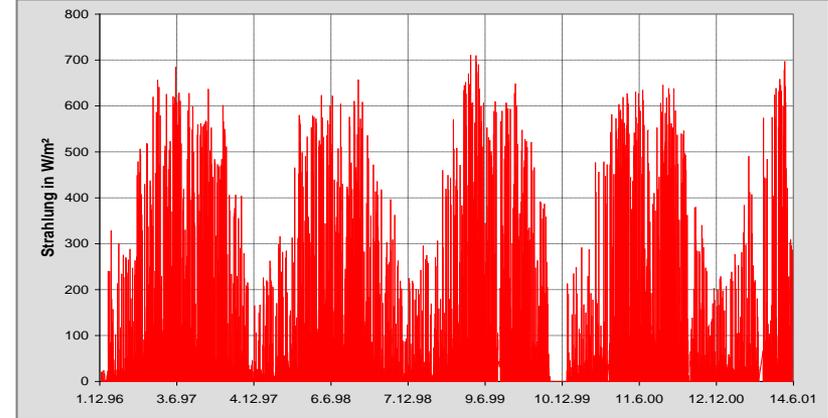


# Wilhelminian style building in Dresden: climate data (12/96 - 6/01)

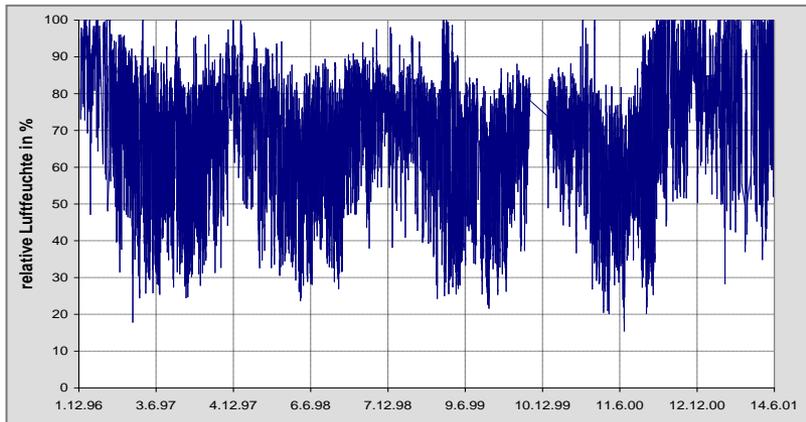
## temperature



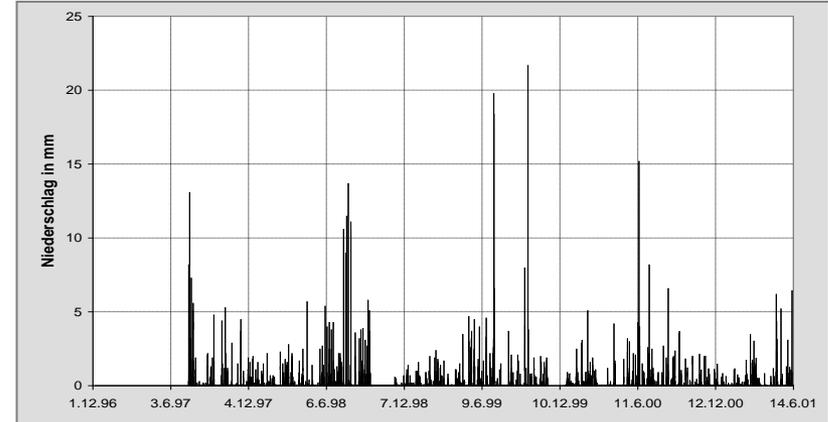
## radiation



## rel. humidity



## precipitation



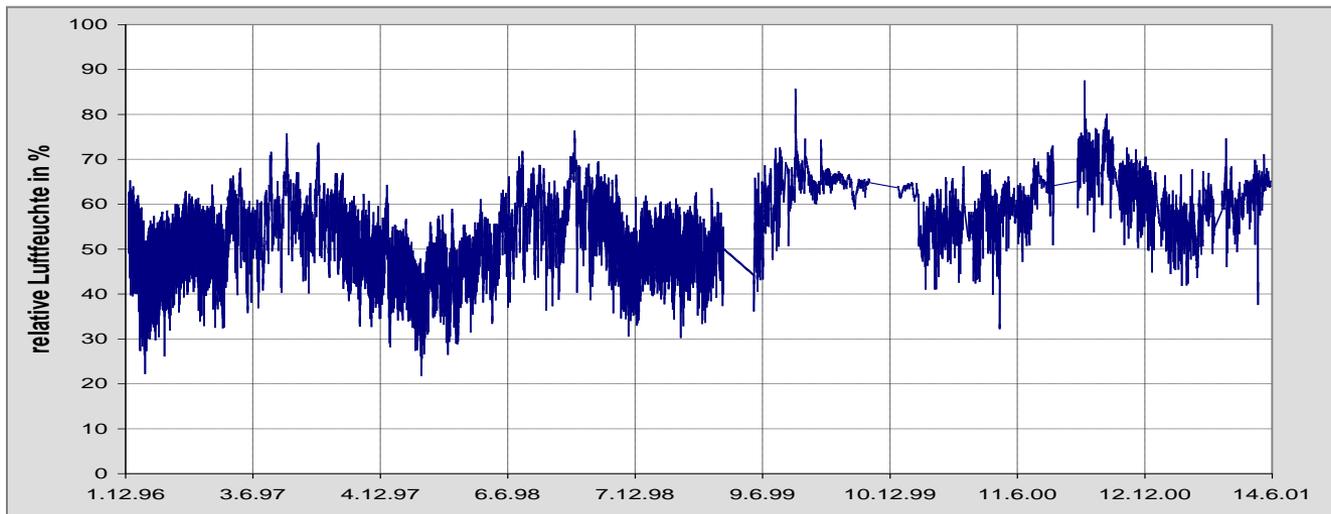
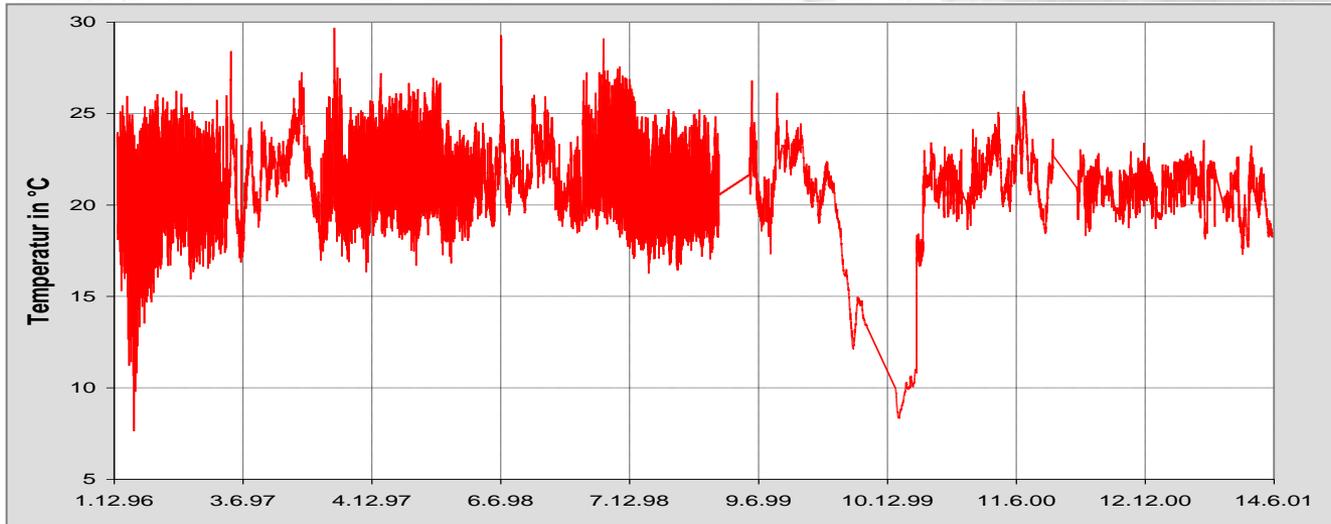
# Wilhelminian style building in Dresden: interior climate data (12/96 - 6/01)



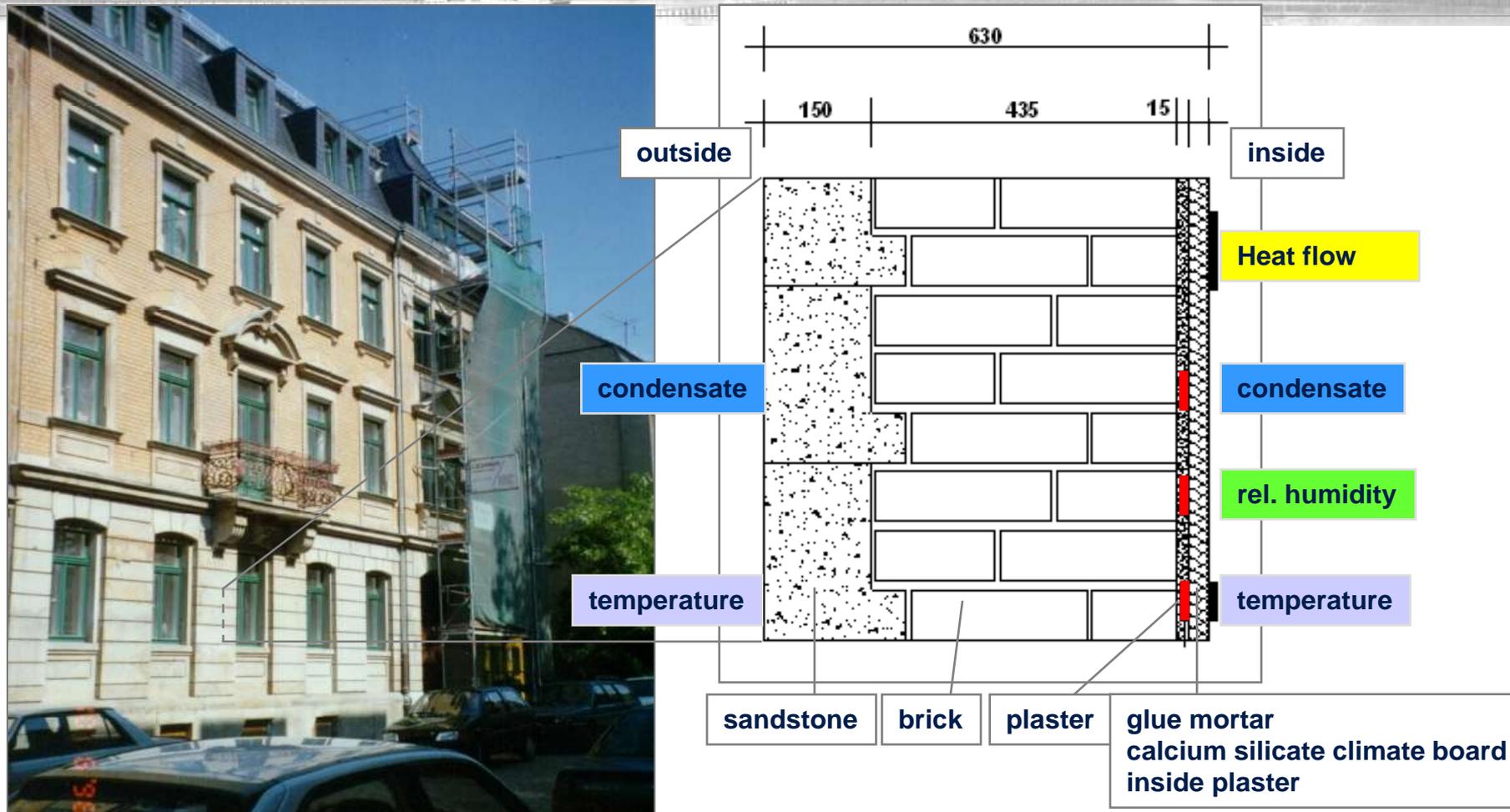
indoor  
temperature

indoor rel.  
humidity

12/96 - 06/01

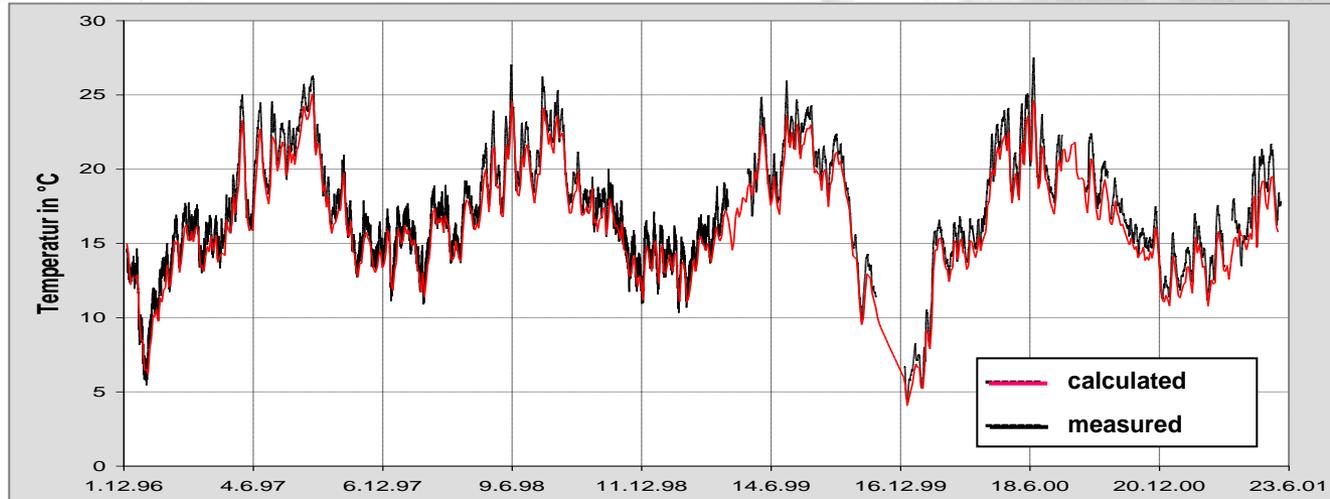


# Wilhelminian style building in Dresden: monitoring points

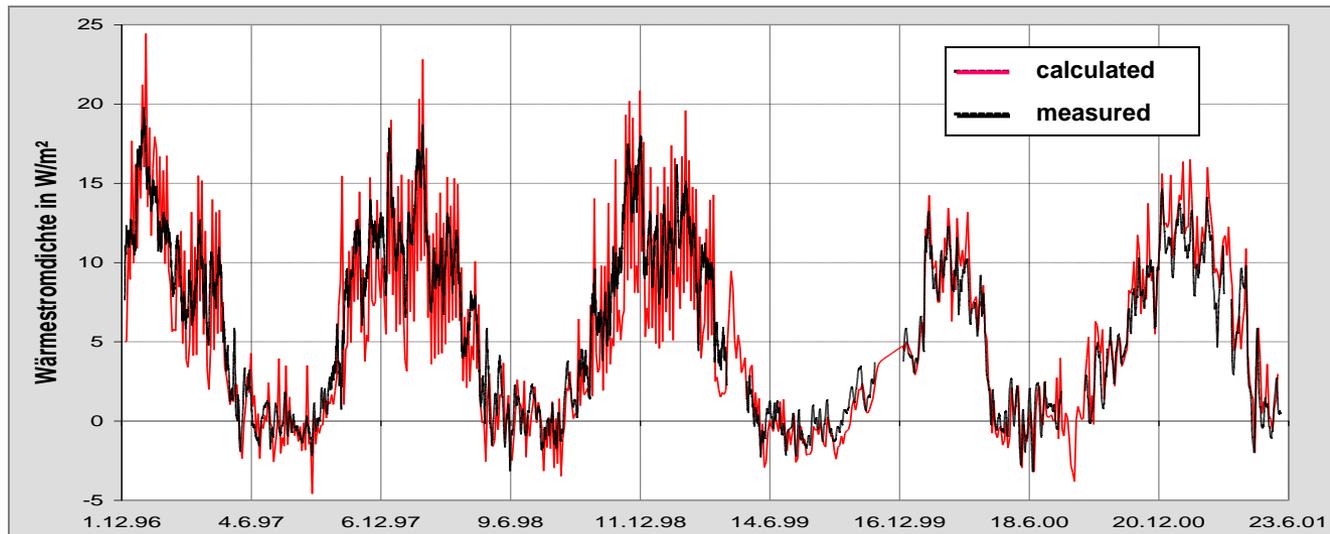


Wall profile and position of monitoring points in the basement

# Wilhelminian style building in Dresden: comparison of measurement and calculation



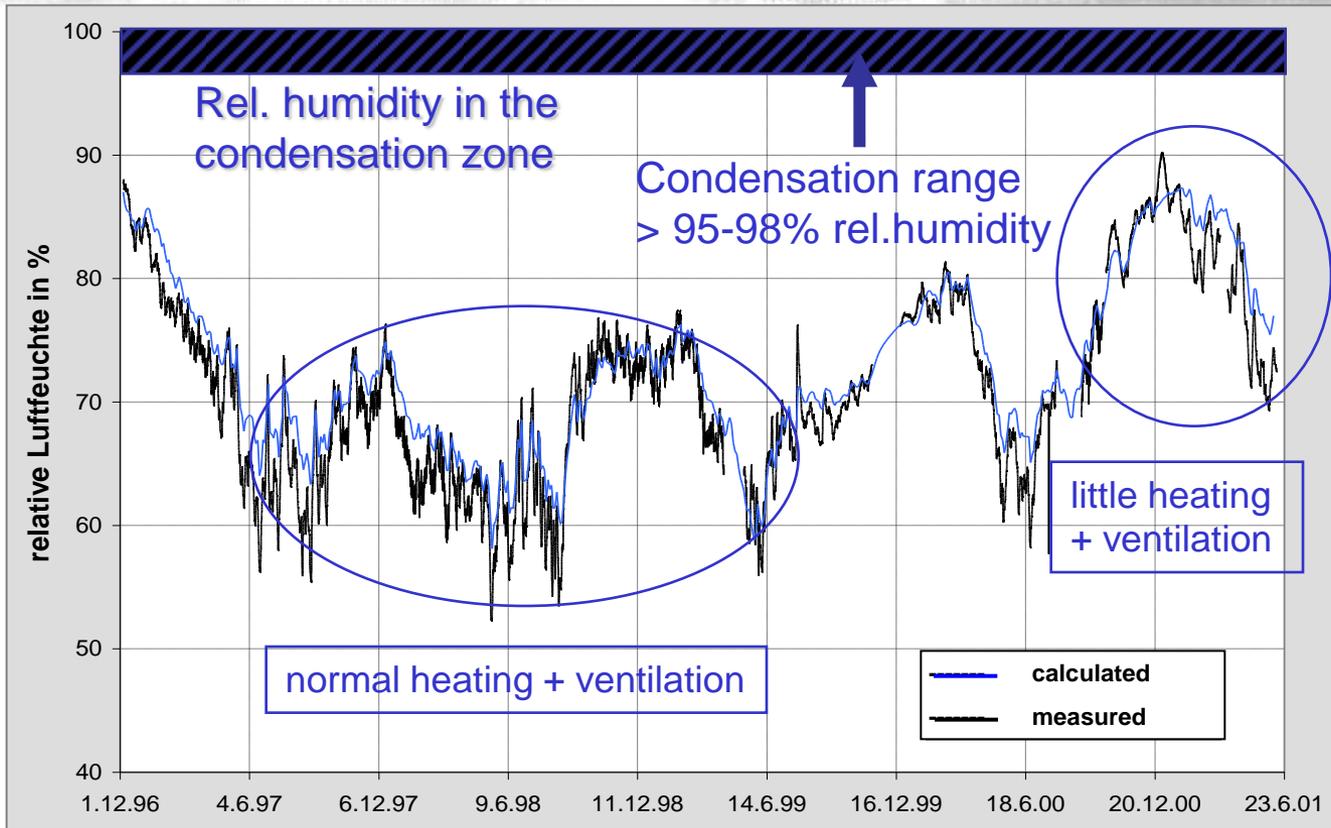
temperature  
cold side of  
insulation



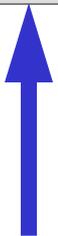
heat flow  
inside surface  
wall

12/96 - 06/01

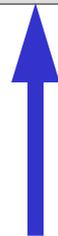
# Wilhelminian style building in Dresden: comparison of measurement and calculation



12/96 - 06/01

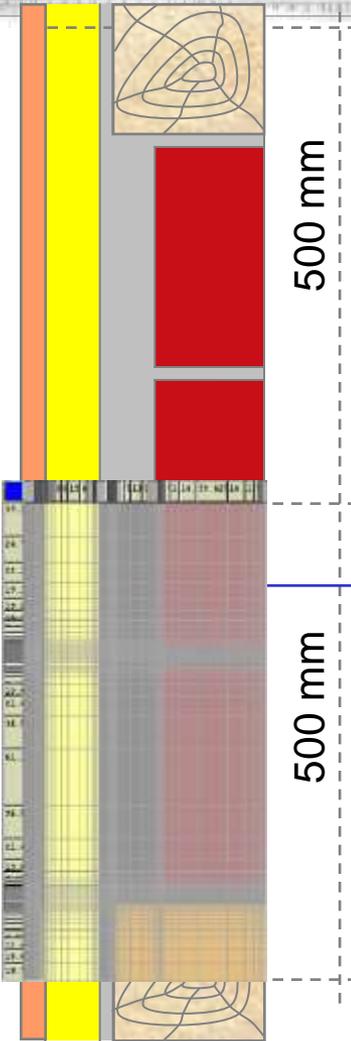


cold winter 1996



unoccupied 1999

inside



# Application Rijksmuseum Amsterdam



# Application Rijksmuseum Amsterdam: calcium silicate climate board (Calsitherm)

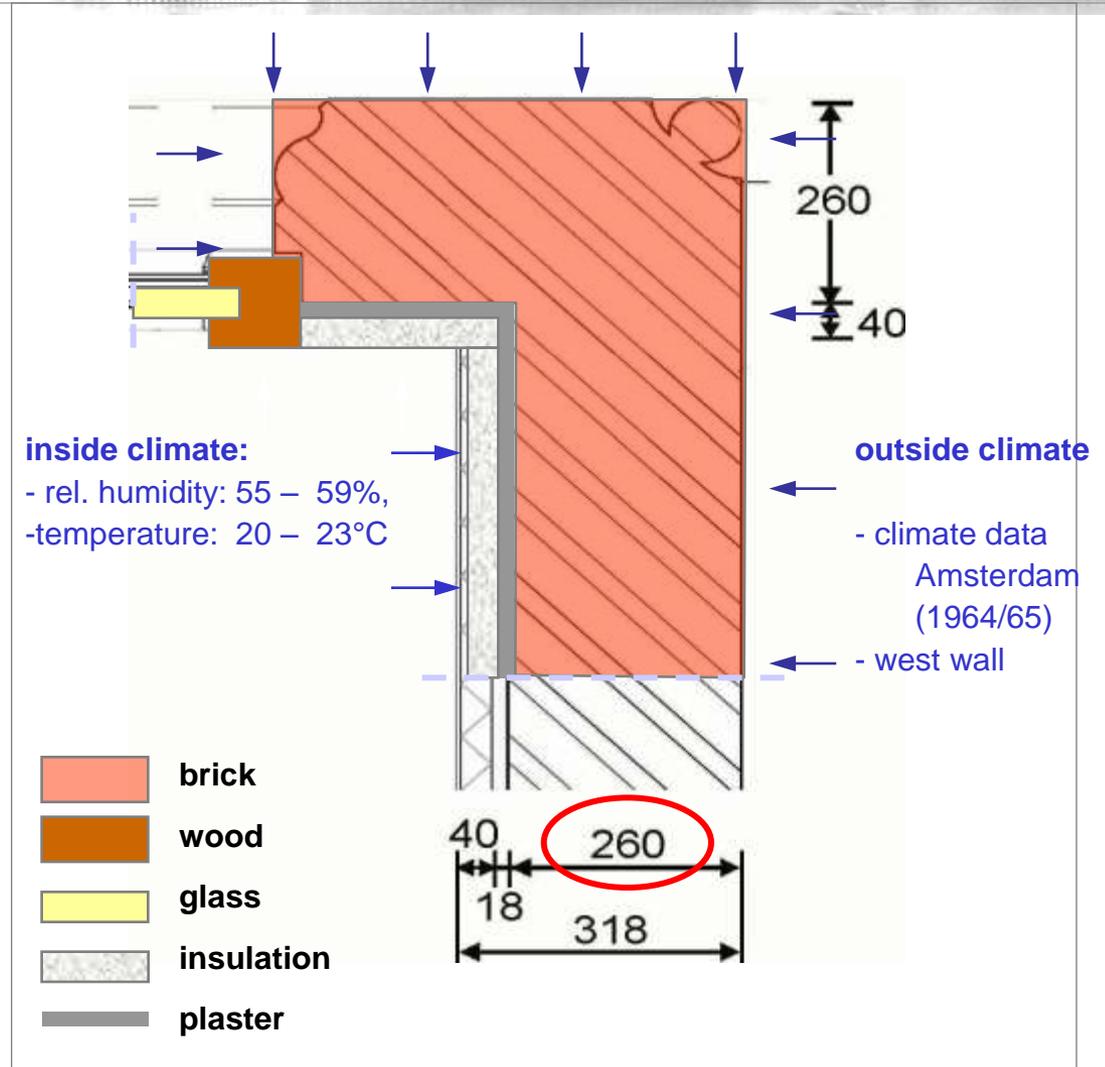
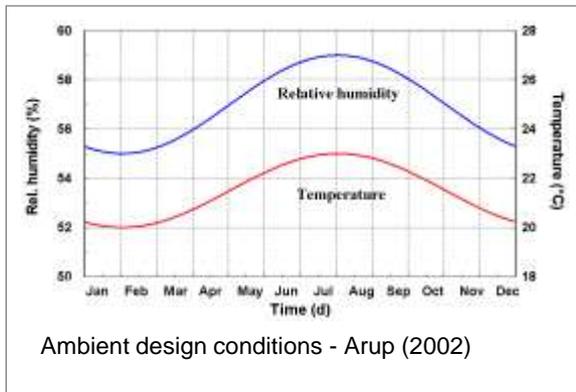
## Mansard:

thickness of brick wall is 260 mm!

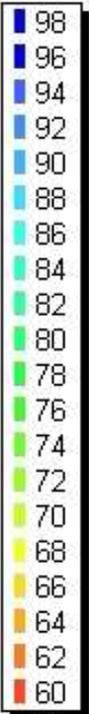
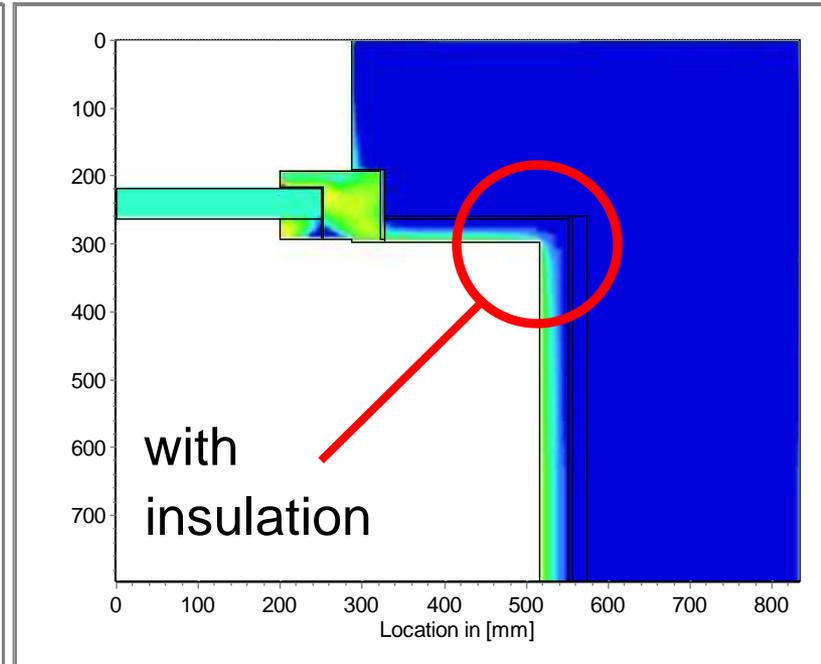
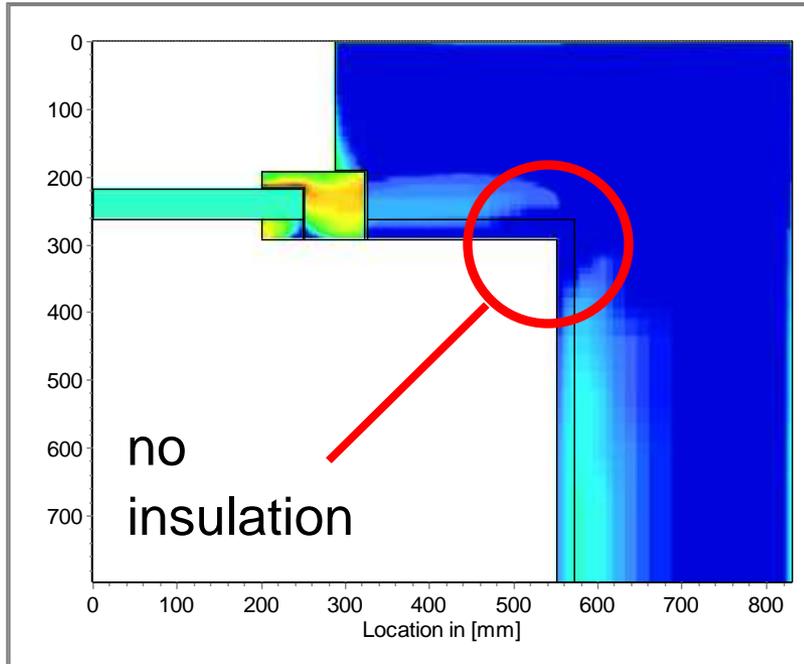
## numerical simulation:

geometry

boundary conditions



## Mansarde:



Field of relative humidity:

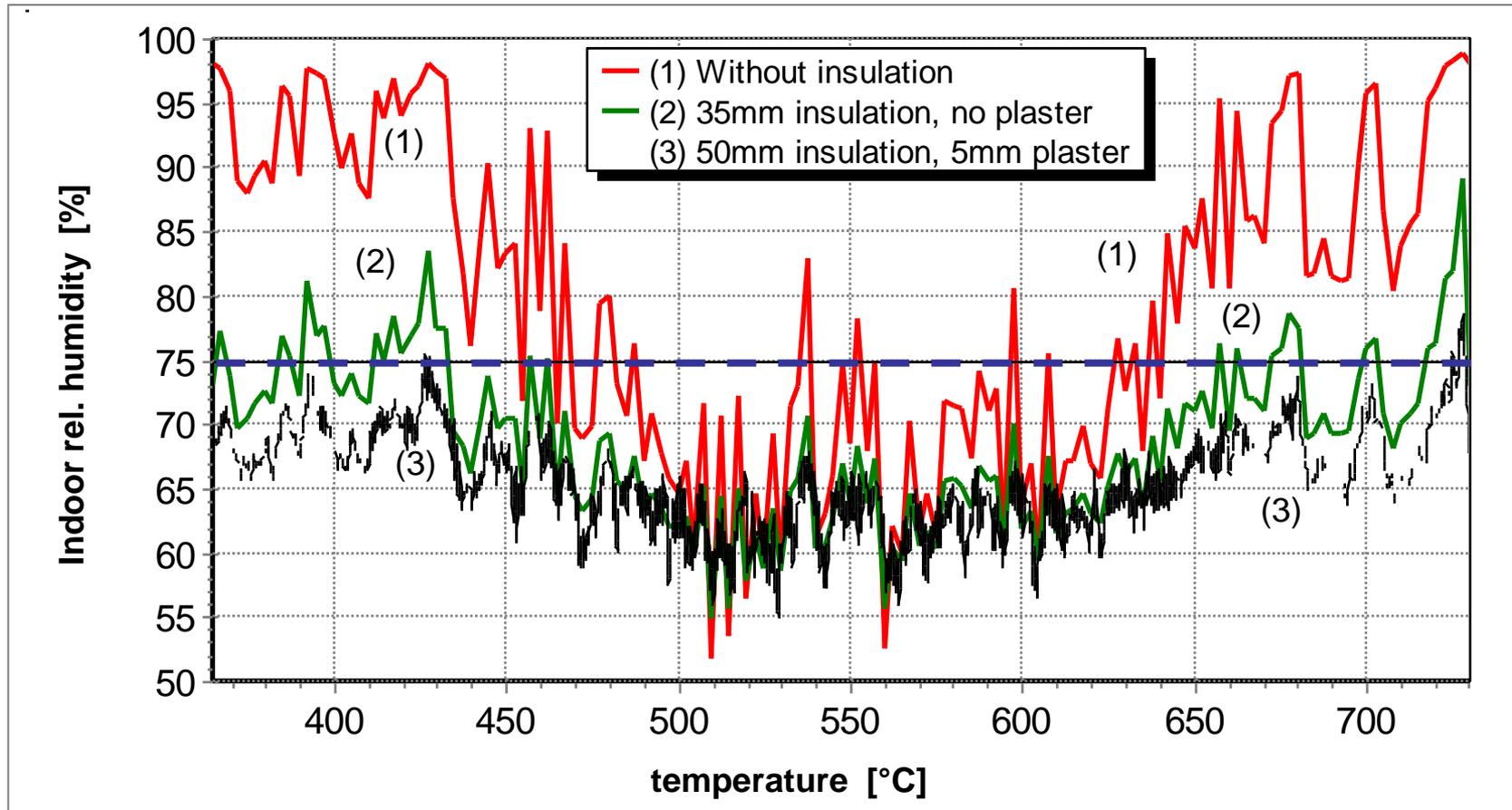
begin of July

middle of Juli after a cloud burst

beginning of November (first cold snap)

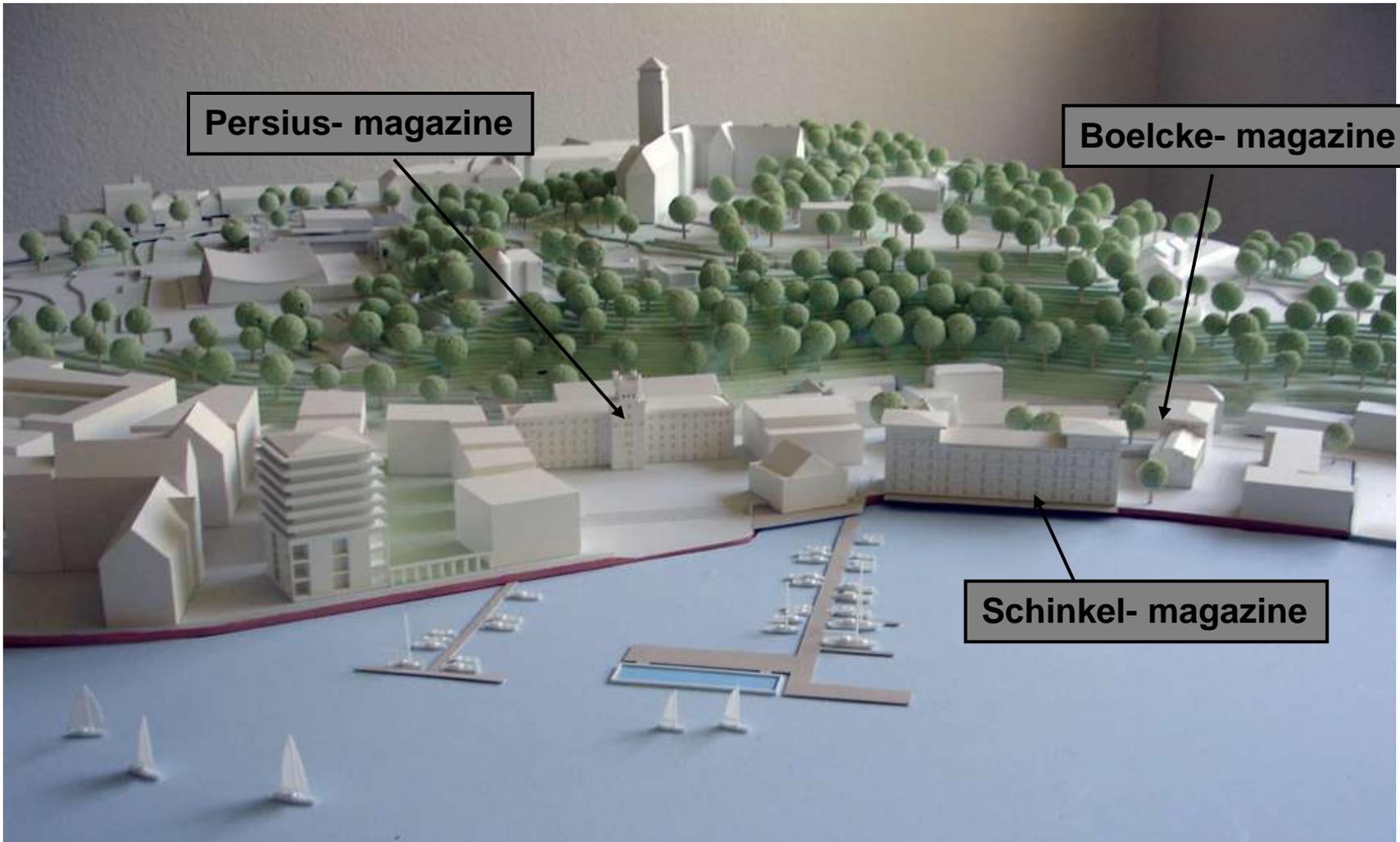
End of December

## Mansarde:



Course of rel. humidity in the 2. year without and having insulation

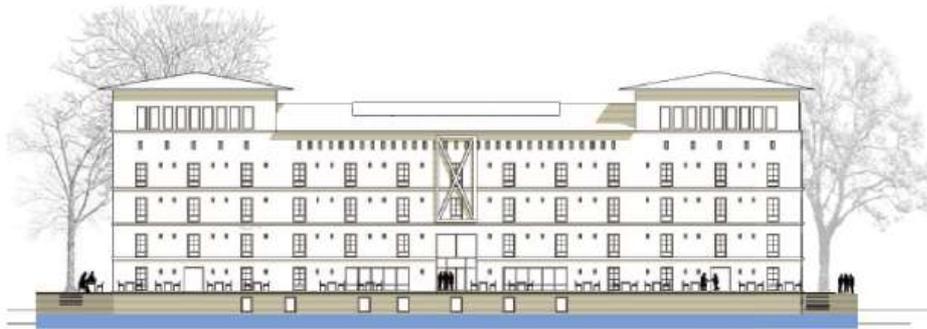
# The project „magazines Speicherstadt Potsdam“



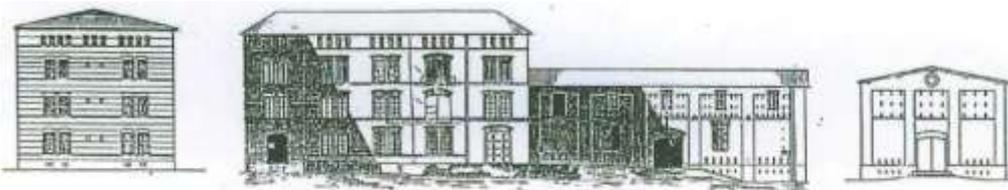
## The historical building ensemble



**Persius- magazine 1688 / 1843**  
flour magazine



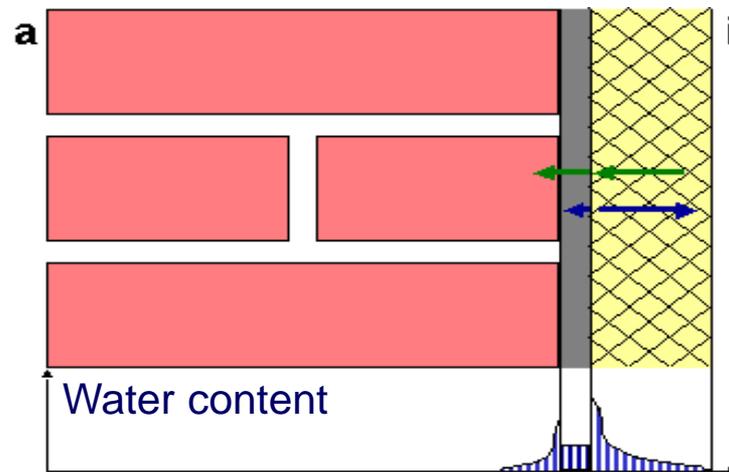
**Hampel and Schinkel-  
magazine 1834-36**  
cereal magazine



**Boelcke 1840 und 1847**  
oat- and roughage magazine

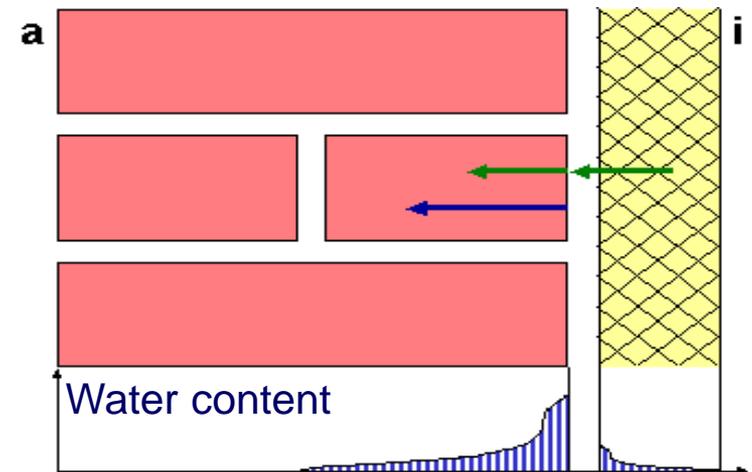
# Capillary contact between old construction and insulation

## Complete contact between insulation and wall

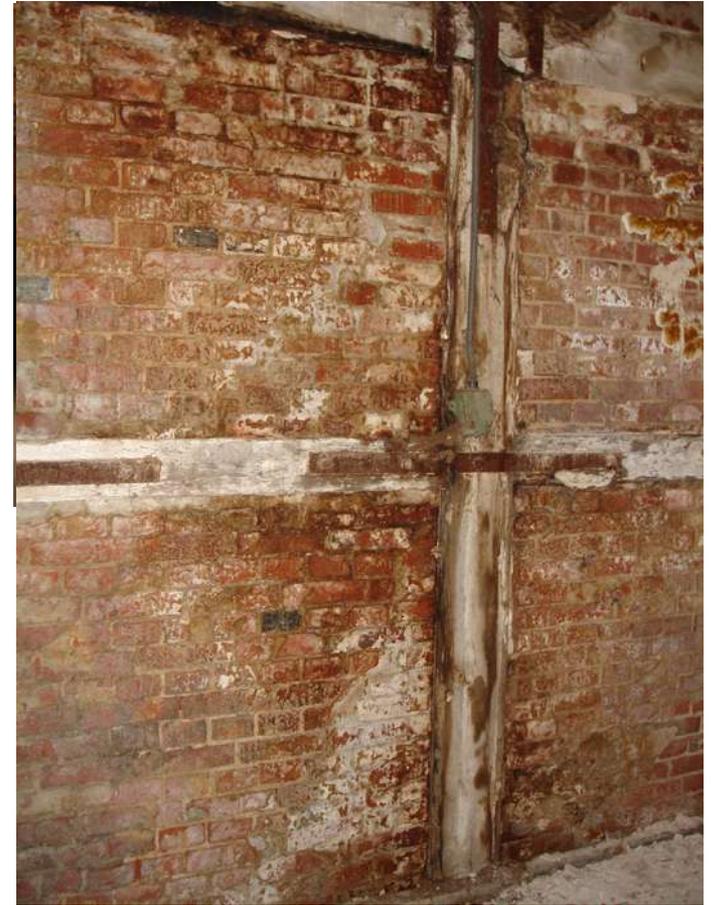


Capillary active insulation

## Air gap between insulation and wall



## Schinkelspeicher M3



## Interior insulation system: insulation loam cork

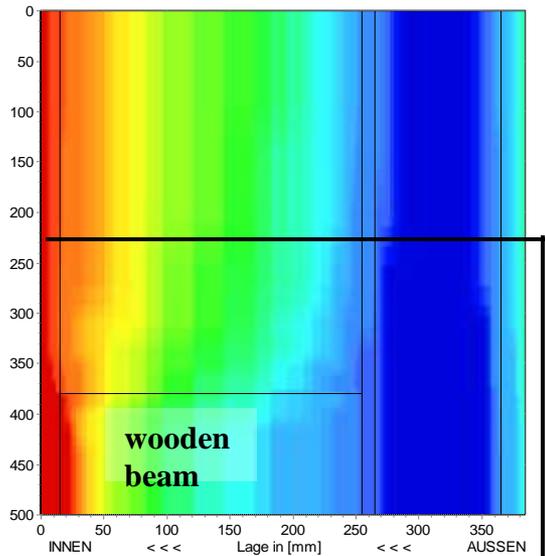


## Interior insulation system: insulation loam cork



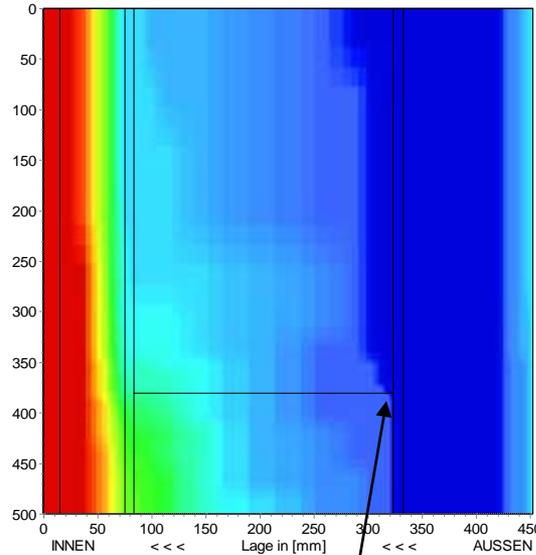
# Comparison of insulation loam cork without driving rain protection

no insulation



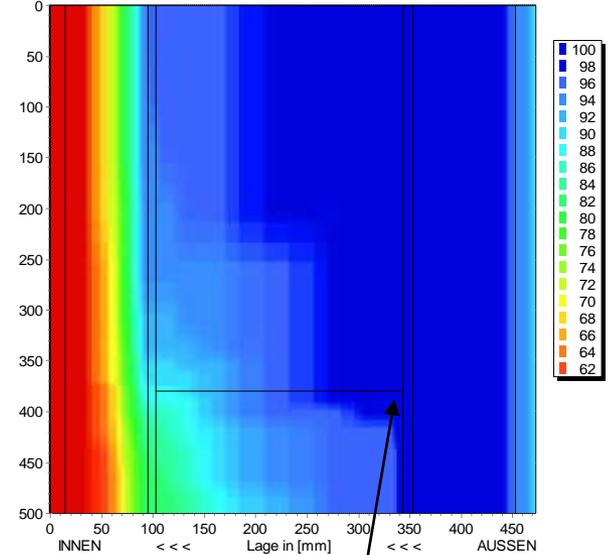
15 mm inside plaster  
 240 mm historic brick  
 10 mm historic mortar  
 120 mm historic outside brick

60mm WDL



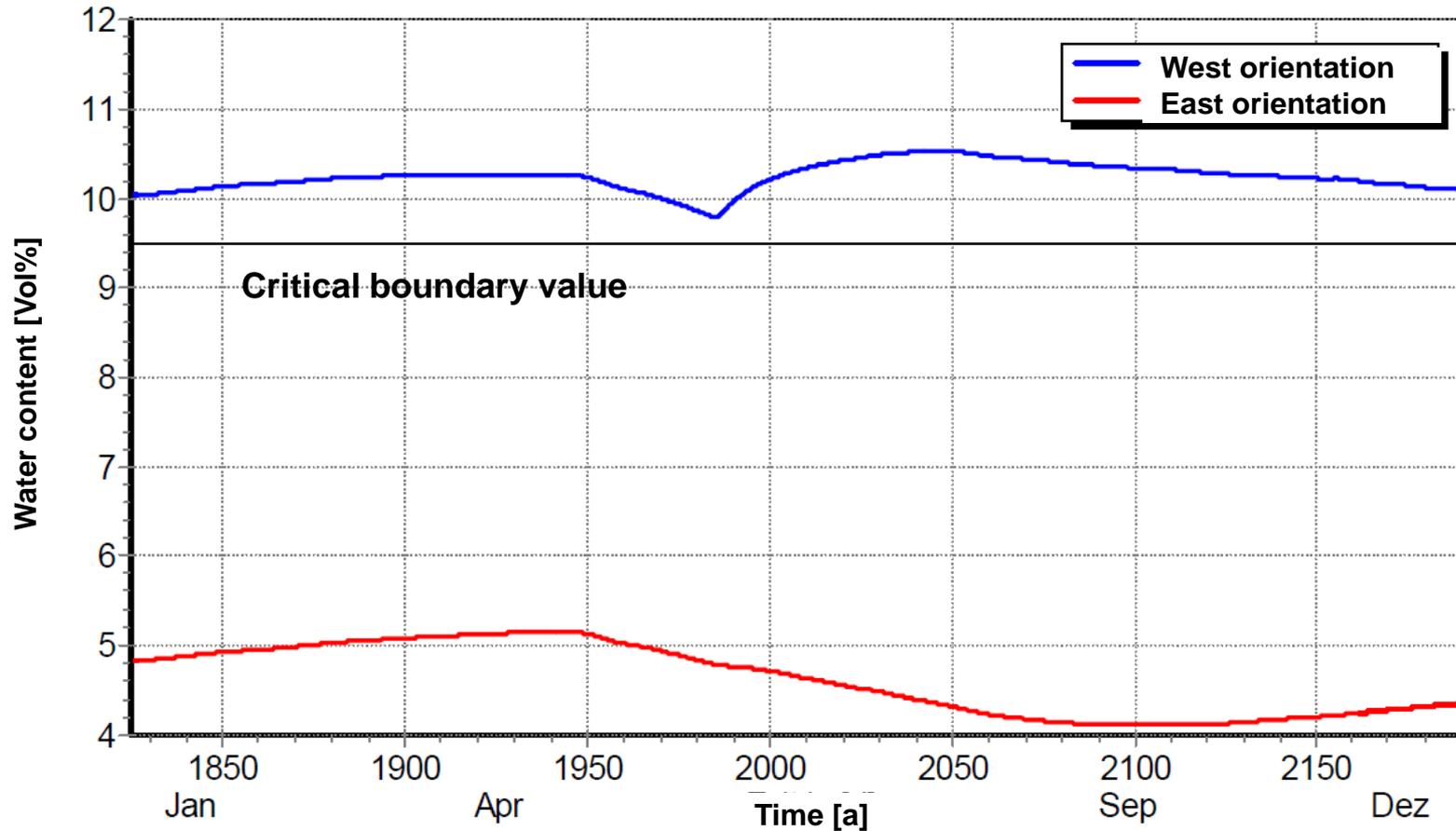
94% rH

80mm WDL



96% rH

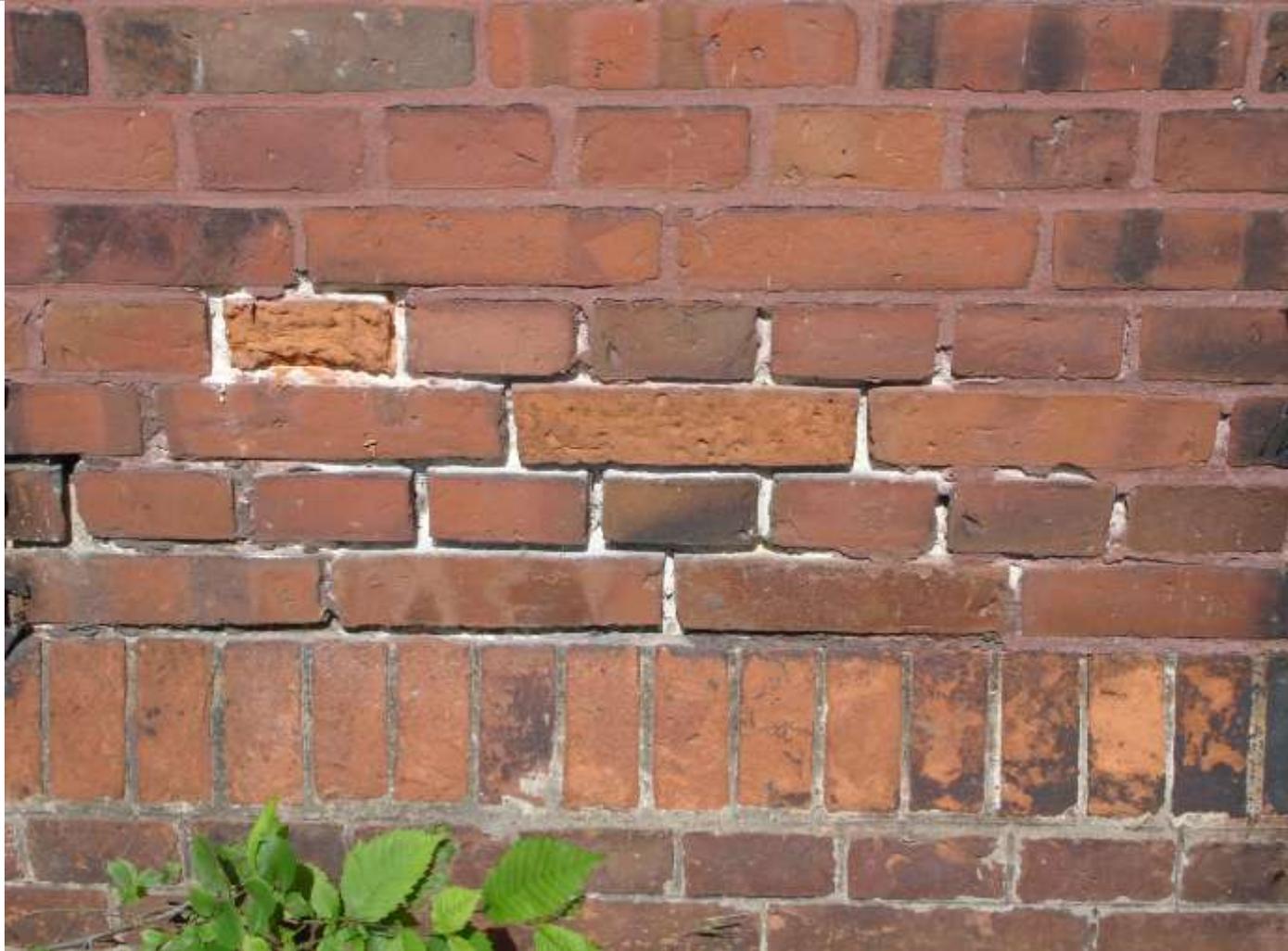
# Water content of wooden beam: west orientation, east orientation



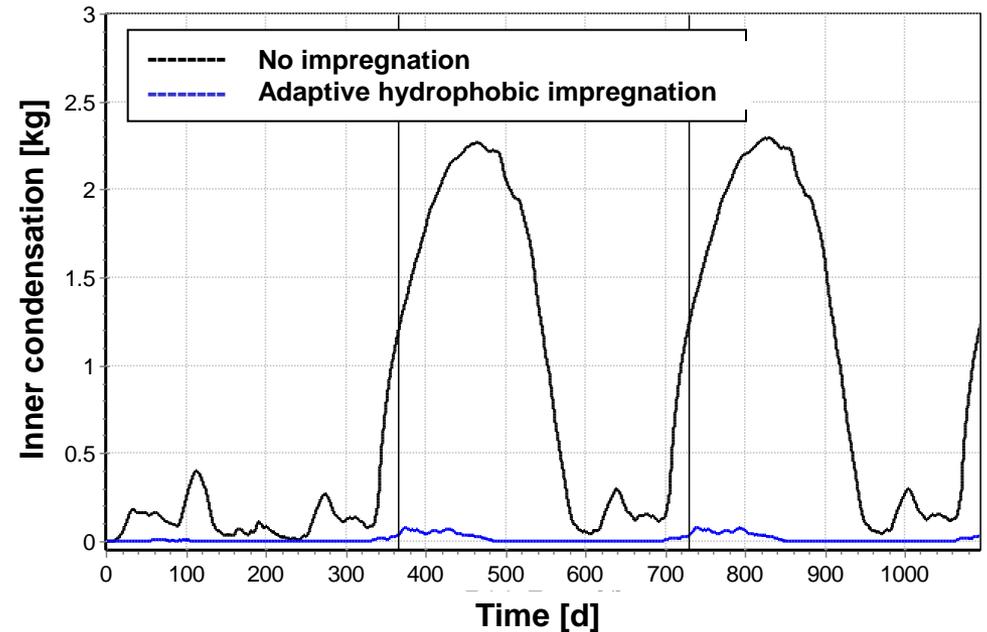
## Wall construction, driving rain protection



## Problem case mortar joints

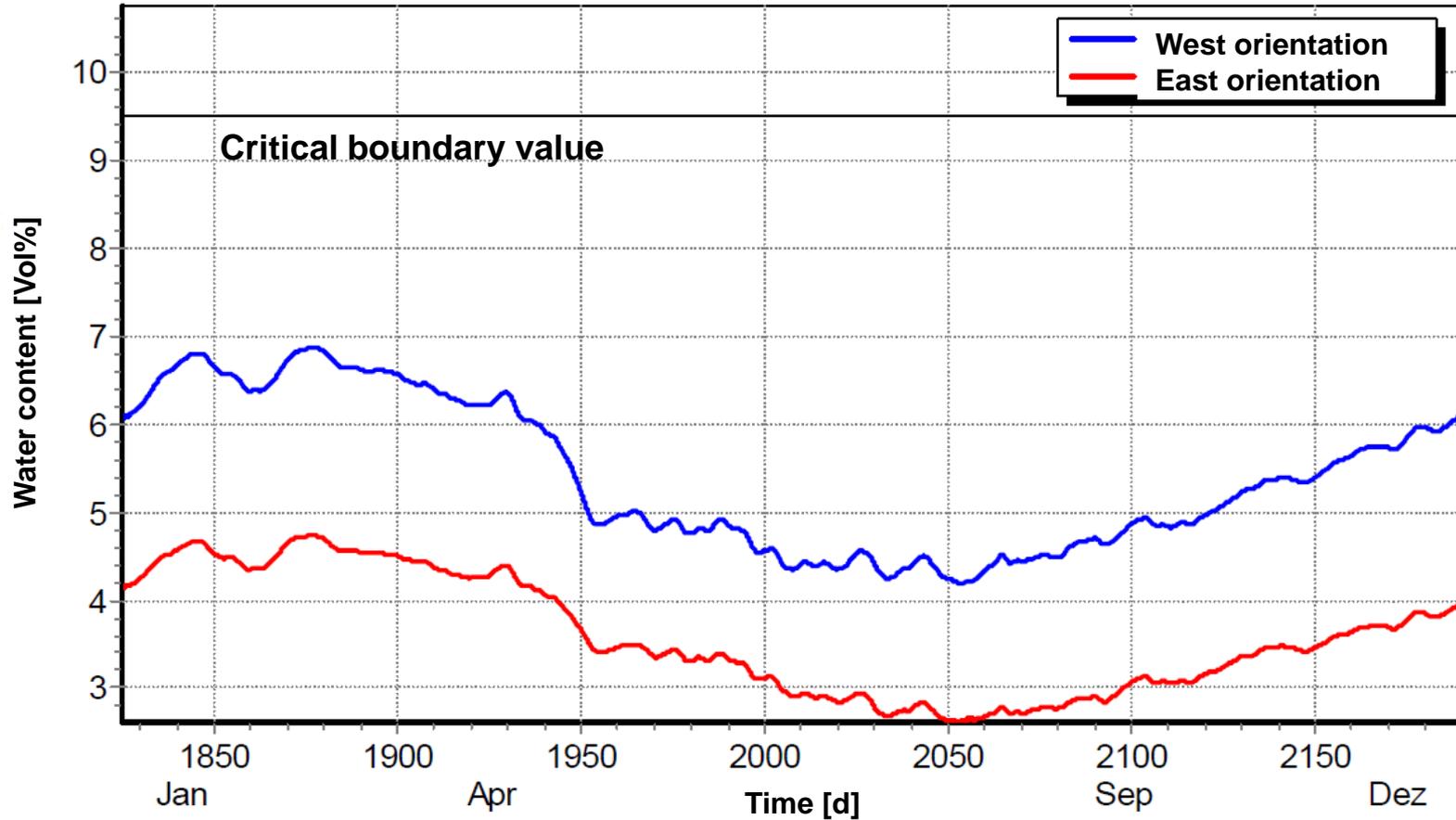


# Driving rain protection: Adaptive hydrophobic impregnation

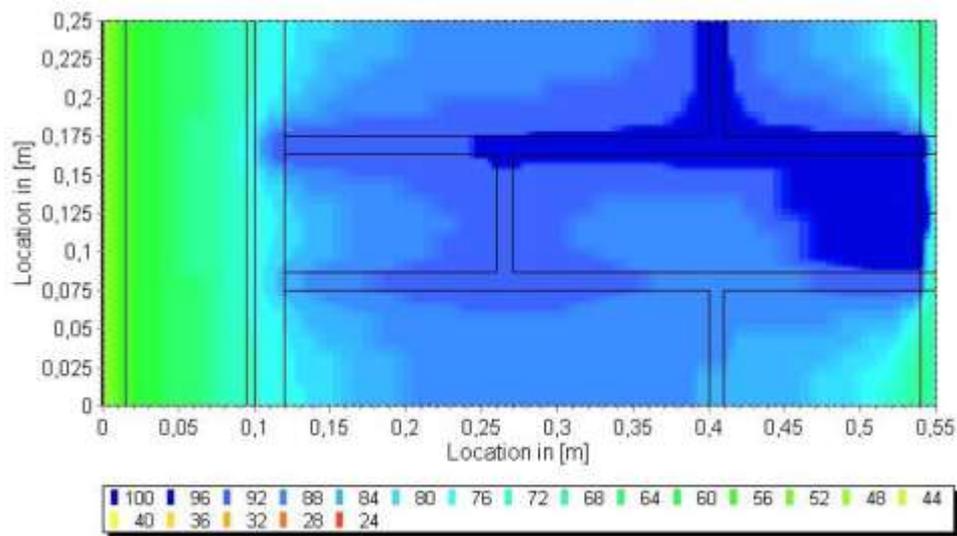


- confident function and durable driving rain protection,
- homogenous infiltration by application > 7mm, here up to 15mm depth,
- applicable on slight moist surfaces → emulsion cream
- keeping drying potential, → no reduction of water vapor transport
- no visual effects after application

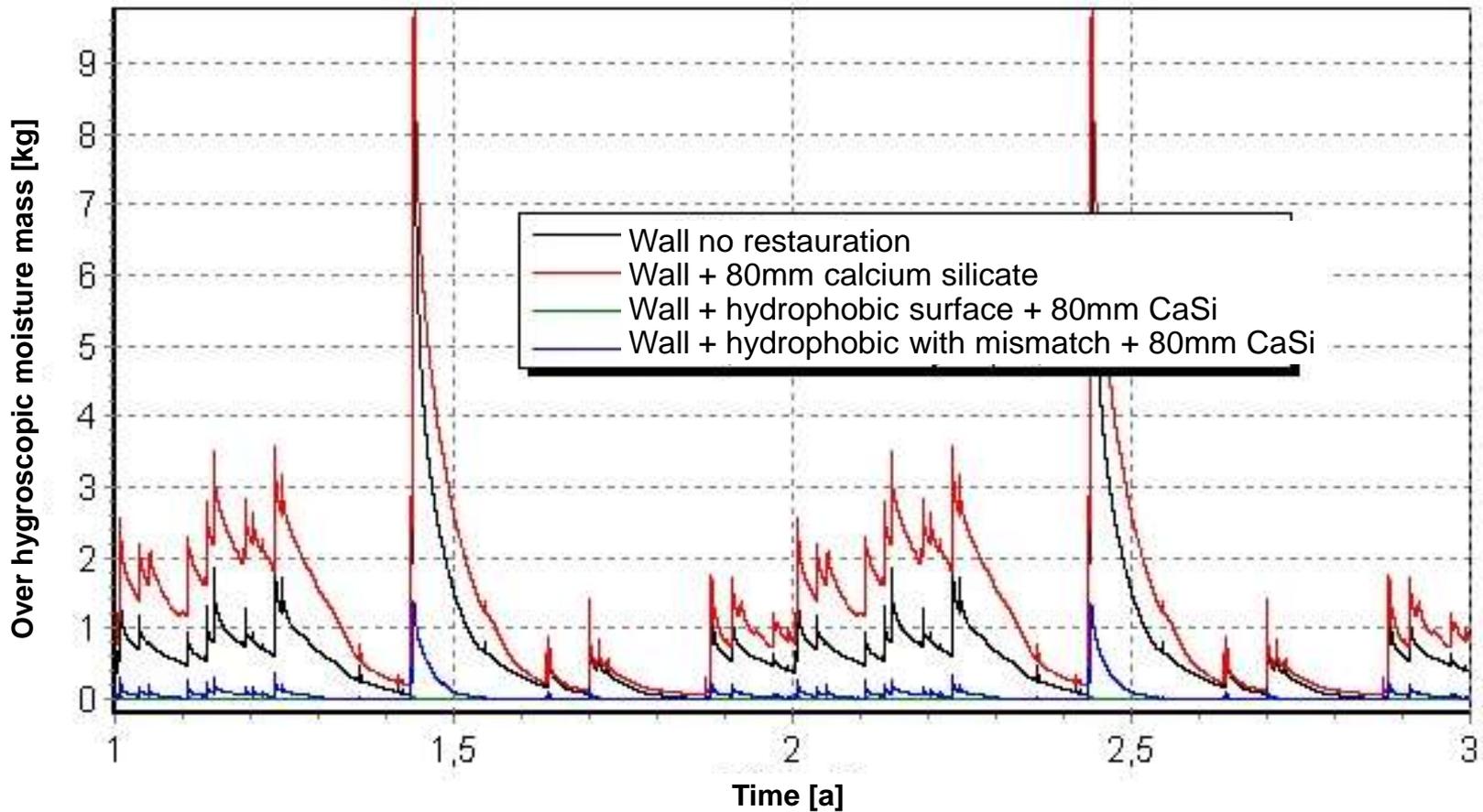
# Water content of wooden beam: west orientation, east orientation



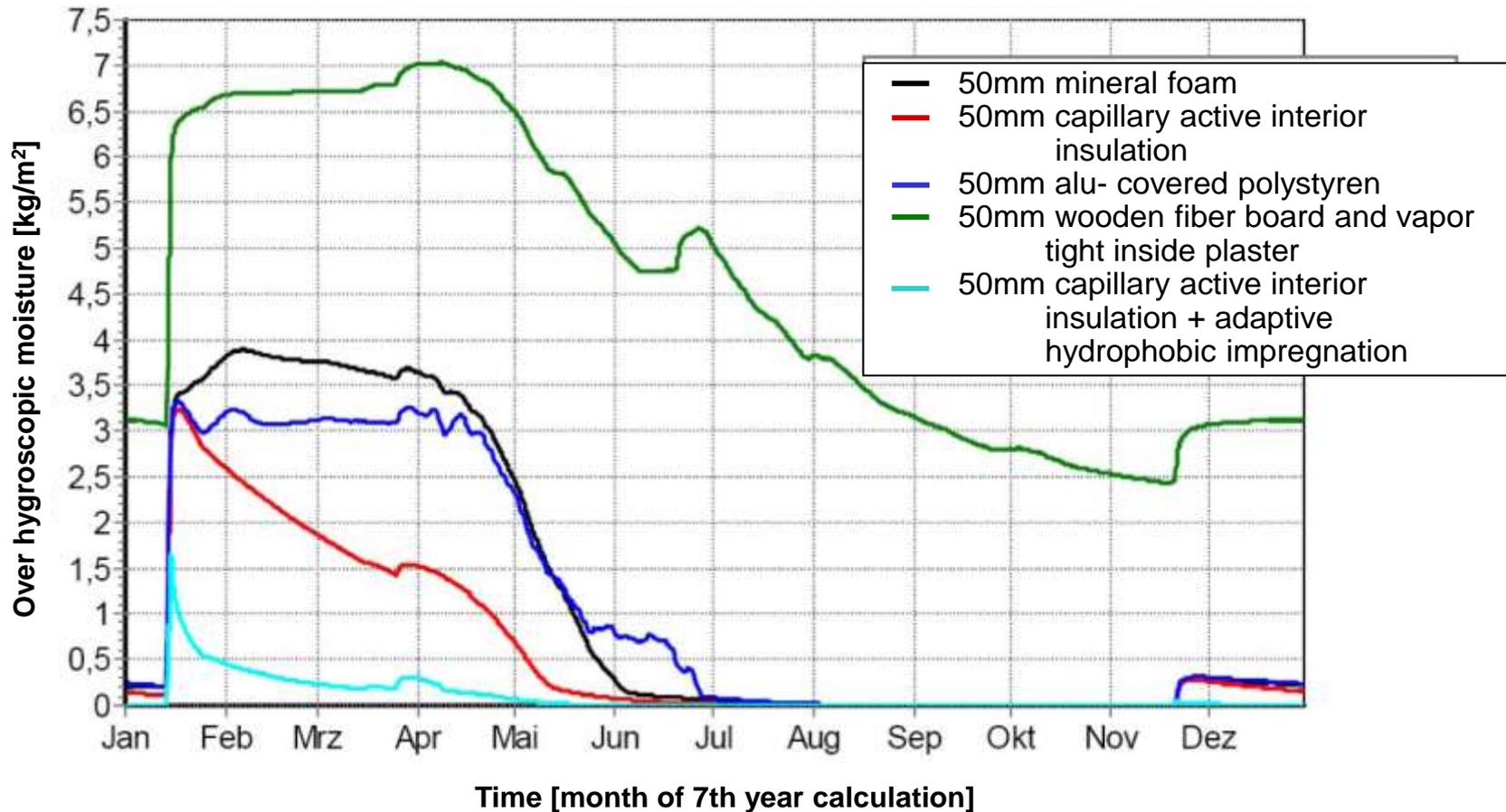
# Hydrophobic impregnation having mismatches for 80mm interior insulation



# Hydrophobic impregnation having mismatches



# Effect of driving rain, a comparison



# „Am Urban“, a city rehabilitation in Berlin Kreuzberg

west



north



east



south



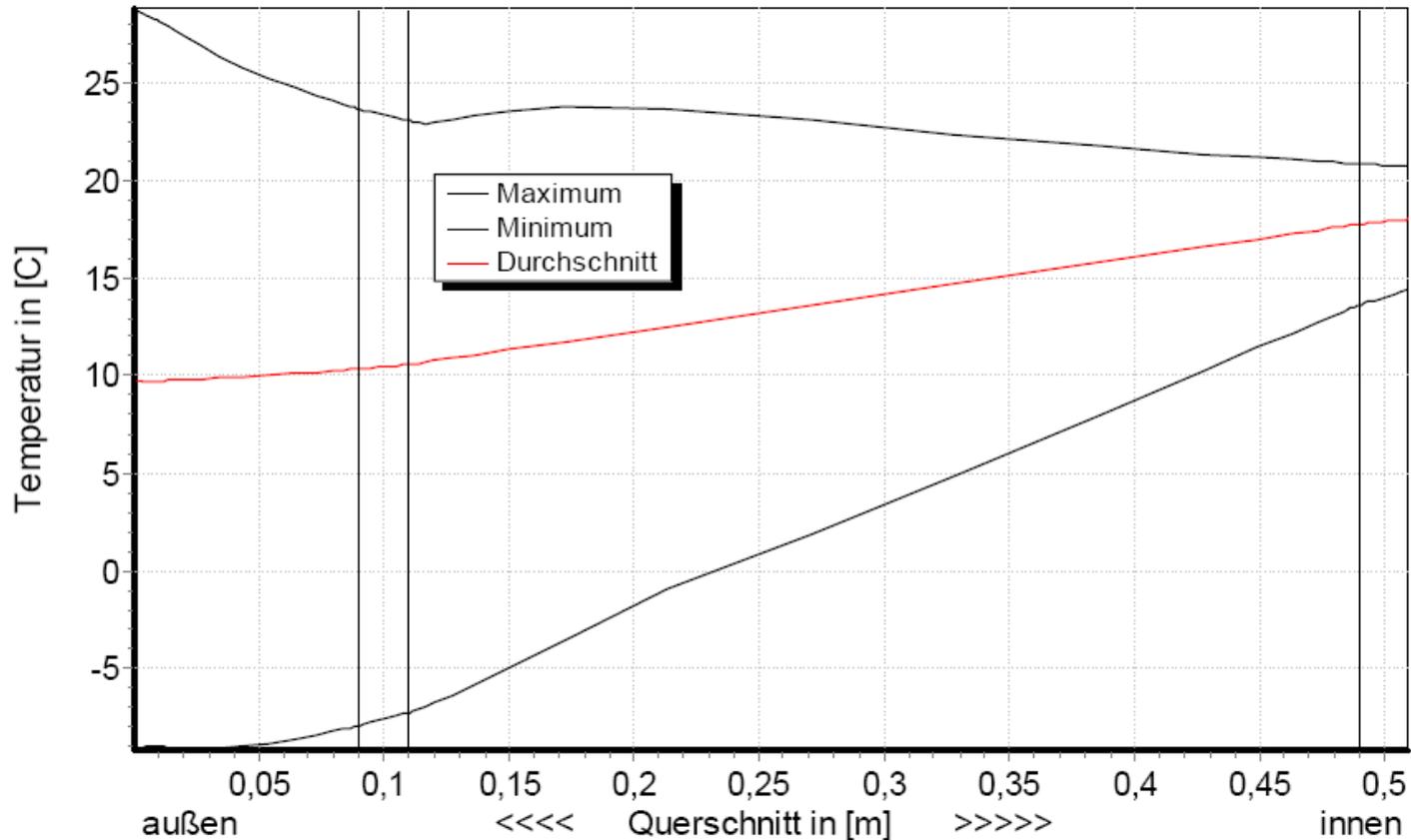
# „Am Urban“, a city rehabilitation in Berlin Kreuzberg



## hard brick type

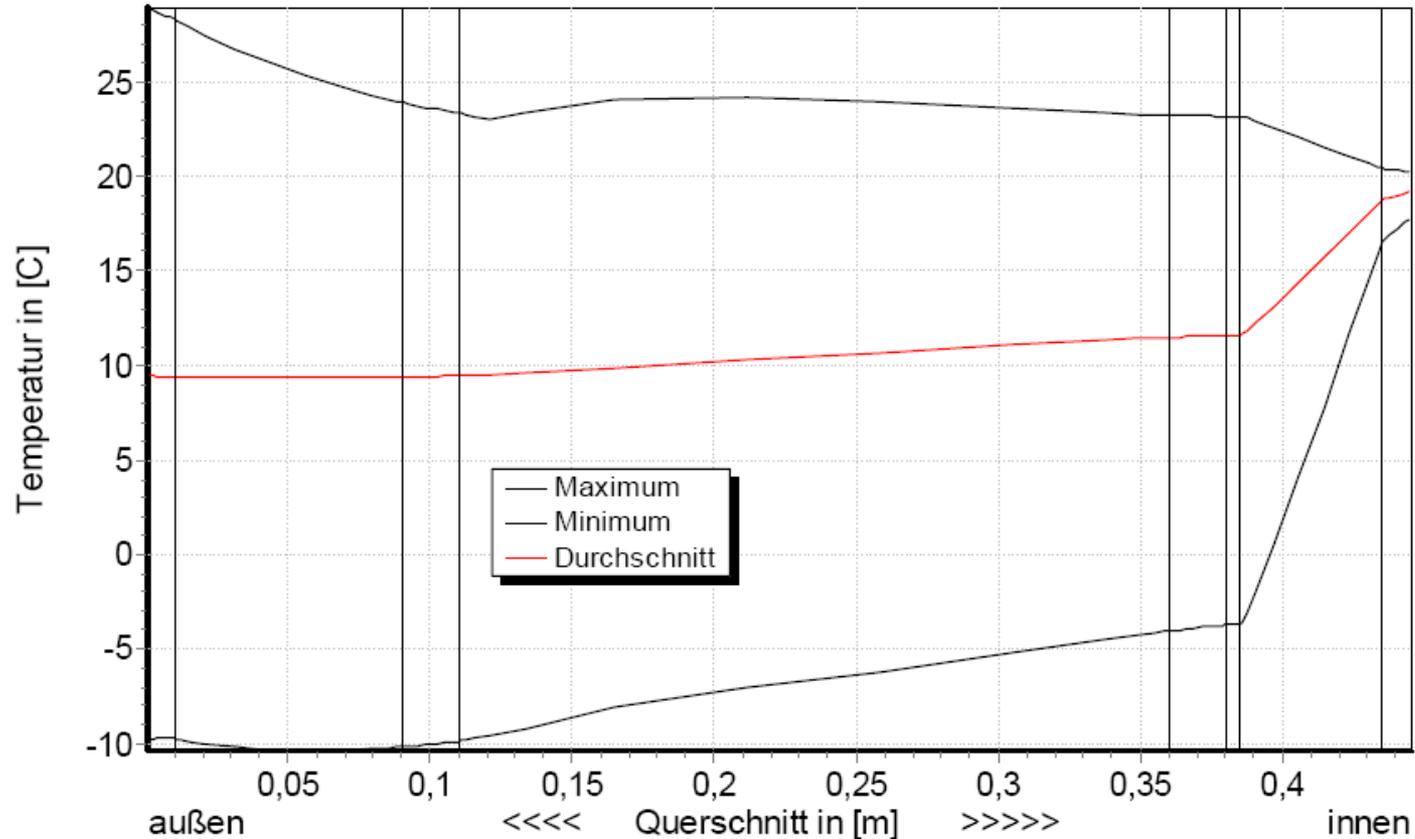


# Analysis of historic construction



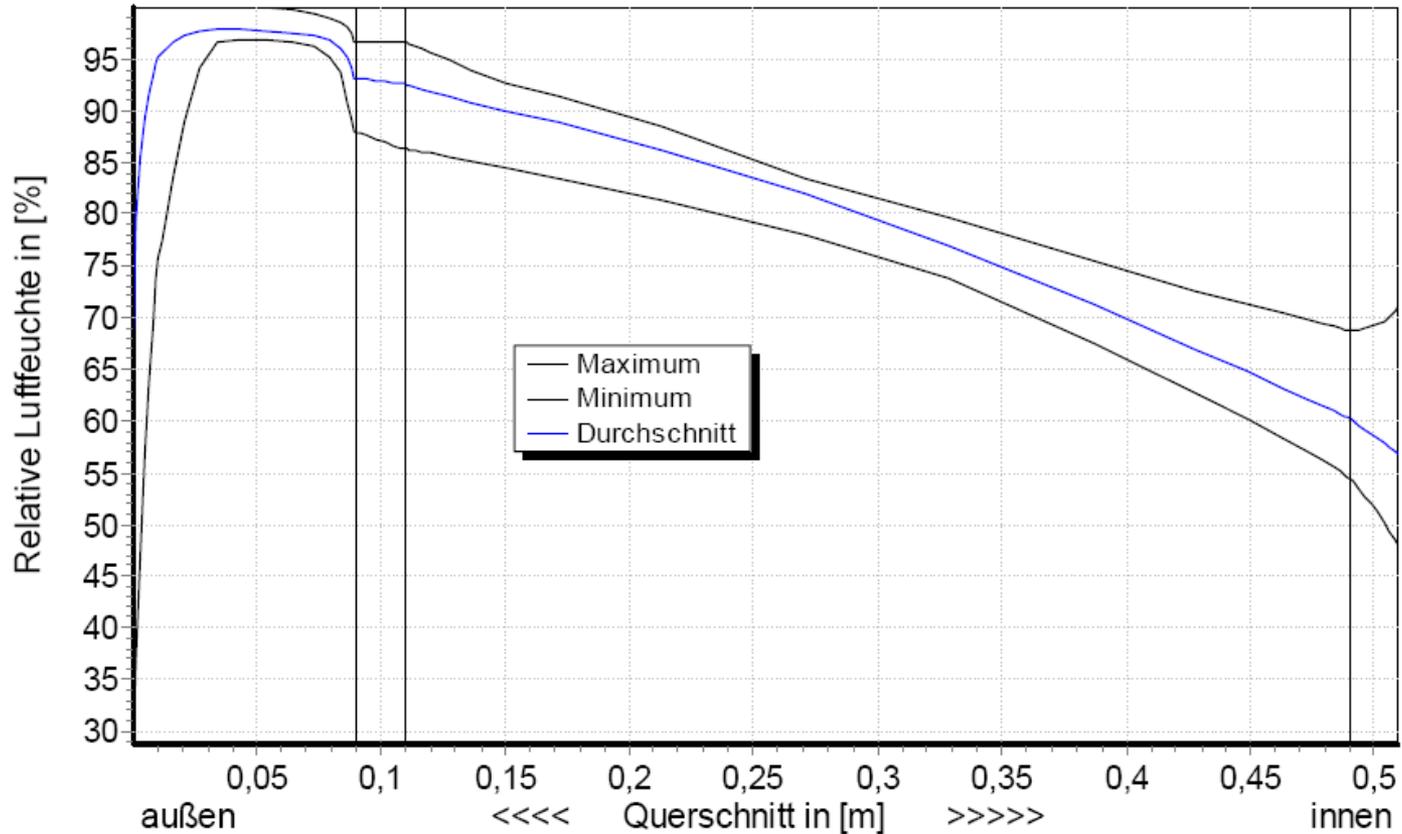
Characteristic temperature profile: outer brick wall 51 cm thickness without hydrophobic impregnation of the facade (TRY Potsdam)

# Analysis of refurbished construction



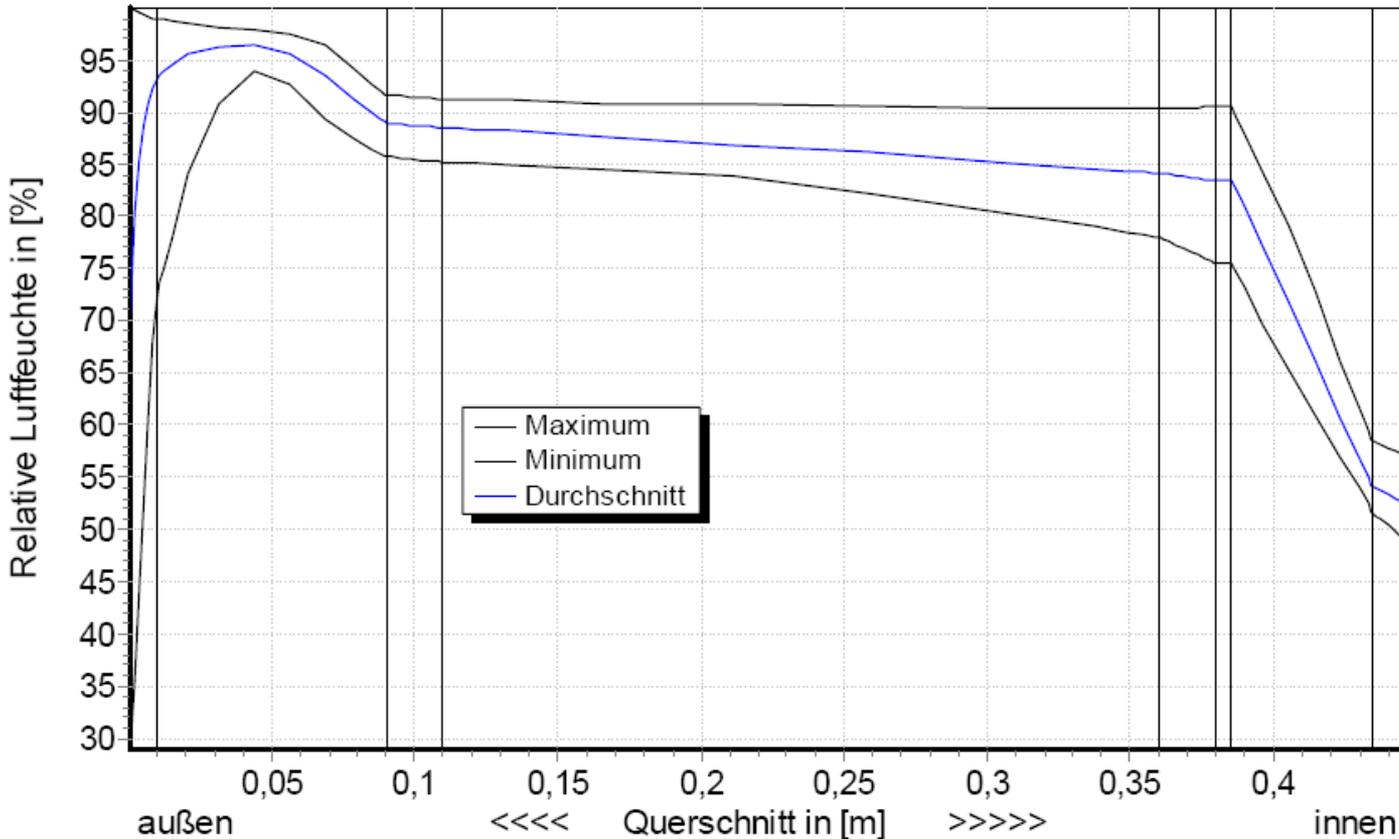
Characteristic temperature profile: outer brick wall 51 cm thickness with insulation and hydrophobic impregnation of the facade (TRY Potsdam)

# Analysis of historic construction



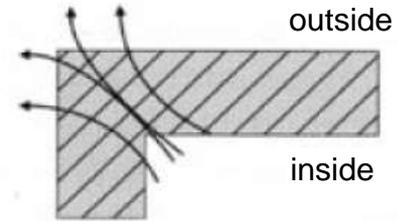
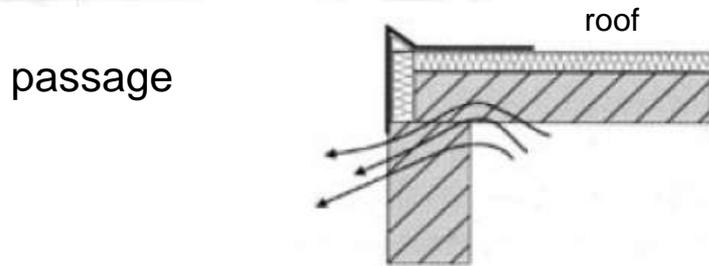
Characteristic relative humidity profile: outer brick wall 51 cm thickness without hydrophobic impregnation of the facade (TRY Potsdam)

# Analysis of refurbished construction

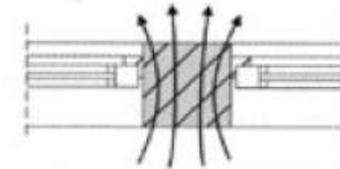
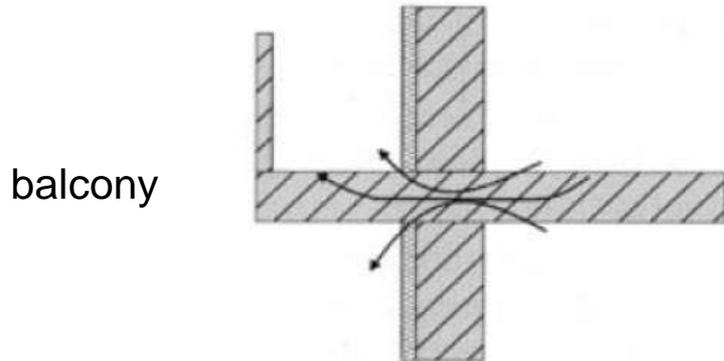


Characteristic relative humidity profile: outer brick wall 51 cm thickness with insulation and hydrophobic impregnation of the facade (TRY Potsdam)

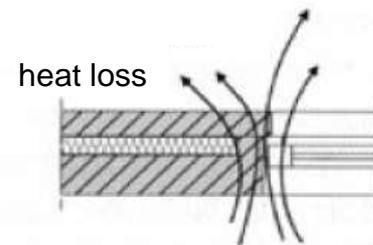
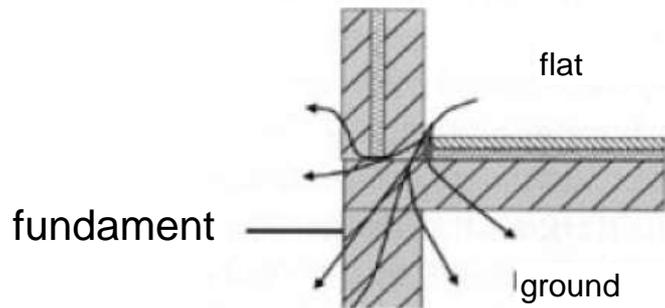
# Typical thermal bridges cause energy losses



building  
corner



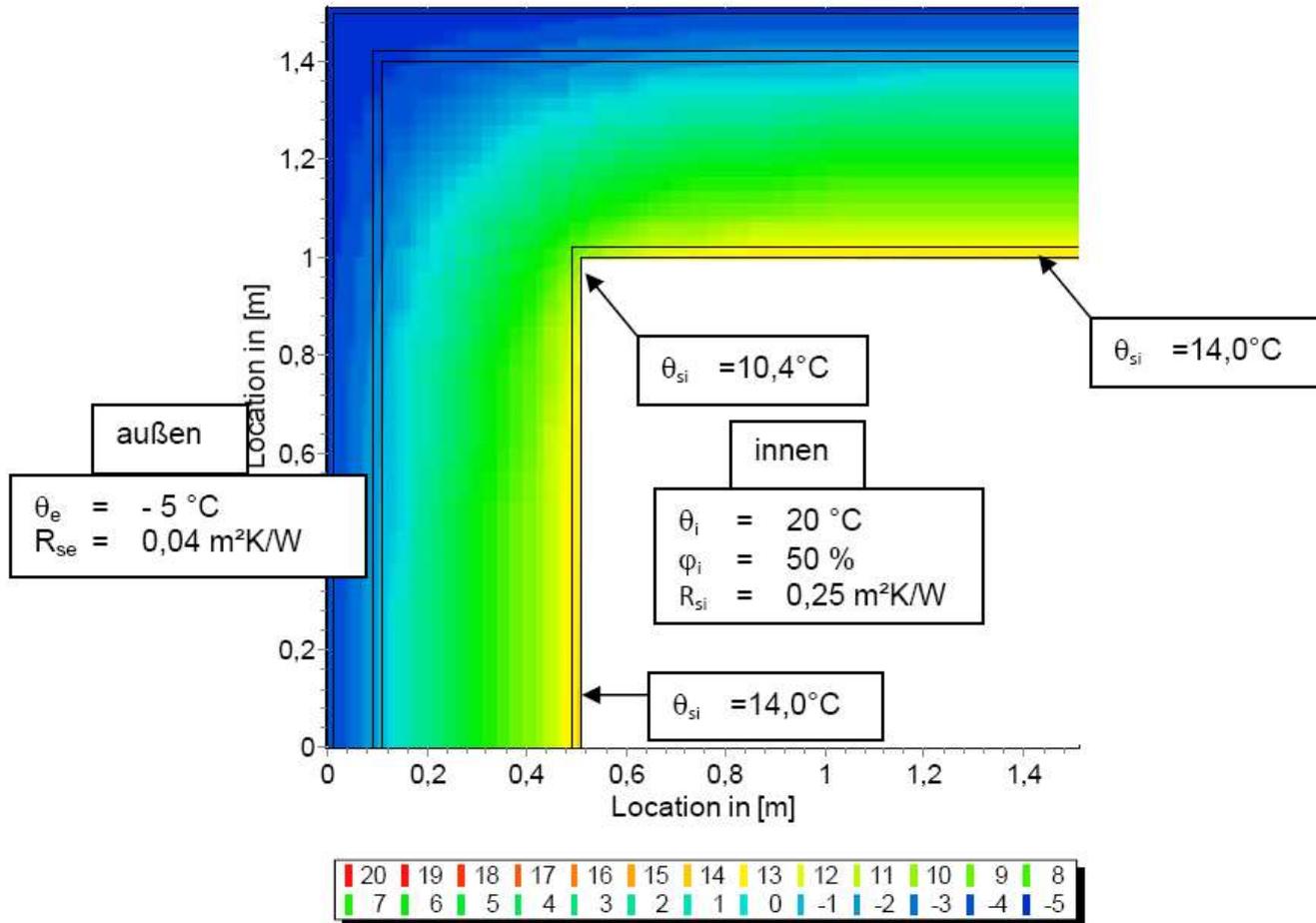
passage due  
to material  
change: e.g.  
concrete beam



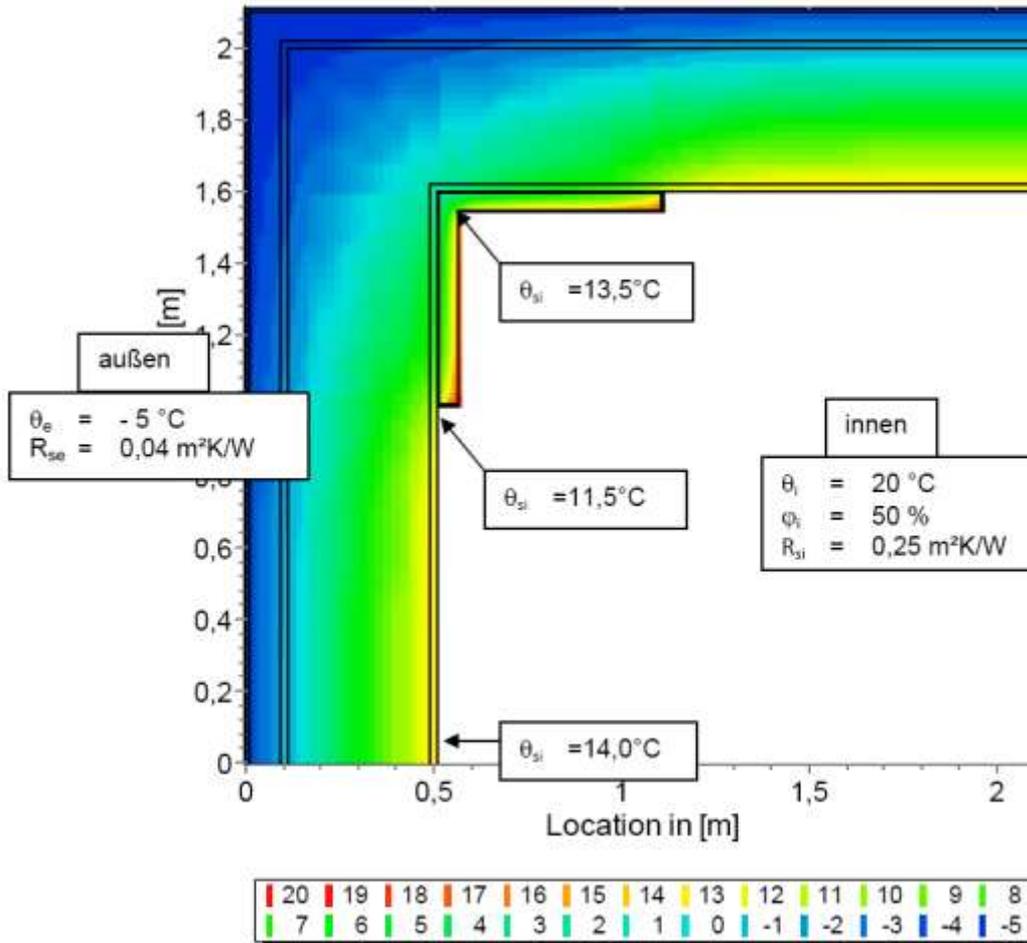
window  
reveal

# Temperature field: wall corner thickness 51 cm, no insulation

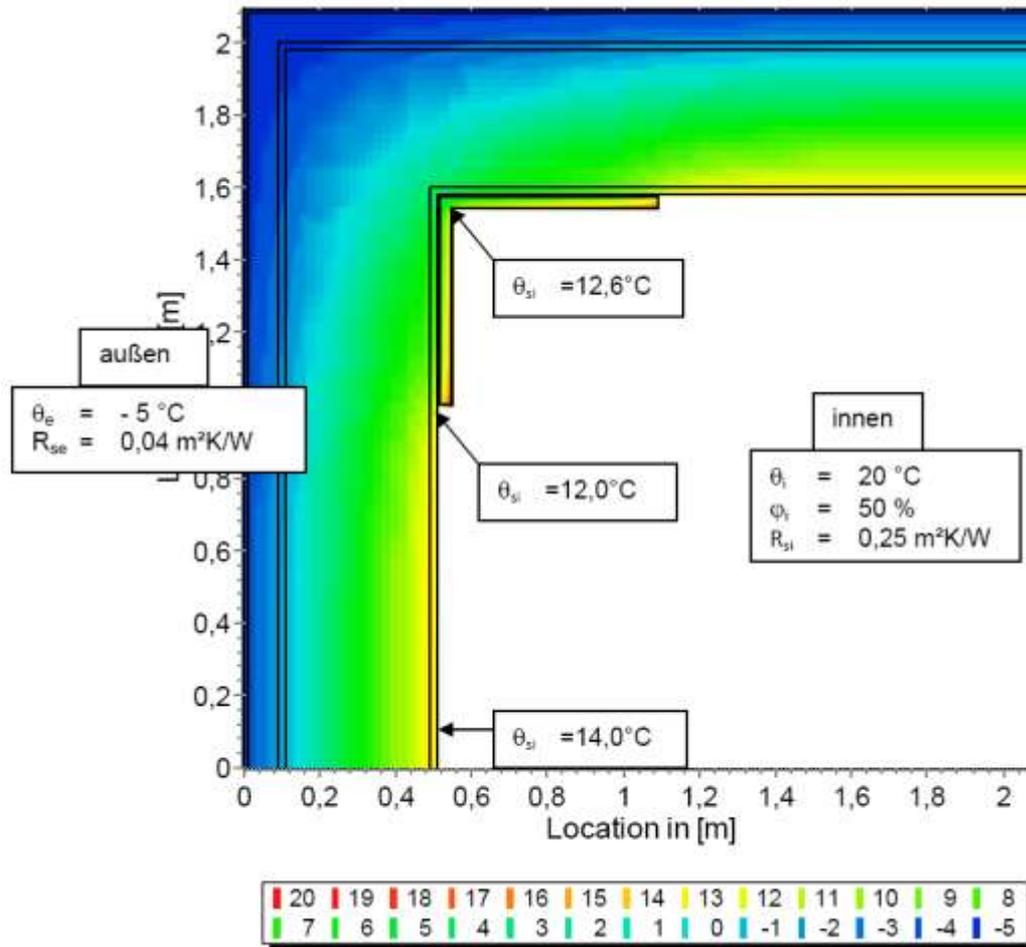
boundary according to German standard regulation DIN 4108 part 2



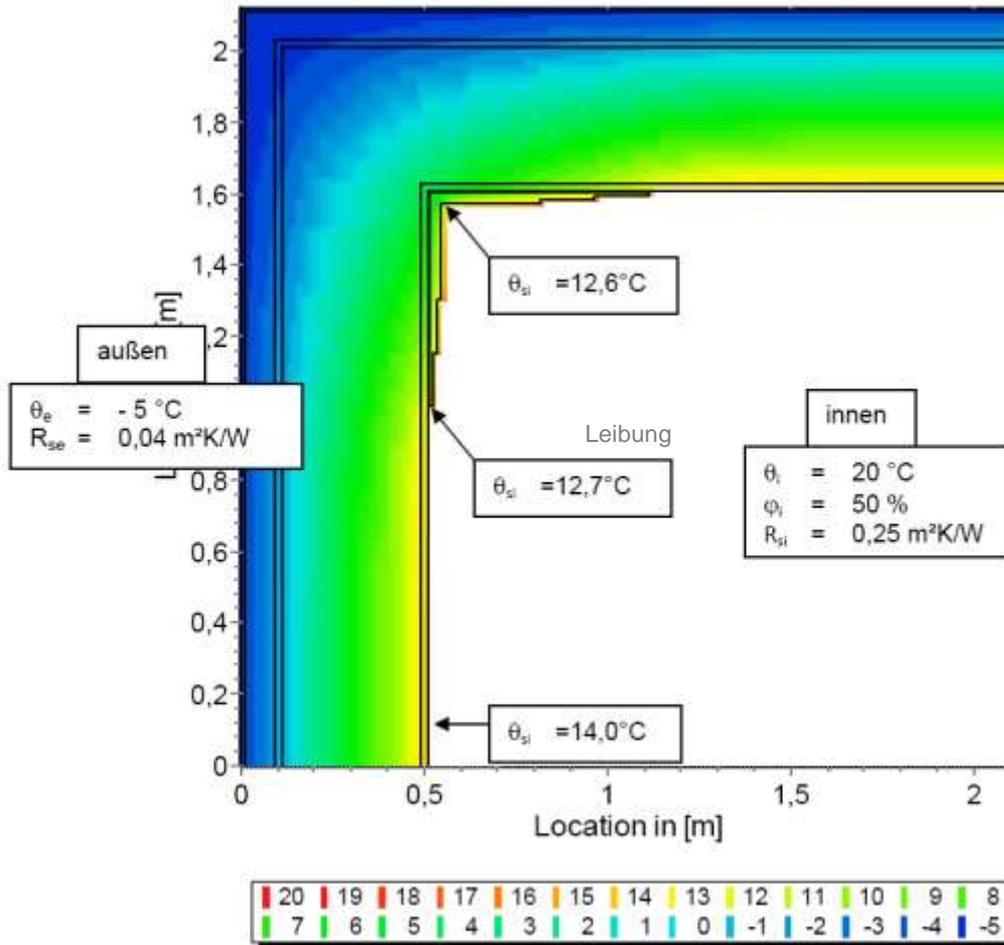
# Temperature field: wall corner thickness 51 cm, corner insulation 5cm CaSi, boundary according to DIN 4108 part 2



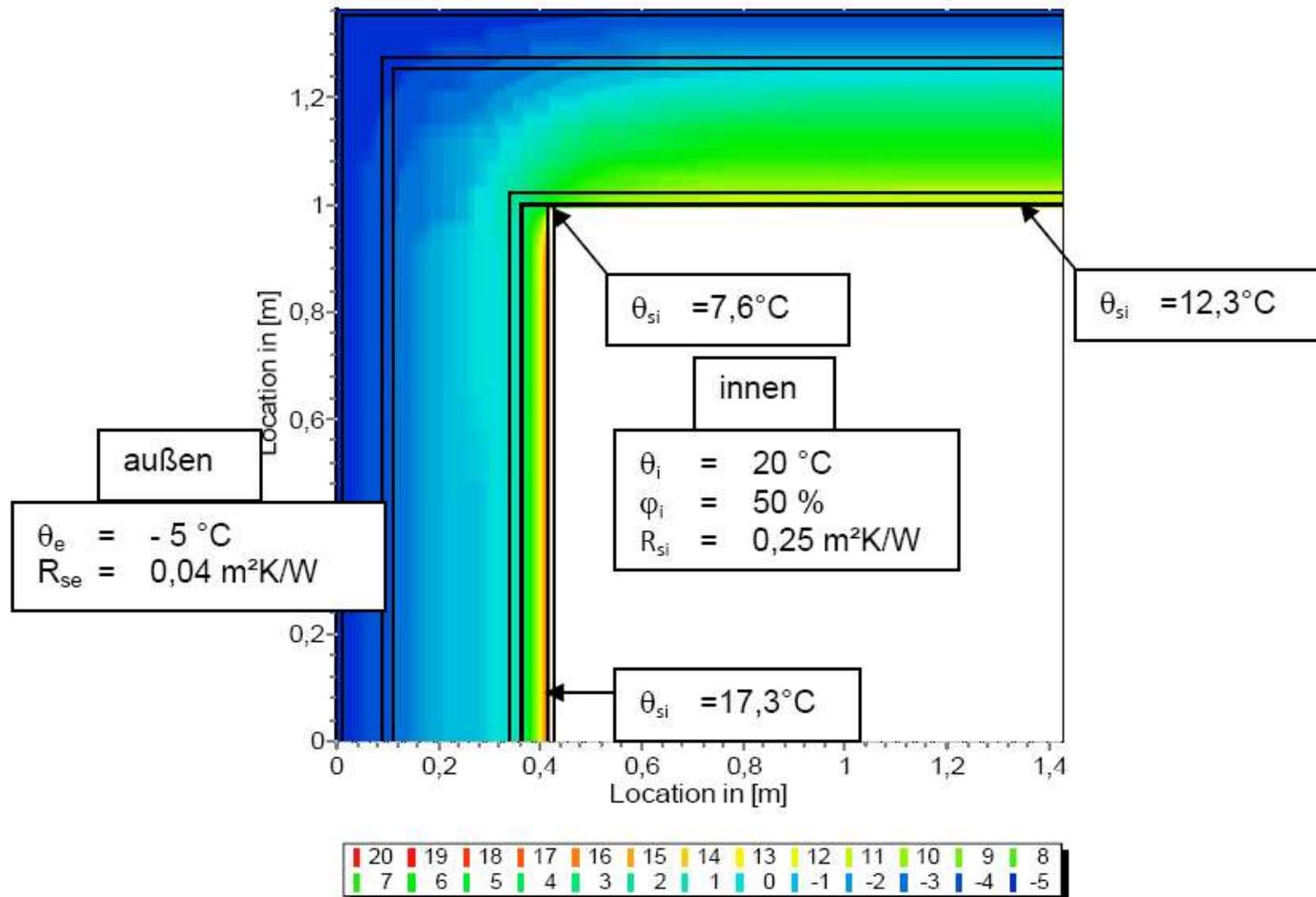
# Temperature field: wall corner thickness 51 cm, corner insulation 3cm CaSi, boundary according to DIN 4108 part 2



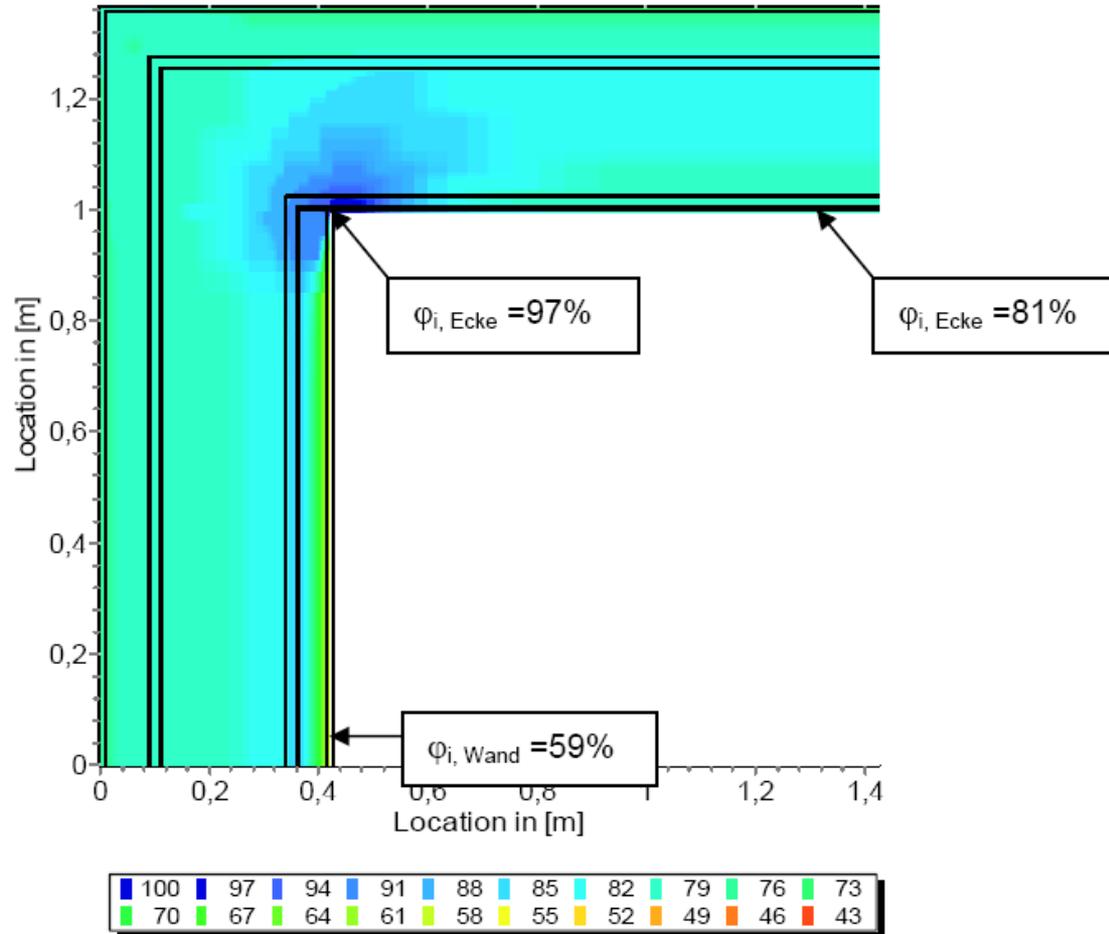
# Temperature field: wall corner thickness 51 cm, corner insulation 3 - 1cm CaSi, boundary according to DIN 4108 part 2



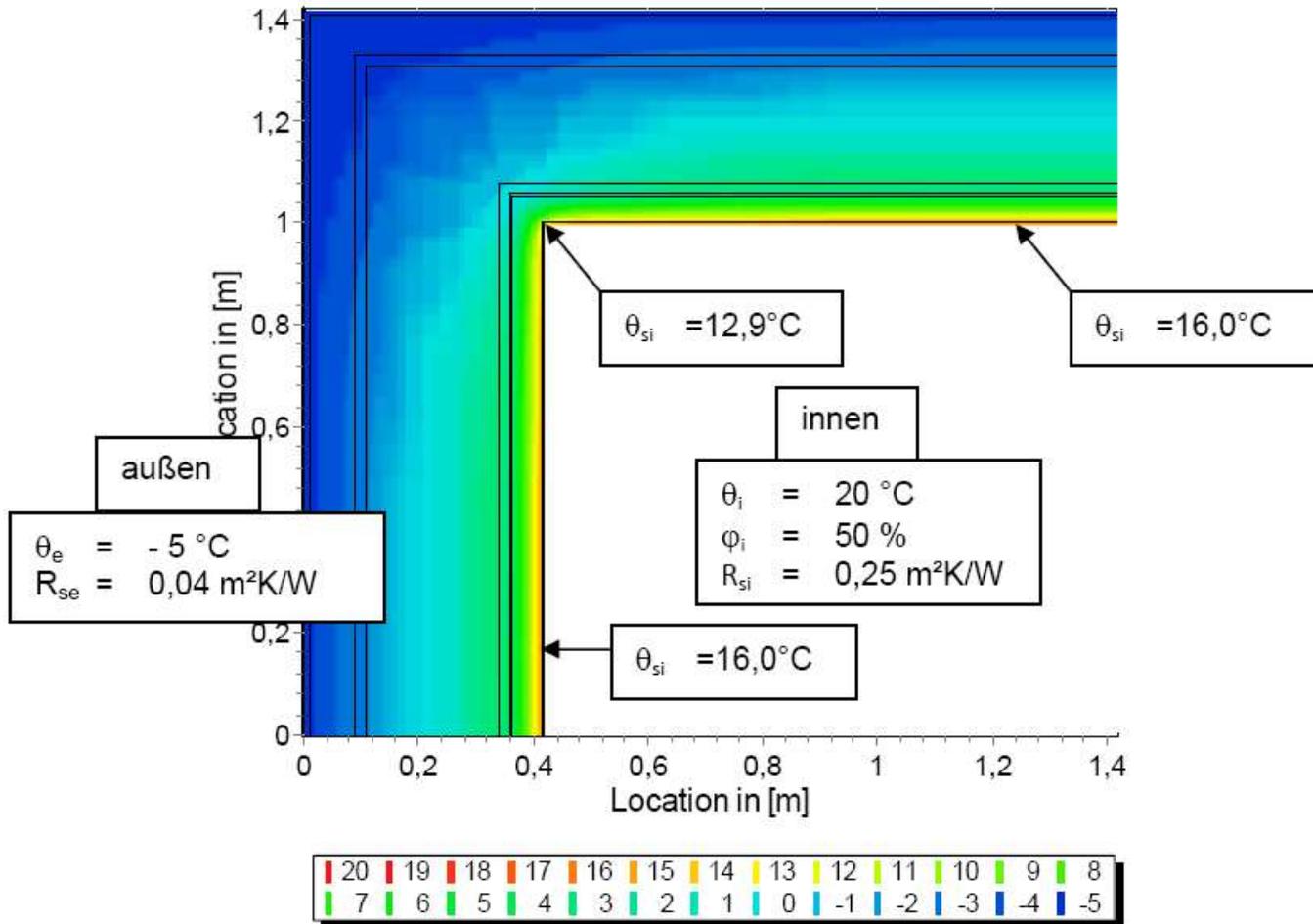
# Temperature field: wall corner thickness 51 cm, corner insulation cm iQ-Therm, boundary according to DIN 4108 part 2



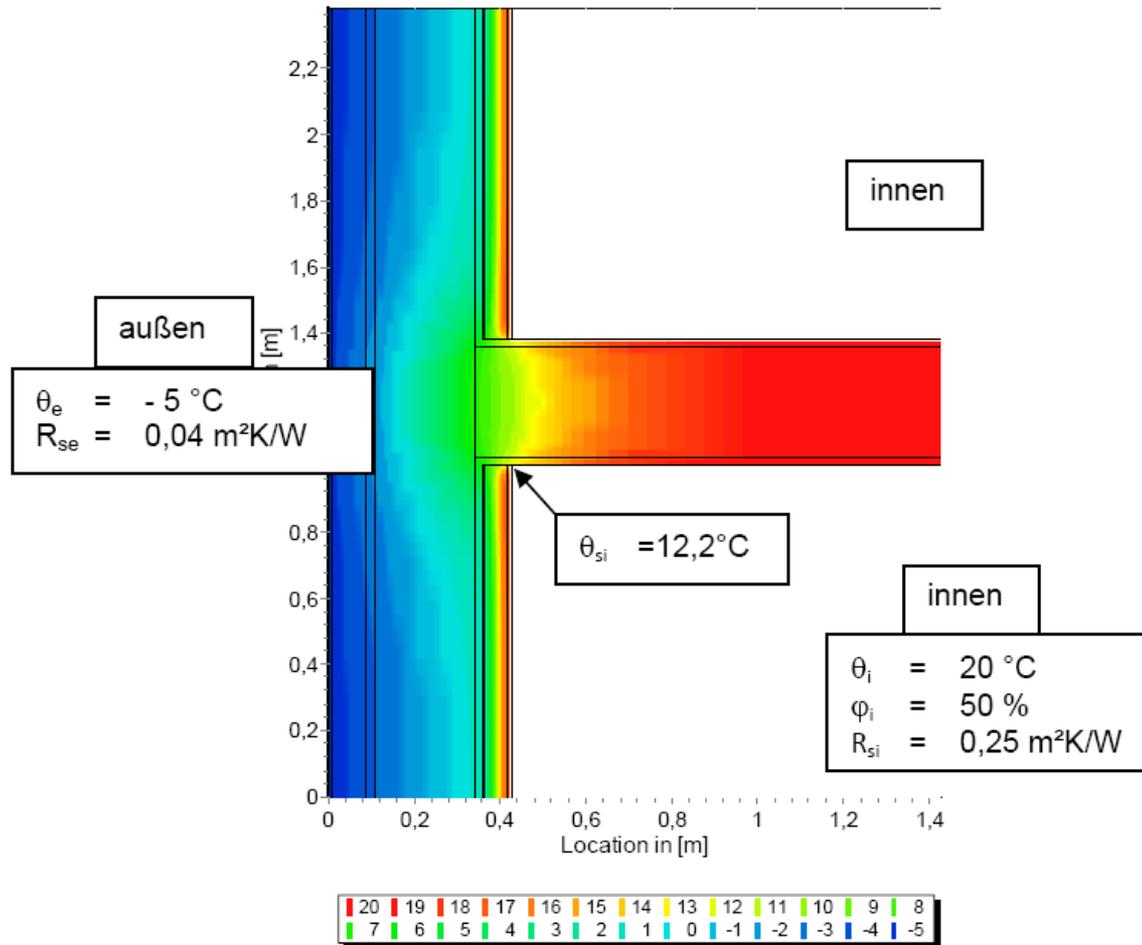
# Rel. humidity field: wall corner thickness 51 cm, corner insulation cm iQ-Therm, boundary according to DIN 4108 part 2



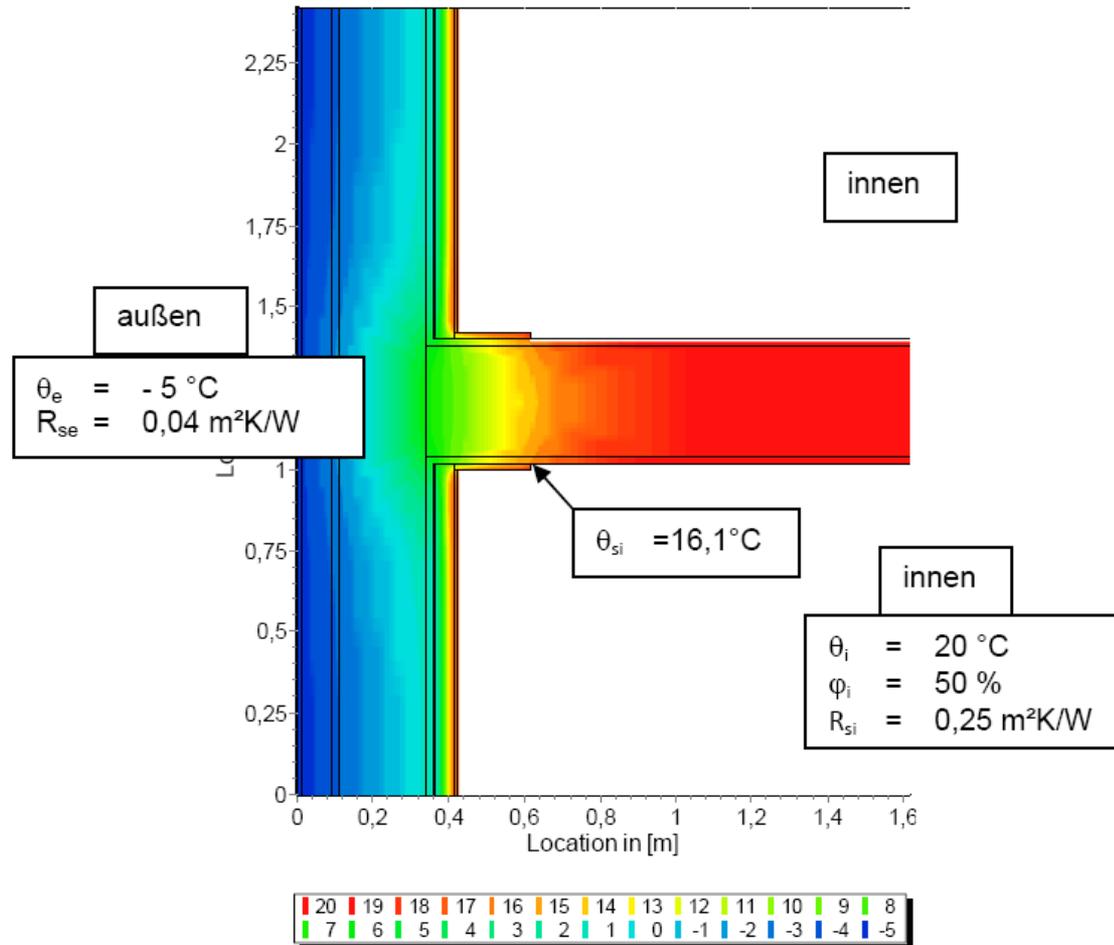
# Temperature field: wall corner thickness 51 cm, corner insulation cm CaSi, boundary according to DIN 4108 part 2



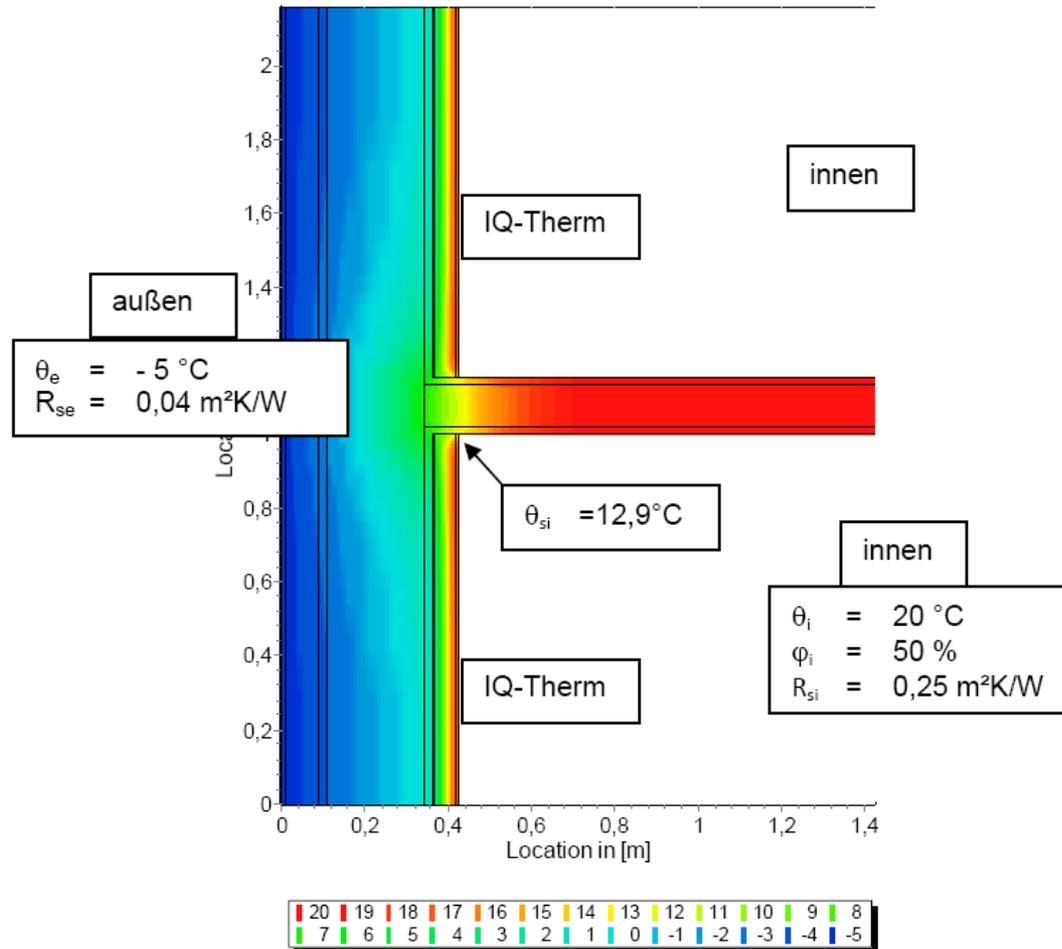
# Temperature field: outer wall thickness 38cm with 5cm iQ-Therm insulation, inner wall thickness 38cm, DIN 4108 part 2



# Temperature field: outer wall thickness 38cm and 5cm iQ-Therm insulation, inner wall thickness 38cm with 2cm insulation of 20cm length, DIN 4108 part 2

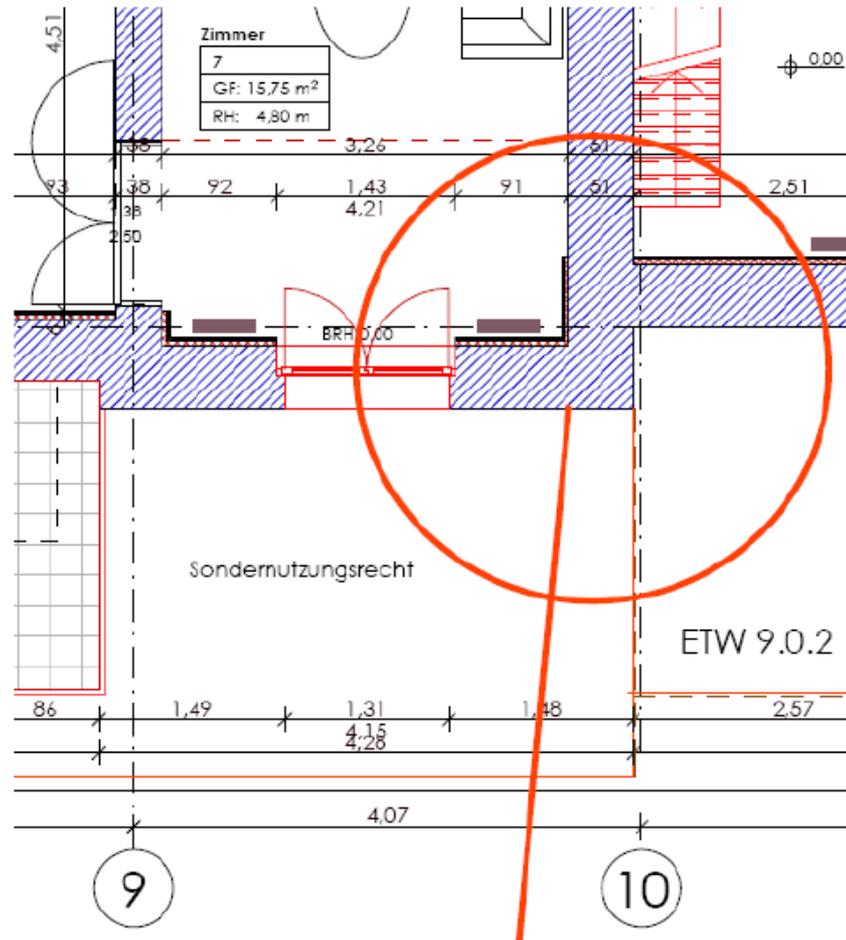


# Temperature field: outer wall thickness 38cm with 5cm iQ-Therm insulation, inner wall thickness 14cm, DIN 4108 part 2



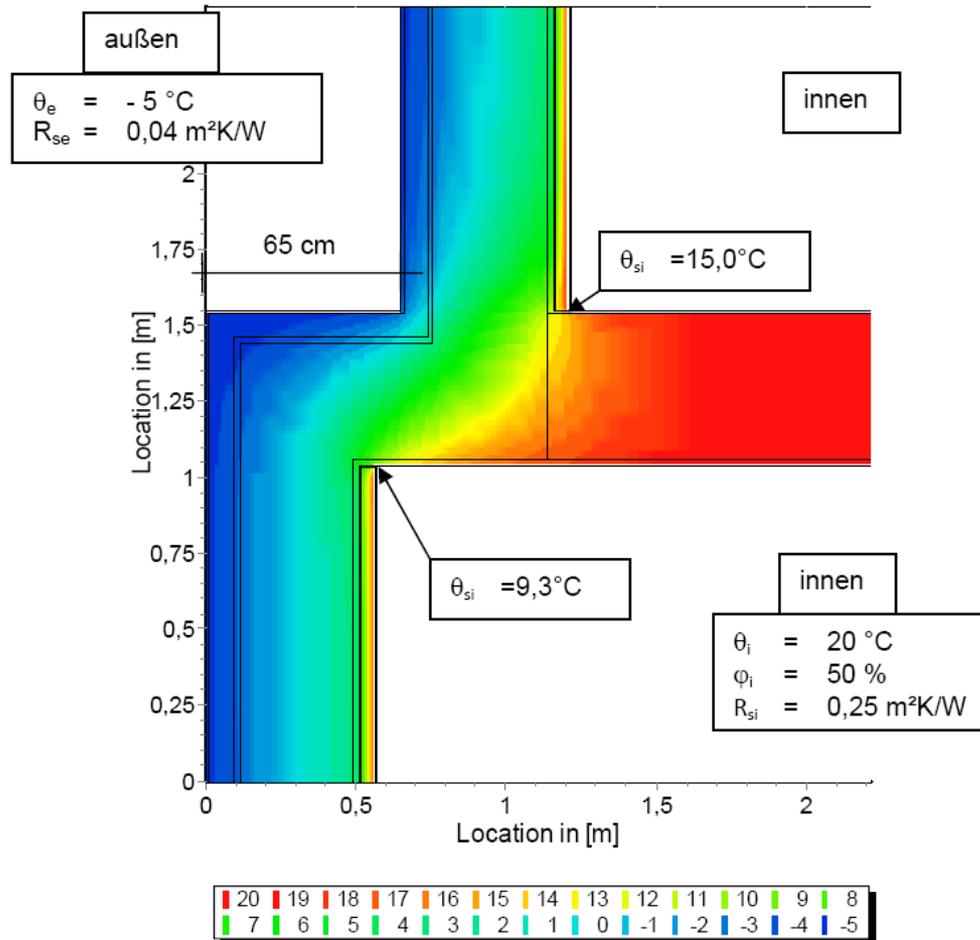
# Complex construction with corner and inner wall: wall shift: 0,65 m

## Konstruktionsaufbau



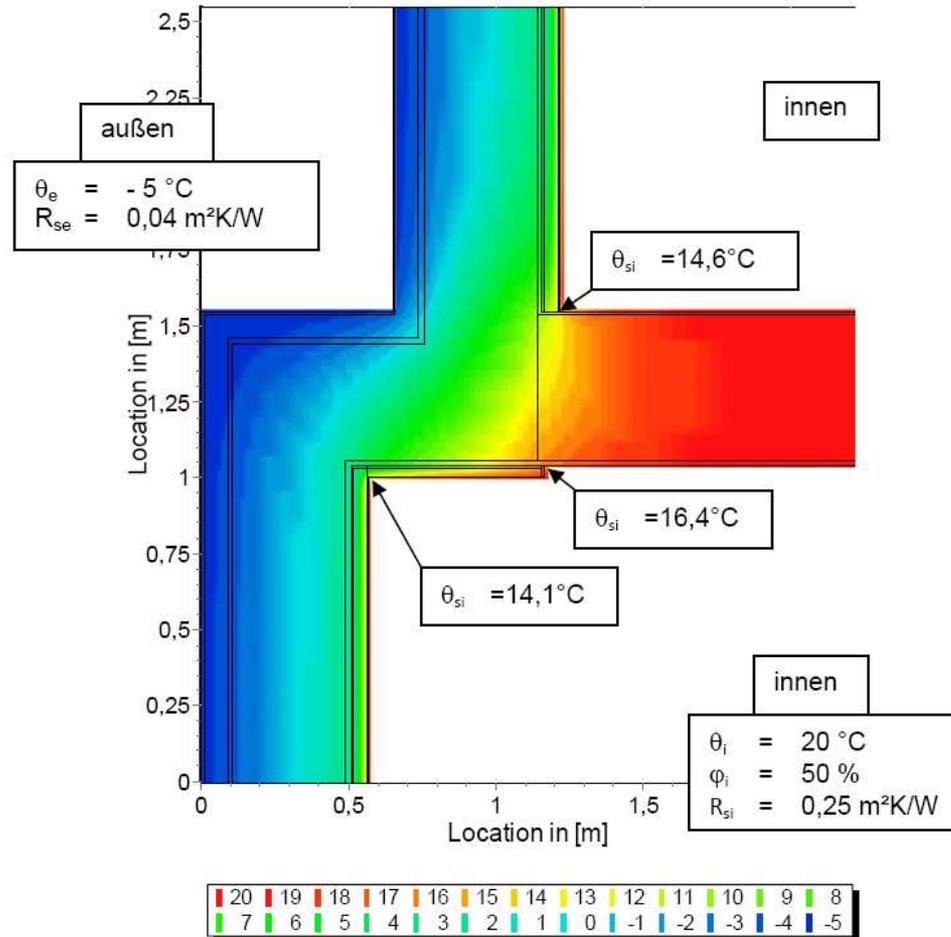
# Complex construction with corner and inner wall:

wall shift: 0,65 m, outer wall thickness 51cm and 5cm iQ-Therm insulation, inner wall thickness 51cm, DIN 4108 part 2



# Complex construction with corner and inner wall:

wall shift: 0,65 m, outer wall thickness 51cm and 5cm iQ-Therm insulation, inner wall thickness 51cm with 3cm insulation of 58cm length, DIN 4108 part 2

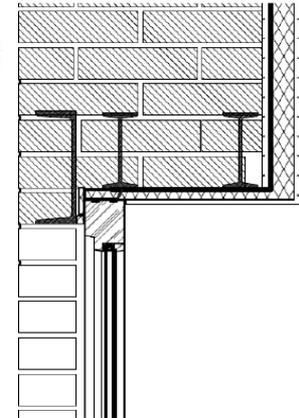
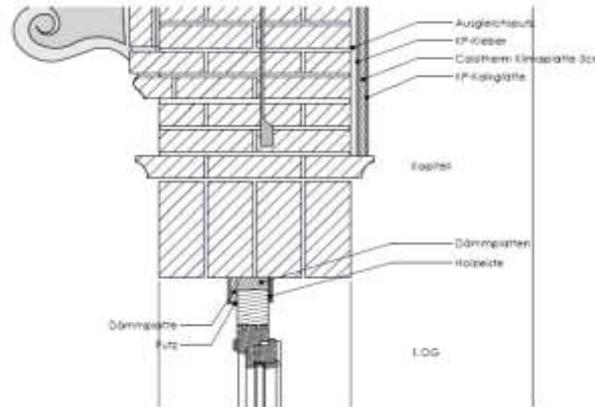
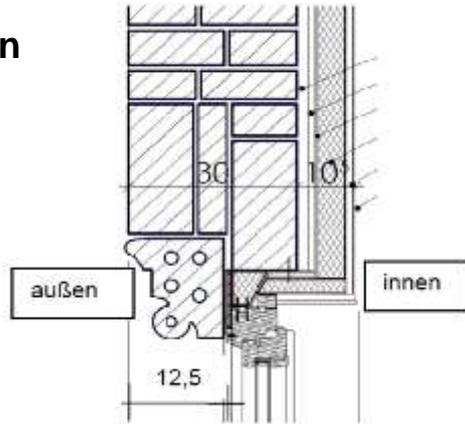


# Window details:

## Westfassade

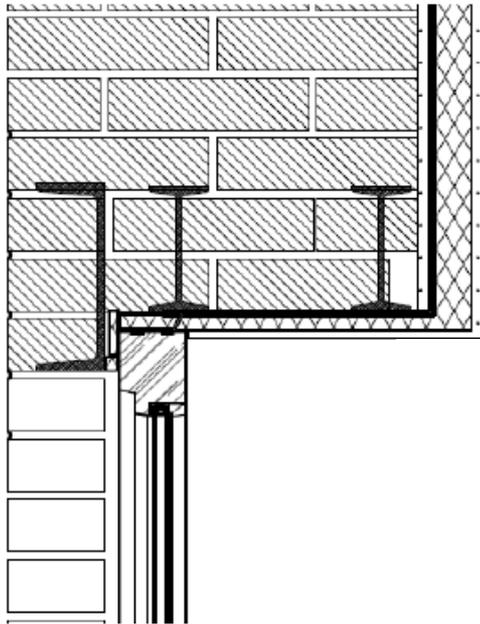


## Detailskizzen

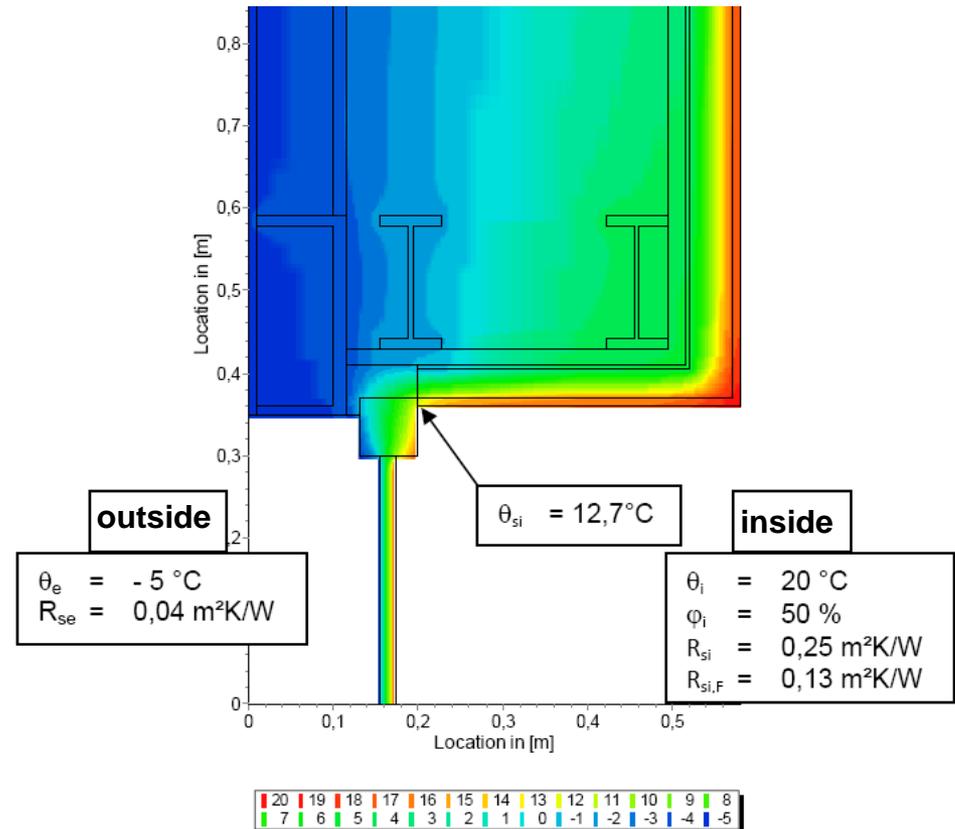


# Window detail: ... steel beams standardized climate

Drawing detail

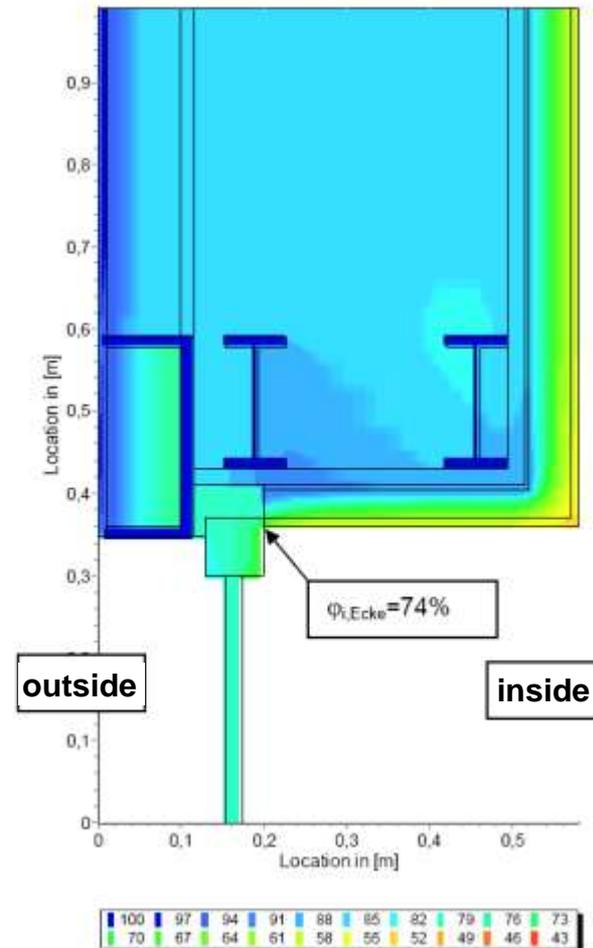
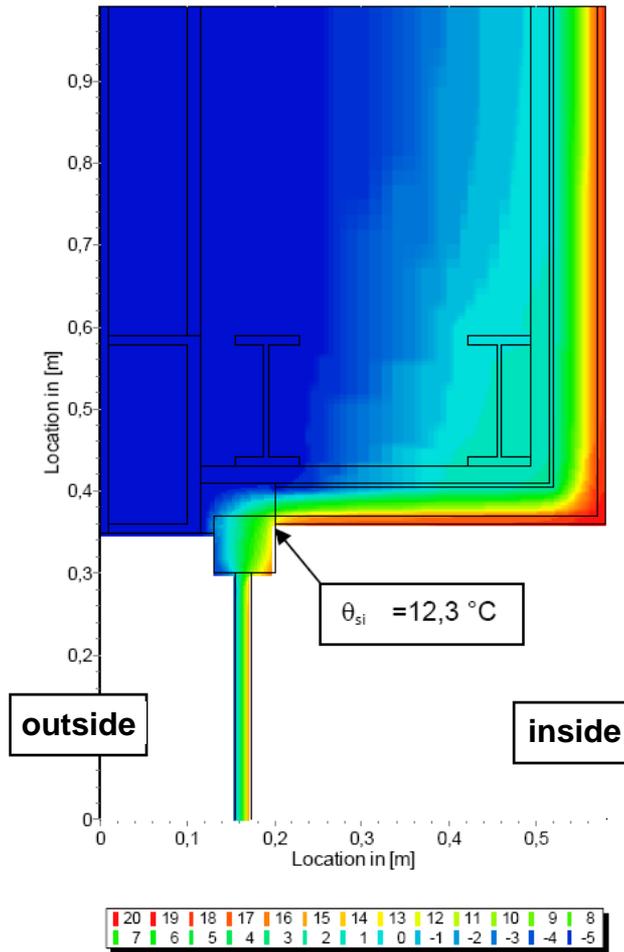


Thermal calculation

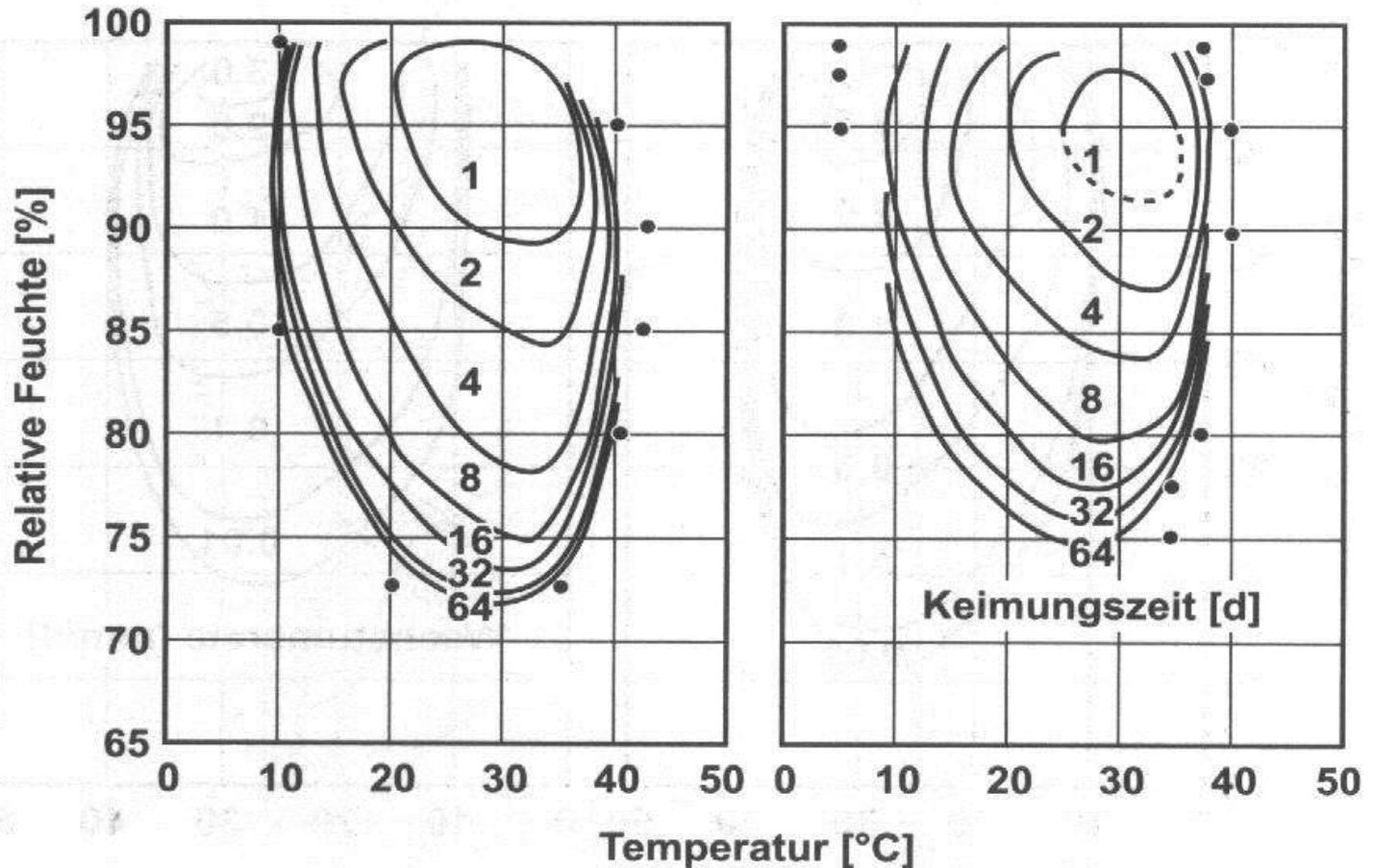


# Window detail: ... steel beams real climate

## Hygro thermal simulation

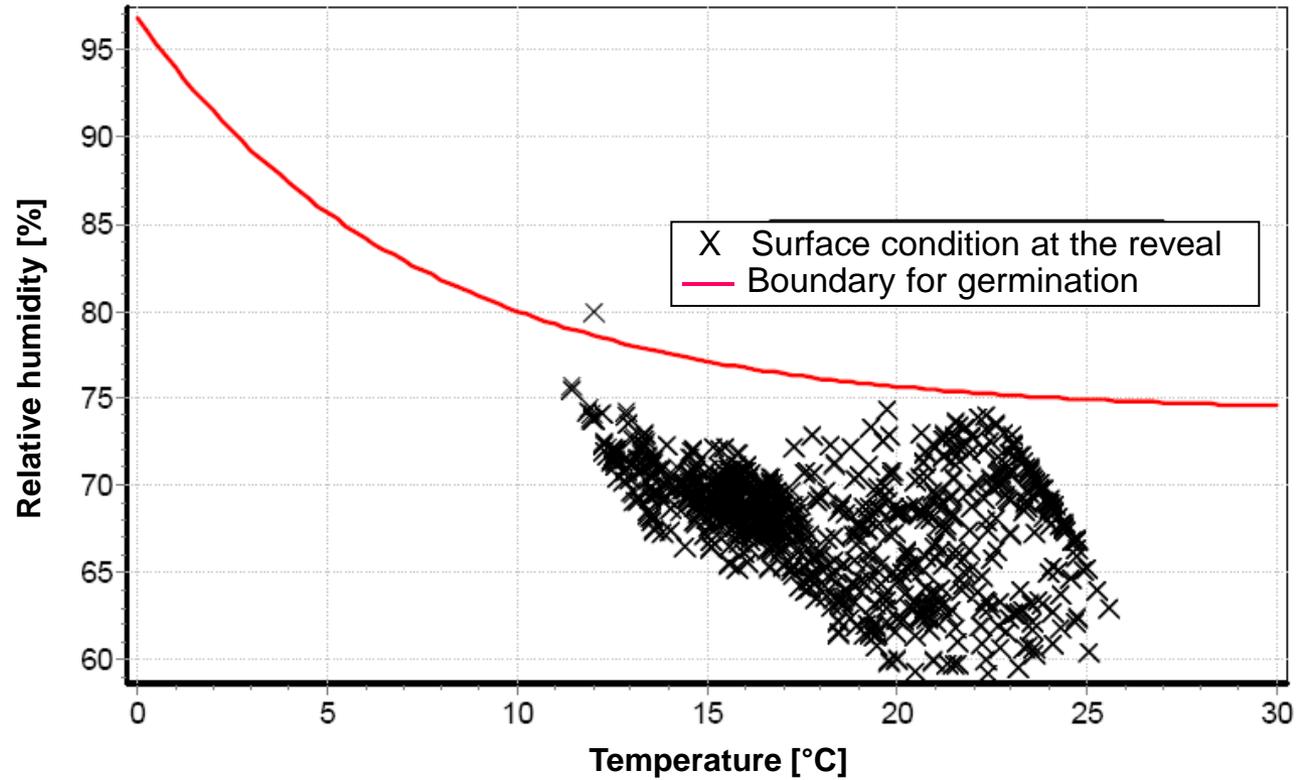
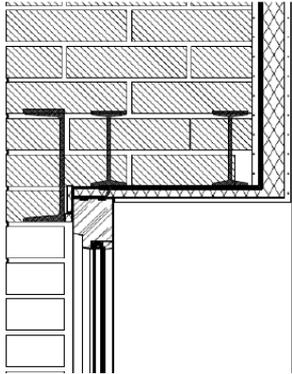


# Schimmelwachstums - Isoplethensystem (Keimung): Aspergillus restrictus (links) und A. versicolor (rechts) (Smith)



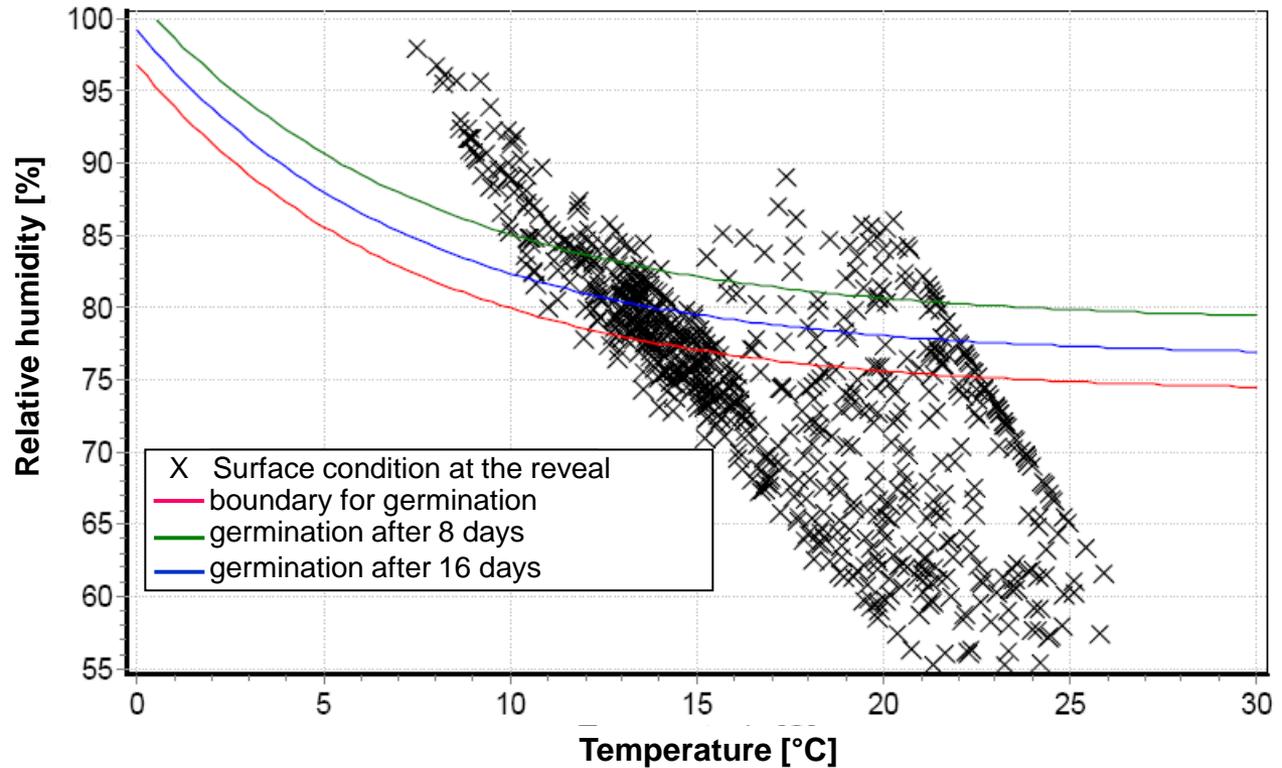
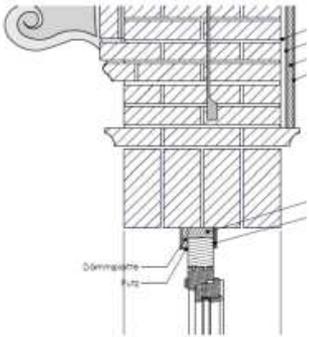
Die Punkte zeigen Bedingungen, bei denen nach 95 Tagen noch keine Keimung stattgefunden hat.

# Window detail: ... steel beams real climate

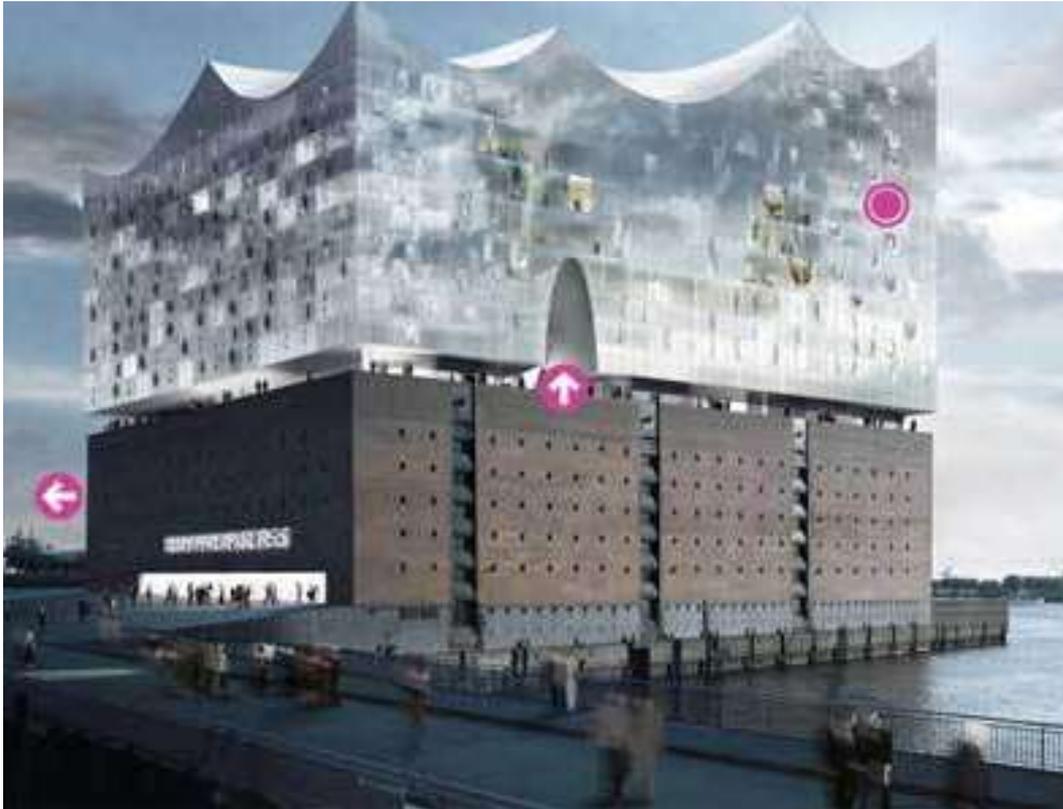


Yearly cycle of temperature and relative humidity in the window reveal

# Window detail: building 7b ... real climate



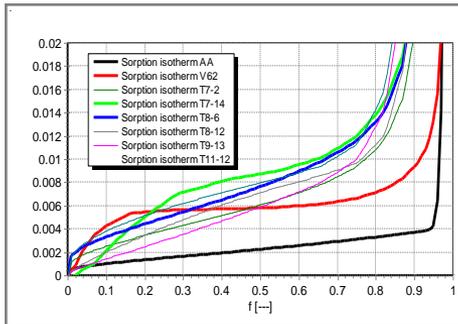
Yearly cycle of temperature and relative humidity in the window reveal



Elbe - Philharmony Hamburg

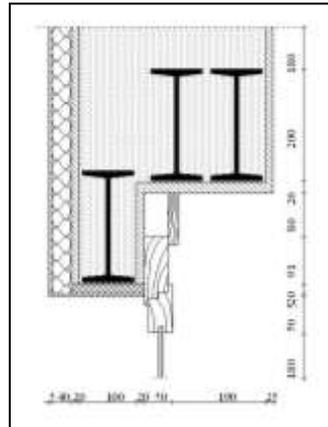
# Investigation of hygrothermal performance of walls under uncertainties → stochastic simulation

## Variation of input parameters



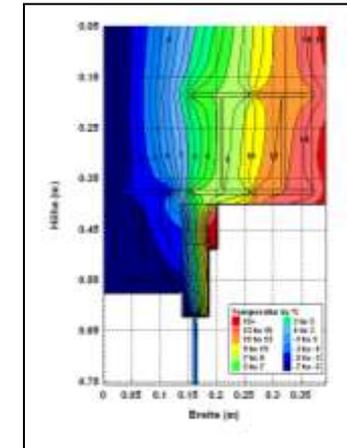
- Material properties
- Boundary conditions
- Workman ship
- ...

## Selection of construction detail



- Evaluation
- Benchmarking
- ...

## Hygrothermal simulation



# Variation of material parameters

Basic Parameters	Symbol [Units]	Trasskalk leichtputz	Calcium silicate	Calsitherm KP-Kleber	Remmers Grundoutz	brick	Hydrophobic brick
Density	$\rho$ [kg/m <sup>3</sup> ]	1432 (30)	222 (2.0)	1473 (40)	995 (35)	1850 (15)	1850
Specific heat capacity	$c_0$ [J/kg·K]	630 (20)	1303 (45)	1018 (60)	862 (90)	847 (20)	847
Thermal conductivity	$\lambda$ [W/m·K]	0.40 (0.02)	0.057 (0.002)	0.92 (0.06)	0.22 (0.01)	0.81 (0.05)	0.81
Open porosity	$\Psi_o$ [m <sup>3</sup> /m <sup>3</sup> ]	0.51 (0.015)	0.92 (0.01)	0.45 (0.015)	0.62 (0.02)	0.3 (0.1)	0.29
Saturation moisture content	$\Psi_{sat}$ [m <sup>3</sup> /m <sup>3</sup> ]	0.5 (0.015)	0.91 (0.01)	0.26 (0.015)	0.33 (0.015)	0.22 (0.015)	0.22
Capillary moisture content	$\Psi_{cap}$ [m <sup>3</sup> /m <sup>3</sup> ]	0.33 (0.01)	0.82 (0.02)	0.03 (0.005)	0.19 (0.01)	0.20 (0.01)	0.03
Water absorption coefficient	$A$ [kg/m <sup>2</sup> s <sup>0.5</sup> ]	0.08 (0.005)	0.95 (0.03)	0.008 (0.0015)	0.022 (0.003)	0.2 (0.01)	0.0022
Water vapor diffusion resistance factor	$\mu_{dry}$ [ - ]	10.9 (1.3)	5.4 (0.3)	38.5 (3.0)	11.3 (1.0)	22.5 (2.5)	24.0 (4.0)
Liquid water conductivity at saturation moisture	$K_{sat}$ [ s ]	4.5E-11 (1.0E-11)	8.4E-09 (1.2E-09)	2.2E-11 (1.0E-11)	9.1E-10 (2.5E-10)	7.5E-9 (1.0E-9)	1.9E-10 (1.0E-10)

# Variation of boundary conditions, workman ship

Boundary coefficients	Symbols	Units	Values
Heat transfer coefficient _ interior	$\alpha_i$	W/m <sup>2</sup> K	8 (0.8)
Vapor transfer coefficient _ interior	$\beta_{pi}$	s/m	3e-08 (5e-9)
Heat transfer coefficient _ exterior	$\alpha_e$	W/m <sup>2</sup> K	25.0 (3.0)
Vapor transfer coefficient _ exterior	$\beta_{pe}$	s/m	2e-07 (5e-8)
Absorption coefficient for short wave radiation (on building surface)	$\alpha_K$	-	0.6 (0.1)
Emission coefficient of surrounding ground	$\alpha_G$	-	0.2 (0.04)
Emission coefficient for long wave radiation (on building surface)	$\alpha_L$	-	0.9 (0.09)
Rain exposure coefficient	$\alpha_R$	-	0.63 (0.2)

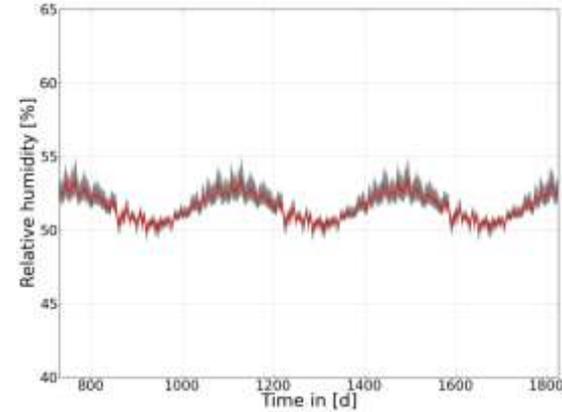
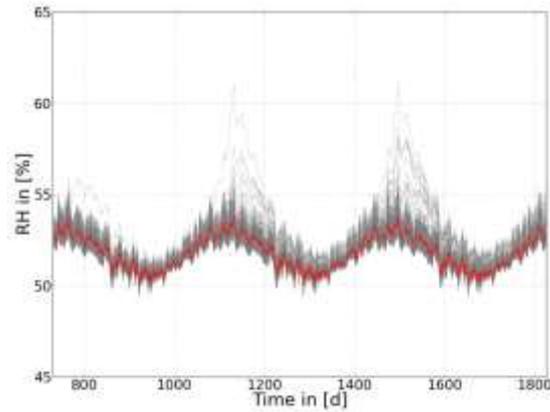
Material	value
Trasskalk_leichtputz	5 (3,7)
Calsitherm KP-Kleber	6 (4,8)
Remmers_Grundputz_ReGP	30 (20,50)
Hydrophobic layer	15 (8,25)

# Results: inner surface wall

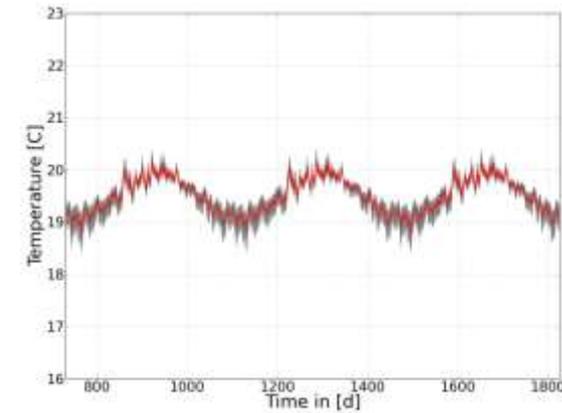
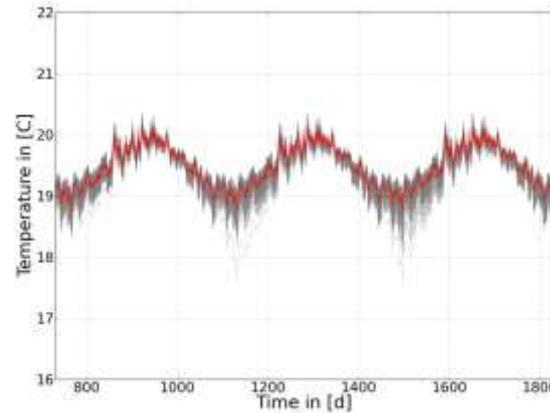
No hydrophobic impregnation

Adaptive hydrophobic impregnation

Rel. humidity



Temperature

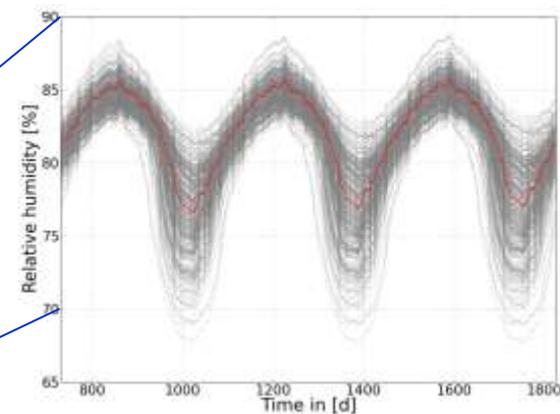
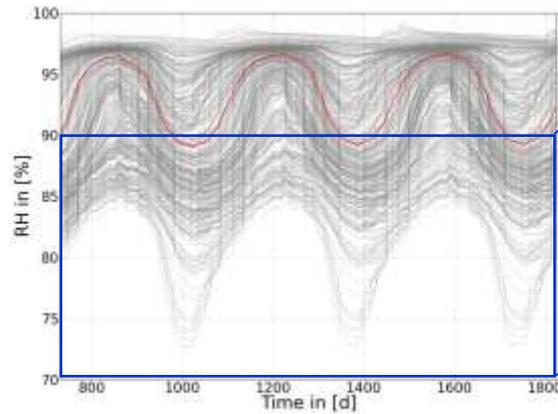


# Results: brick wall behind insulation

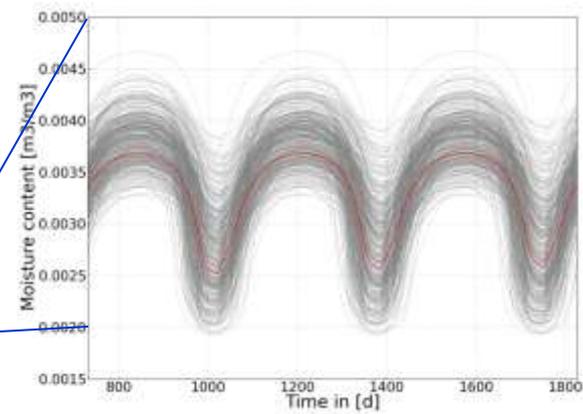
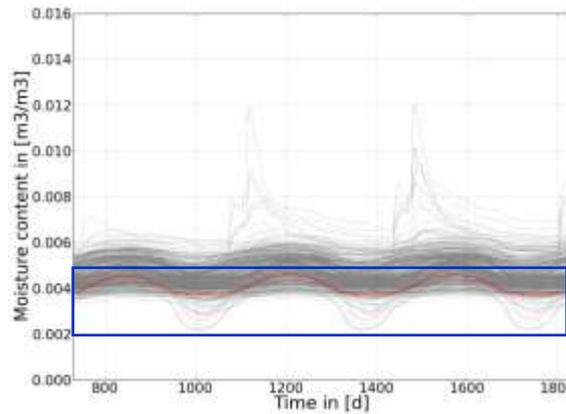
No hydrophobic impregnation

Adaptive hydrophobic impregnation

Rel. humidity



Moisture content

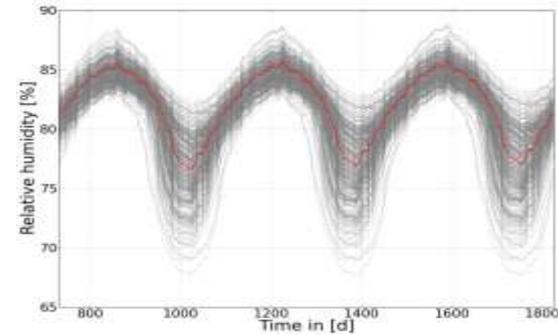
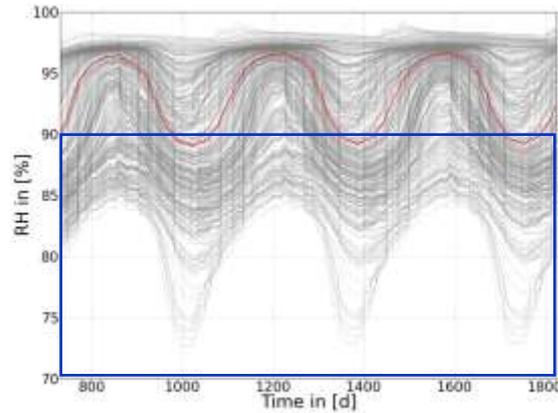


# Results: brick wall behind insulation

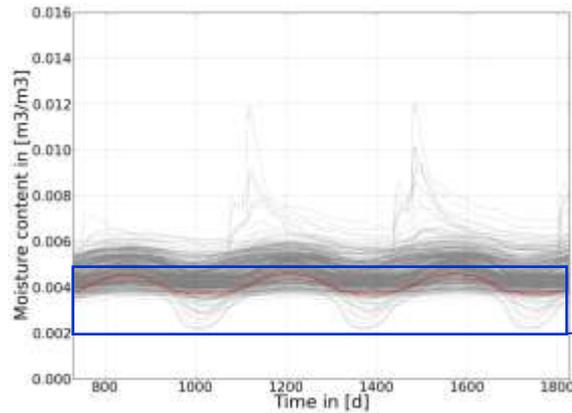
No hydrophobic impregnation

Adaptive hydrophobic impregnation

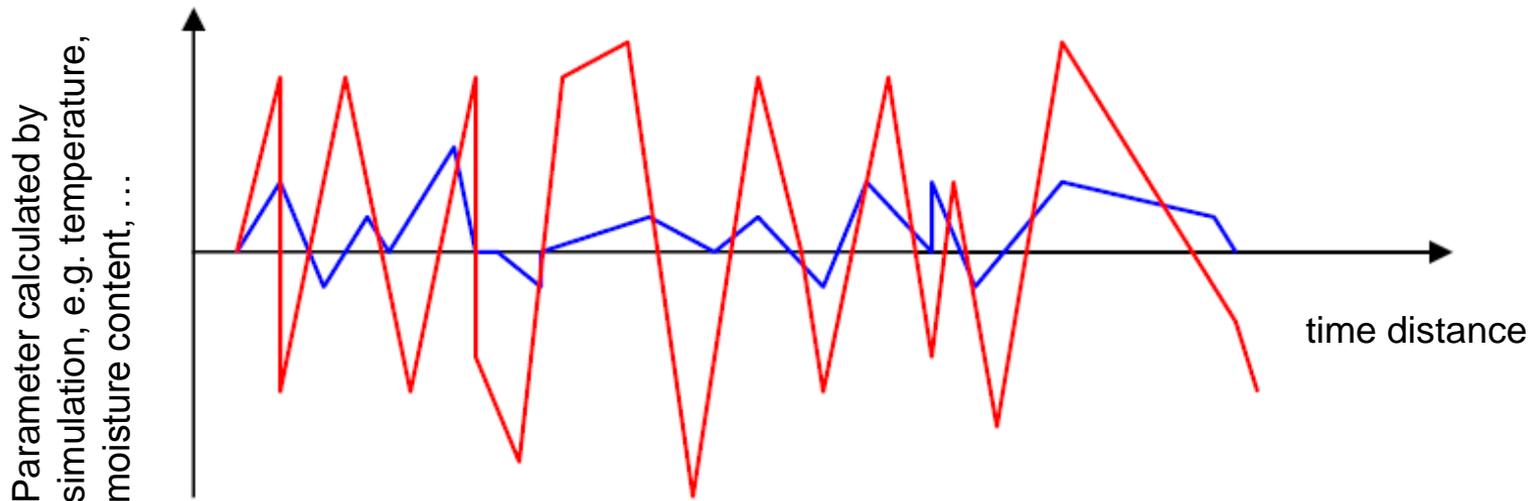
Rel. humidity



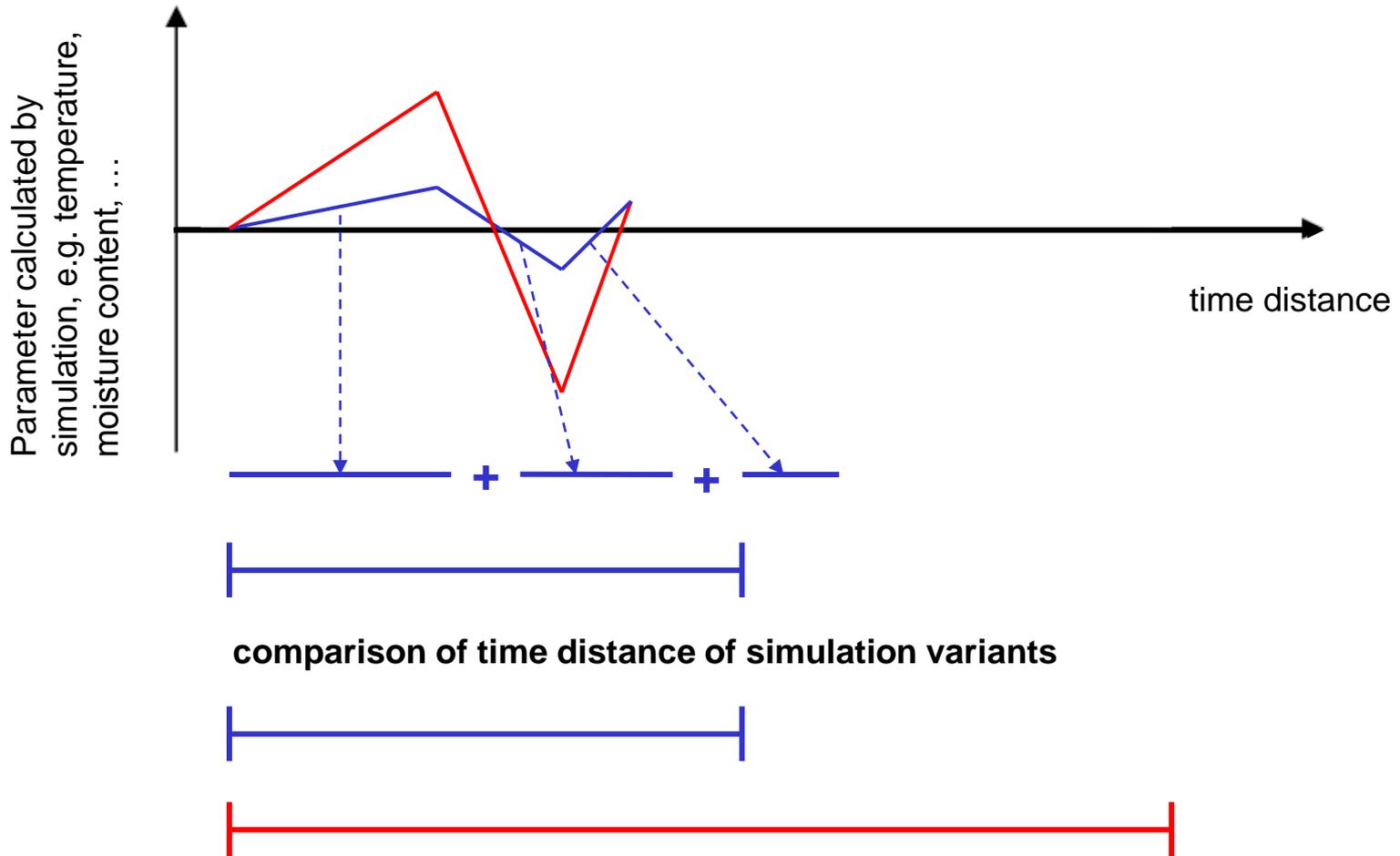
Moisture content



## Generation of specific load parameters



# Interpretation of results



# Evaluation criteria

## Weathering load

$$WL_{\theta} = \sum_{i=1}^{8760} \sqrt{\Delta\theta_{se,i}^2 + \Delta t_i^2} \quad \text{weather- thermal load}$$

$$WL_{\varphi} = \sum_{i=1}^{8760} \sqrt{\Delta\varphi_{se,i}^2 + \Delta t_i^2} \quad \text{weather- hygro load}$$

$$WL_w = \sum_{i=1}^{8760} \sqrt{\Delta w_{se,i}^2 + \Delta t_i^2} \quad \text{weather- hygro load}$$

## Induction stress

$$CIL_{\theta} = \sum_{i=1}^{8760} \sqrt{(\Delta(\bar{\theta}_{se,i} - \bar{\theta}_{xmm,i}))^2 + \Delta t_i^2}$$

$$CIL_{\varphi} = \sum_{i=1}^{8760} \sqrt{(\Delta(\bar{\varphi}_{se,i} - \bar{\varphi}_{xmm,i}))^2 + \Delta t_i^2}$$

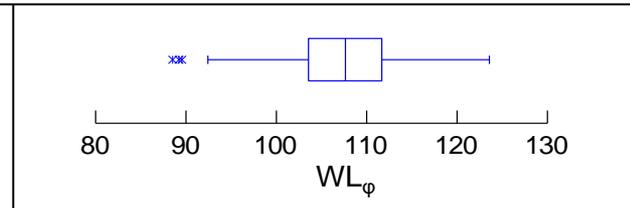
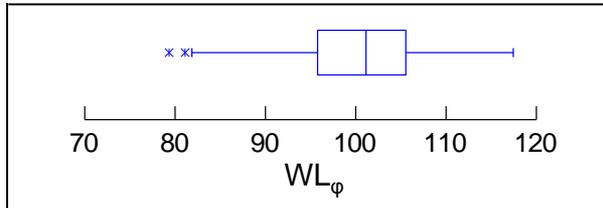
$$CIL_w = \sum_{i=1}^{8760} \sqrt{(\Delta(\bar{w}_{se,i} - \bar{w}_{xmm,i}))^2 + \Delta t_i^2}$$

# Results: Evaluation criteria

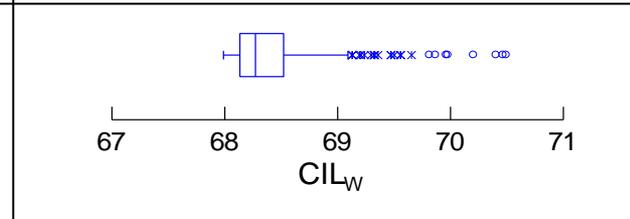
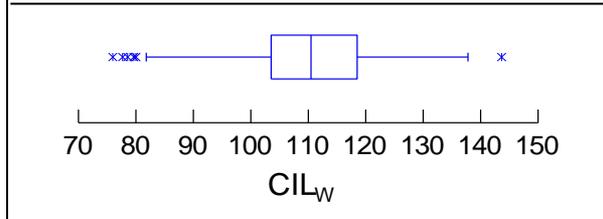
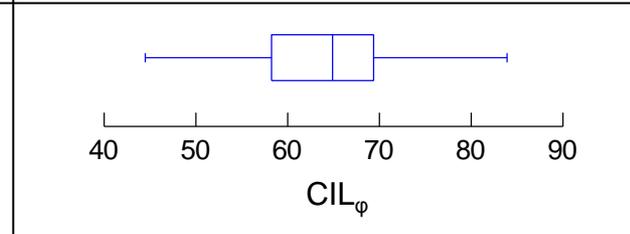
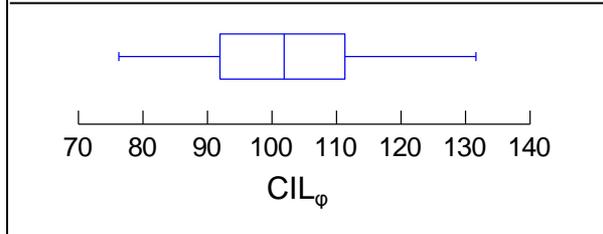
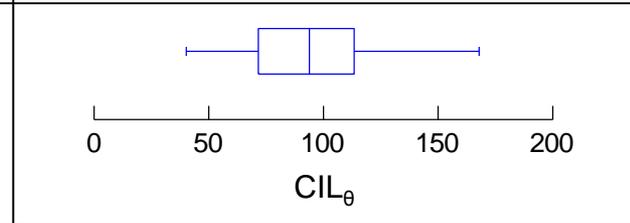
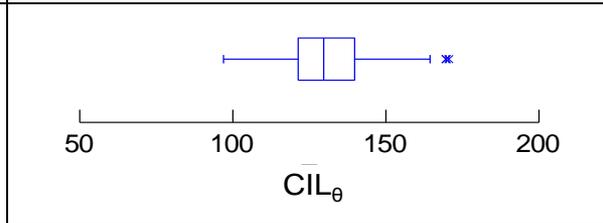
No hydrophobic impregnation

Adaptive hydrophobic impregnation

**Weathering load**



**Induction stress**



# Summary

## Positive effects of interior insulation

- Energy saving and CO<sub>2</sub> –reduction, → contribution to the environmental protection
- Protection against condensate and mould growth → prevention of damaged e.g. after window exchange
- Improvement of thermal comfort → increasing value of rehabilitated building
- Keeping brick masonry constructions as they are
- Fast heating for temporary used rooms
- ...

# Summary

## Advantage of capillary active interior insulation

*(multi functional properties vary between different building materials)*

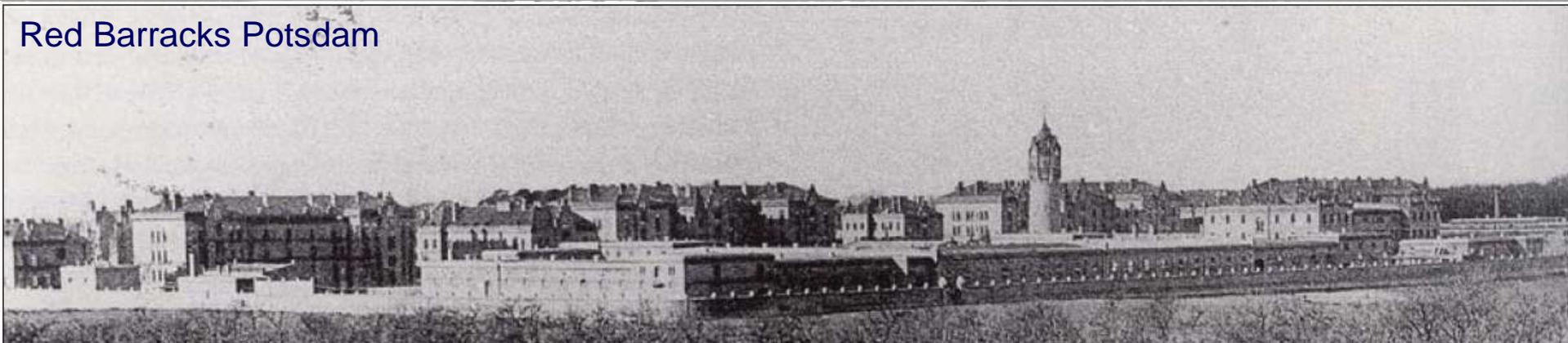
- Moisture regulation of construction
- Keeping healthy room climate
- Diffusion open construction
- Keeping drying potential
- Reduction of freezing damage probability

## Summary

- **Evaluation of thermal bridges:** important for damage free building construction
- **Complex construction details:** actual details are very complex, requirement of numerical computer simulation tools
- **Usage of real climate conditions:** the evaluation under national standard code conditions may cause miss interpretation
- **Interior insulation:** thermal calculations only do not deliver proper results
- **Hygrothermal simulation:** the application of hygro thermal simulation is able to evaluate thermal and hygric behavior under real climate conditions and damages can be prevented.

# Cultural heritage interior inside insulation projects

## Red Barracks Potsdam

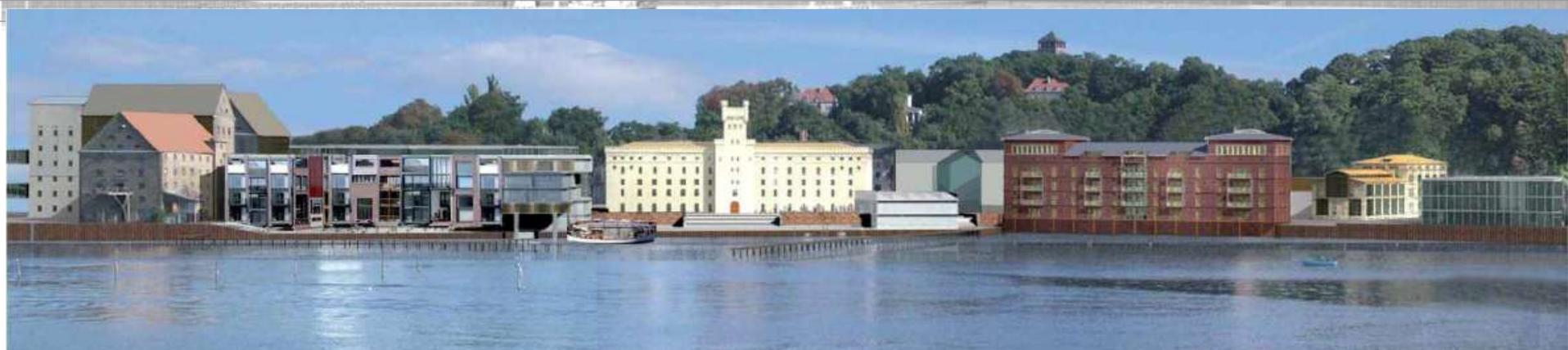


## Quedlinburg numerous Projects

**Planning of ~ 60 interior insulation projects during last 20 years and scientific contribution:**

- “Am Urban” historic town quarter Berlin
- “Neue Forstakademie” Uni. of Appl. Sci. Eberswalde
- Red city hall Berlin Pankow
- “Herrenschießberghaus” in Nuremberg
- Karuna Montessorischule Berlin

# Cultural heritage interior inside insulation projects



Historical magazines at the “Speicherstadt Potsdam”



Elbe philharmony Hamburg



Rijksmuseum Amsterdam



# **Energetic Refurbishment of Brick Buildings**

Dr.-Ing. Rudolf Plagge

Head of the Building Research- and Development Laboratory  
Institute of Building Climatology, University of Technology Dresden