Energetic Refurbishment of Brick Buildings

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CO2OL Bricks ´Conference Rudolf Plagge © 2012 in Tallinn

1. Building physical research laboratory
   Multichamber climate test facility

2. Modeling and simulation
   DELPHIN / COND / CHAMPS / ...

3. Application and test buildings
   Herrnenschliesshaus 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 Sapor 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, CO2-reduction
Reduction of cost of operation

Heating energy consumption kWh/m²a

- Solar buildings
- Construction practice
- Old building constructions
- Research, demonstration projects
- Low energy buildings
- New buildings
- Ultra low energy buildings
- Zero heating buildings

Why insulation?

Protection against condensation and mould

Enhancement of thermal comfort
Behavior of buildings in winter

Outside insulation
- Small vapor flow into the construction

Interior insulation
- Large vapor flow into the construction

Inside
- Brick masonry
- Thermal insulation

Outside
- Vapor pressure
- Temperature

Insulation system basing on materials...

- Perlite
- Mineral fiber
- Mineral foam
- Calcium silicate
- Foam glass
- Wooden fiber boards
- Cellulose
- PUR
Condensation caused by inside insulation

- **Temperature**
- **Water vapor**
- **Condensation zone at the cold side of the insulation**

2 different solutions

Inside insulation vapor tight

- **Temperature**
- **Water vapor**

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

Example for tight systems:

- **Mineral composed having foil or tight**
  - Mineral wool $\lambda \approx 0.04$ W/mK
  - Foam glass $\lambda \approx 0.045$ W/mK

- **Organic composed having foil**
  - Styrofoam $\lambda \approx 0.04$ W/mK
  - Cellulose, wooden fibers $\lambda \approx 0.04$ W/mK

- **Design Systems**
  - Vacuum pannel $\lambda \approx 0.008$ W/mK
  - Mineral wool + pyrogen silicat acid $\lambda \approx 0.02$ W/mK
condensation zone is located at the cold side of insulation

fast redistribution of condensate by capillary forces

fast evaporation
reduction of local moisture

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, ...

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 $\lambda \sim 0.045 - 0.055 \text{ W/mK}$

composites
- 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 $\lambda \sim 0.03 \text{ W/mK}$
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
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
- Temperature
- Relative humidity
- Precipitation

Indoor temperature

Indoor relative humidity

12/96 - 06/01
Wilhelminian style building in Dresden: monitoring points

Wall profile and position of monitoring points in the basement:
- Outside
- Inside
- Heat flow
- Condensate
- Relative humidity
- Temperature
- Sandstone
- Brick
- Plaster
- Glue mortar
- Calcium silicate climate board
- Inside plaster

Wilhelminian style building in Dresden: comparison of measurement and calculation

Temperature:
- Cold side of insulation
- Inside surface wall

Heat flow:
- Inside surface wall

Measurement and calculation:
- 12/96 - 06/01
- Calculated vs. measured
- Temperature in °C
- Heat flow in W/m²
Wilhelminian style building in Dresden: comparison of measurement and calculation

relative Luftfeuchte in %
gemessen
berechnet
Condensation range: > 95-98% rel. humidity

Investigated details/questions:
Application Rijksmuseum Amsterdam
- Which type of insulation?
- Which thickness of insulation?
- Drying behavior?
- Free od condensate?
- Mould risk?
- Risk of freesing?
- solution to constructive details?
- Distance of paintings from wall?
**Application Rijksmuseum Amsterdam: calcium silicate climate board (Calsitherm)**

**Mansard:**
- Thickness of brick wall is 260 mm!

**Numerical simulation:**
- Geometry
- Boundary conditions

**Ambient design conditions - Arup (2002):**
- Outside climate:
  - Temperature: 20 – 23°C
- Climate data Amsterdam (1964/85)
- Wood wall

**Relative Humidity:***
- Middle of July after a cloud burst
- Beginning of November (first cold snap)
- End of December

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**Application Rijksmuseum Amsterdam**

**Mansarde:**
- Field of relative humidity:
  - Begin of July
  - Middle of July 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

- (1) Without insulation
- (2) 35mm insulation, no plaster
- (3) 50mm insulation, 5mm plaster

Indoor rel. humidity [%]

Temperature [°C]

The project „magazines Speicherstadt Potsdam“

- Persius-magazine
- Boelcke-magazine
- Schinkel-magazine
Comparison of insulation loam cork without driving rain protection

- **no insulation**
- **60mm WDL**
- **80mm WDL**

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

- 94% rH
- 96% rH
Water content of wooden beam: west orientation, east orientation

- West orientation
- East orientation

Critical boundary value

Water content [Vol%] vs. Time [a]

Wall construction, driving rain protection
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 \(\rightarrow\) emulsion cream
- keeping drying potential, \(\rightarrow\) no reduction of water vapor transport
- no visual effects after application
Water content of wooden beam: west orientation, east orientation

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<tr>
<th>Time [d]</th>
<th>Water content [Vol%]</th>
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<td>West orientation</td>
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Critical boundary value

Hydrophobic impregnation having mismatches for 80mm interior insulation

Mismatches of hydrophobation
Hydrophobic impregnation having mismatches

Graph showing the change in hygroscopic moisture mass over time for different wall conditions:
- Wall no restauration
- Wall + 80mm calcium silicate
- Wall + hydrophobic surface + 80mm CaSi
- Wall + hydrophobic with mismatch + 80mm CaSi

"Am Urban", a city rehabilitation in Berlin Kreuzberg

Photos of the buildings from different angles:
- west
- east
- north
- south
Typical thermal bridges cause energy losses

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 - 1 cm 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
**Relative humidity field:** wall corner thickness 51 cm, corner insulation cm iQ-Therm, boundary according to DIN 4108 part 2

- $\vartheta_{\text{inner}} = 87\%$
- $\vartheta_{\text{outer}} = 81\%$

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

- $t_{\text{outer}} = -5^\circ C$
- $R_{\text{out}} = 0.04 \text{ mK/W}$
- $t_{\text{inner}} = 12.9^\circ C$
- $R_{\text{in}} = 0.25 \text{ mK/W}$
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

Window details:
Hygrothermal simulation

Window detail: … steel beams
real climate

Summary

Positive effects of interior insulation

- Energy saving and CO₂-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

**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.
Conclusions

Energetic upgrade of historic building construction requires detailed knowledge in various fields

- building materials
- construction details
- real climate conditions
- hygrothermal simulation tools

→ A special education is required for an adequate refurbishment
→ New fields of education for architects, engineers, handcraft:
  - university level (TU-Dresden)
  - graduation level (WTA)

Cultural heritage interior inside insulation 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
- "Herrenschiederhaus" in Nuremberg
- Karuna Montessorischule Berlin

Red Barracks Potsdam

Elbe philharmony Hamburg
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