Current topics and challenges in German building physics research

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Technische Universität Dresden
Institute of Building Climatology
Germany
City of Dresden
## Professors

<table>
<thead>
<tr>
<th>Name</th>
<th>Title</th>
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</thead>
<tbody>
<tr>
<td>Prof. John Grunewald</td>
<td>Chair of Building Physics</td>
</tr>
<tr>
<td>Prof. Stefan Stüer</td>
<td>Chair of Building Services</td>
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## Research Groups

<table>
<thead>
<tr>
<th>Name</th>
<th>Title</th>
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<tbody>
<tr>
<td>Dr. Andreas Nicolai</td>
<td>Head of the Modeling and Software Development Group</td>
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<tr>
<td>Dr. Rudolf Plagge</td>
<td>Head of the Building Physics and Materials Laboratory</td>
</tr>
<tr>
<td>Dr. Andreas Söhnchen</td>
<td>Head of the Knowledge Transfer and Engineering Experts Group</td>
</tr>
</tbody>
</table>

## Employees

- 20 Scientific Employees (3 permanent)
- 10 PhD Candidates (3 external)
- 20 Student Research Assistants
Research topics

New insulation systems
Durability & damage analysis
Comfort & indoor air quality
Energy storage & savings
Museum Application Examples

Netherlands

Rijksmuseum Amsterdam
Thermal Insulation of Envelope Walls

Germany

Historical City of Dresden
Flooding and Drying of old Brickwork Masonry

Japan

Kumamoto Castle
Temperature and Humidity conditions in the exhibition room
The Rijksmuseum undergoes its most comprehensive renovation in its history

- Indoor conditions do not meet museum requirements
- Moist walls ~ bricks tested, high moisture contents found up to 20 Vol% (close to capillary saturation)
- Moisture buffer capacity of the walls should be improved
Building physical questions

Which insulation material, Which thickness?
Drying behavior?
Condensation, Risk of mold?
Moisture buffering, Indoor climate?
Frost damages by rain?

- How design details?
- Micro climate near wall surfaces?
- Positioning of paintings?
Hygrothermal performance of heavy brickwork masonry

Museum conditions

1. Existing construction

2. Foam glass insulation

3. Calcium silicate insulation

Natural climate

- Temperature
- Short wave radiation
- Long wave radiation
- Relative humidity
- Wind
- Rain
- Cloudiness

- Weather data from Amsterdam (1964/65, from the Arup Company)
- Long wave radiation from nearest location (Bremen)
- Rain fall data from nearest location (Bremen - amount of rain adjusted to monthly mean values of Amsterdam)

Ambient hygrothermal design conditions – Arup 2002

Summer: 23°C / 54%
Winter: 20°C / 50%
Tolerance: ±2K / ±5%
Rijksmuseum: Simulation results

Drying:

Current State

- Initial state
- After 1 month
- After 3 months
- After 6 months
- After 9 months
- After 1 year

Location in [m]

- 0.60
- 0.50
- 0.40
- 0.30
- 0.20
- 0.10
- 0.05
- 0.00

Water content in Vol%

- 110
- 100
- 90
- 80
- 70
- 60
- 50
- 40
- 30
- 20
- 10
- 0

Integral Water mass

- 110
- 100
- 90
- 80
- 70
- 60
- 50
- 40
- 30
- 20
- 10
- 0

Time in years

- 0
- 0.1
- 0.2
- 0.3
- 0.4
- 0.5
- 0.6
- 0.7
- 0.8
- 0.9

Water mass in kg/m²

- Vorhandene Konstruktion
- Schaumglas-Dämmung
- Calciumsilikat-Dämmung

Existing Construction

- Foamglass insulation
- Calcium silicate insulation

Museum Application Examples

Symposium Tampere 2013
Museum Application Examples

during the 5th year for a 400mm brick wall

Relative humidity on inner wall surface

- (1) 400mm brick wall without insulation
- (2) 30mm Cellular glass on 400mm brick wall
- (3) 30mm Calcium silicate on 400mm brick wall

Relative Humidity in %

- 70 % limit (not acceptable, mold growth, danger of condensation)
- 60 % limit (acceptable, paintings must have spacing)

Time in years

Rijksmuseum Amsterdam
Hygrothermal Application Examples

Risks being analyzed by Delphin 5 simulations

**Internal wall surface**
- Dampness
- Condensation
- Improper microclimate
- Salt efflorescence
- Mold growth

**Wall body**
- Interstitial condensation
- Reduction of thermal insulation
- Decay of materials due to moisture accumulation

**External wall surface**
- Surface wetting, Condensation, Algae growth
- Deterioration due to temperature and moisture cycles
- Crack induction according to magnitude and frequency of gradients
- Frost damage by crystallization, freezing-thawing cycles
Building energy performance

Net energy
End energy
Primary energy
B.2 Siedlungswohnbauten 1920er-1950er Jahre

Building model for energy analysis

Radebeul, Pestalozzistr. 13

John Grunewald, Finnish Building Physics Symposium Tampere 2013
Building Energy Balances

Gains
- Solar
- Internal

Losses
- Transmission
- Ventilation

Net energy
- Windows
- Walls
- Lighting
- Equipment
- Inhabitants

Final energy
- Walls
- Windows/Doors
- Ceilings/Floors
- Infiltration
- Nat. Ventilation
- Mech. Ventilation

Primary energy
- Coefficients of Performance
- Primary energy factors

Funding?
- Low energy
- Zero energy
- Plus energy

Primary energy factors
- \( \sum \text{Gas} \)
- \( \sum \text{Electr.} \)
- \( \sum \text{Demand minus Generation} \)
John Grunewald, Finnish Building Physics Symposium Tampere 2013
Federal energy research program

Aims 2050

- Reduction of greenhouse gas emissions by 80 to 95% compared to 1990 (2020: 40%)
- Reduction of primary energy consumption by 50% compared to 2008
- Reduction of power consumption by approximately 25% compared to 2008 (2020: 18%)
- Development of renewable energy sources at a proportion of 60% in gross (2020: 18%) or 80% of gross electricity consumption (2020: at least 35%).
Pilot Projects for Energy Efficient Cities

Pilot projects are to show how energy efficiency in communities can be improved via intelligent use and networking of innovative technologies, planning and management methods. The EnEff:Stadt research initiative identifies assessment criteria and concepts as well as planning aids for municipalities and other actors, such as the housing industry and public utilities. In the context of the initiative, exergetically and economically optimised combinations of measures are developed for defined quarters. The implementation of these measures acts as an example and their effects are measured. The research is carried out in typical housing schemes. Development results are tested and assessed in typical city quarters. At the same time, the realisation of energy concepts and their monitoring and measurement is intended to implement the concept of integral planning. The aim is a minimum 30 percent reduction in primary energy use in the entire quarter through consistent application of new technologies and intelligent planning. The transfer of research and development results will provide the specific expertise needed to meet the urban development challenges of the future.

The Community of Wüstenrot: Energy-independent by 2020

Wüstenrot is set to become energy-independent by 2020: scenarios for the development of renewable energies are being calculated based on a 3D urban model, strategies for economically utilising this potential are being developed and measures for increasing the
Residential Area (+energy*)
Ludmilla Wohnpark Landshut

- Earth heat exchangers (research focus)
- Building energy monitoring & model calibration
- Influence of energy metering information on human behavior
- Role of residential area in the electricity / gas network (national grids)

www.eneff-stadt.info (energy efficient cities / networks)

*primary energy supply > demand

Duration: 2010 - 2013
Ludmilla Wohnpark Landshut (2010-2013)

Layout of the residential area

- 8 multi-family multi-storey houses
- 14 single-family houses
- 1 energy concept

Source: Ludmilla-Wohnbau GmbH

www.ludmilla-wohnpark-landshut.de
Energy concept

Renewable energy

- Solar
- Geothermal
- Biogas

Energy supply

- Photo-voltaik
- Heat Pump
- Combined Heat+Power
- Gas-fired hot water tank

Energy demand

- single-family houses
- multi-family multi-storey houses

Source: PhD Volker Stockinger
Ludmilla Wohnpark Landshut (2010-2013)

Monitoring on the Residential / Building / Apartment level

Whole Residential Area
- Biogas demand
- Combined heat-power generated electricity
- Final heating energy

Each Building
- Generated PV electricity
- Electricity demand of controlled ventilation
- Temperatures/Humidities/CO₂ in air ducts

Each Apartment
- Electricity demand
- Heating and DHW energy demand
- Room temperature and relative humidity in 18 apartments
- CO₂ concentration in 10 apartments

Source: Ludmilla-Wohnbau GmbH  
www.ludmilla-wohnpark-landshut.de
Ludmilla Wohnpark Landshut (2010-2013)

**Building model to estimate energy demand**
created by using DesignBuilder software

Analysis of energy balances and indoor comfort

Source: Bachelor thesis by Huber/Bichler
Building model to estimate energy demand

created by using DesignBuilder software

Hourly operative room temperatures vs. outdoor temperature

Natural vs. mechanical ventilation (min. fresh air provided)

Source: Bachelor thesis by Huber & Bichler
shallow geothermal energy

Source: PhD Volker Stockinger
Ludmilla Wohnpark Landshut (2010-2013)

Ground model created by using Delphin 5 software

Issues to be addressed:
- Collector model + Heat pump
- 3D Approximation
- Ground water flow
- Freezing / Thawing processes

* www.bauklimatik-dresden.de
http://champs.syr.edu/
EnOB: Research for energy-optimised construction

"Buildings of the future" is the guiding concept behind EnOB – research for energy-optimised construction (the name EnOB is an abbreviation of the equivalent German term Energieoptimiertes Bauen). The research projects sponsored by the German Federal Ministry of Economics and Technology involve buildings that have minimal primary energy requirements and high occupant comfort, with moderate investment costs and significantly reduced operating costs. This requires sophisticated building concepts and innovative technologies. For this reason, EnOB places an emphasis on research and development in construction engineering and technical building equipment, such as low-exergy systems, building elements with vacuum insulation, or innovative glazing and facade systems. A second focus is on scientifically evaluating energy-optimised buildings. Therefore factors determining success and performance-related criteria are identified for designers, manufacturers and operators of buildings. Learn more about the various areas on which EnOB research is focussing, and about the testing of new concepts, technologies and materials in model projects.

Net zero-energy buildings & co

Laboratory for sustainable construction

read more
Structure of the EnOB Research Program

National Funding by German Ministry of Economics and Technology

Research and Development

Demo Buildings

Accompanying Research

ViBau
vacuum insulation

LowEx
low exergy technologies

EnBau
new energy-optimized buildings

EnSan
energy-optimized retrofitting

MONITOR
• workshops
• symposiums
• analysis
• simulation
• teaching
• learning platform

Know-How

EnBop
Optimized building operation

evaluation, case studies, methods

other technology clusters

Gebäudepraxis Nichtwohnungsbau

Gebäudetechnik

Forschungsintensive Demonstrationsbauvorhaben

Technology transfer
Retrofitting of a Type-P2 large panel construction in Wittenberg

Year of construction: 1976
Main research focus: application of SOLARWALL air collectors for DHW and preheating of supply air

[Graph showing energy savings: before retrofitting 158 kWh/m²a, after retrofitting 48.5 kWh/m²a, 70% Savings]

Source: Fraunhofer IBP
EnSan

Retrofitting of 3 residential buildings in Hofheim

Year of construction: 1927
Main research focus: application of prefabricated large-unit vacuum insulation panels

75% Savings

Source: Fraunhofer IBP
Retrofitting of a Wilhelminian style building in Zittau

Year of construction: about 1900
Main research focus: application of capillary-active calcium silicate panels together with interior insulation

67% Savings

Source: Fraunhofer IBP
Examples of demonstration projects

More than 50 demonstration projects in total, about 25 still running.

- German Federal Environmental Agency
  - EnBau

- Service and Administration Center Barnim
  - EnBau

- Municipal Library and Museum Nuremberg
  - EnSan
Challenges

- low heating energy demand (50 % less than standard)
- preconditioning of air with earth heat exchanger
- ventilation with heat recovery = 73 %
- limitation of electric power usage
- minimization of (solar) cooling requirements by sun protection, optimized window to wall ratio, low internal gains, high thermal mass with adobe walls etc.
Examples of demonstration projects

More than 50 demonstration projects in total, about 25 still running.

German Federal Environmental Agency

Service and Administration Center Barnim

Municipal Library and Museum Nuremberg
Challenges

- well-insulated wood facade elements with cellulose insulation
- windows with triple glass panes, low emissivity coating
- sophisticated daylight and artificial lighting concept, with a large amount of transparent surface area facing the interior combination zones
- foundation piles equipped with absorber registers for heating and cooling
- ventilation systems with heat recovery efficiency of up to 80%
- vacuum insulation and PCM in selected rooms
EnBau

Energy gain by production from renewable resources

Energy demand by occupancy and building operation
Examples of demonstration projects

More than 50 demonstration projects in total, about 25 still running.

German Federal Environmental Agency

Service and Administration Center Barnim

Municipal Library Nuremberg
Municipal Library Nuremberg

destruction in WW II
re-erected in 1950s
used as public library

general reconstruction 2009/2010
Challenges

- building will contain the various library functions at a central location in Nuremberg
- energy consumption 30% below EnEV (German Energy Saving Ordinance)
- optimized glazing area
- massive construction, heat insulation on outside and between areas with different operating temperatures
- ground water cooling
- storage of manuscripts, incunabula, prints and maps from the Middle Ages
- climate stabilization in magazines with historic books and documents
Building model to estimate energy demand
created by using DesignBuilder software
Building model to simulate annual energy demand

- Effective energy demand
- Effective energy gains
- Final (end) energy
- Primary energy

created by using DesignBuilder software

John Grunewald, Finnish Building Physics Symposium Tampere 2013
Simulation results:

by EnergyPlus

Final energy power = 121 kWh/m²
Final energy gas = 82 kWh/m²
Primary energy = FE power * 2.7 + FE gas * 1.1 = 365 kWh/m²

Effective energy demand break down in kWh/m²a

- Heating
- Lighting
- Electricity
- DHW
- Misc.
Objective: ensure stable room climate conditions, dimensioning of HVAC, low energy demand

Measurement of sorption isotherm for paper and historic books
TRNSYS + Delphin simulation of climate in magazines

Relative humidity in magazine for historic books in %

without moisture storage

required climate corridor
45 ..55 % rel. hum.

with moisture storage of books

Nuremberg City Library
Building performance simulation

Buildings - Energy demand
Rooms - Thermal comfort
Constructions - Moisture, Durability
<table>
<thead>
<tr>
<th>Year</th>
<th>Wall Assemblies</th>
<th>Room Models</th>
<th>Whole Buildings</th>
<th>Libraries</th>
</tr>
</thead>
<tbody>
<tr>
<td>1988</td>
<td>DIM 1, DIM 2, DIM 3</td>
<td>Heat-Air-Moisture analysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>DELPHIN 4</td>
<td>Single-zone, single-node thermal model, 1D-walls</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2003</td>
<td>+ Salts</td>
<td>Therakles ...</td>
<td>Single-zone, multi-node HAM model, 3D-walls</td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>+ Pollutants (VOC adsorption, diffusion)</td>
<td></td>
<td>CHAMPS-Multizone ...</td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>CHAMPS-BES</td>
<td></td>
<td></td>
<td>NANDRAD ...</td>
</tr>
<tr>
<td>2012</td>
<td>+ Multi-language and multi-platform support</td>
<td></td>
<td></td>
<td>Framework ...</td>
</tr>
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</table>

**Libs:** CVODE lib, CC lib

**Sundials, IBK, Airflow, Pollutants, Solver libs**
Structure of the EnOB research program

National Funding by German Ministry of Economics and Technology

Research and Development

Demo Buildings

Accompanying Research

EnTool 2013
Symposium, Workshop & Summer School
Tools and Data for energy-optimized Buildings, Neighborhoods, Residential Areas and Cities

in the rooms of the SLUB Library by the Dresden University of Technology (TUD)
Institute of Building Climatology (IBK)

EnTool

MONITOR
- workshops
- symposiums
- analysis
- simulation
- teaching
- learning platform

Know-How

Evaluation, case studies, methods

EnBop

Optimized building operation
MULTIZONE SIMULATION + DETAILED WALL MODELS + DETAILED ROOM MODELS

- Architecture
- Constructions
- Zone activities
- Lighting concepts
- HVAC systems

Constructional modeling
- Thermal storage effects
- Panel heating systems
- Hygrothermal processes
- Durability
- Micro climate, Emissions

Thermal zone modeling
- Radiant heaters
- Radiation balance
- Temperature stratification
- Air convection
- Comfort calculation
NANDRAD

- Building geometry
- Construction data + Materials
- Zone activities (user profiles)
- Lighting systems
- HVAC systems
- Climate data

Compatible to EnergyPlus by support of IDF standard

Zonal single-node network model for calculation of

- Temperature
- Moisture
- Air pressure
- VOC concentration

in each zone.

With financial support from
NANDRAD + HAJAWEE

- Building geometry
- Construction data + Materials
- Zone activities (user profiles)
- Lighting systems
- HVAC systems
- Climate data

HAJAWEE Room model

Discretisation of rooms
- Temperature stratification
- Air convection in rooms
- External radiation balances
- Internal radiation
- Comfort calculation
- Internal heat sources (e.g. radiators)
**NANDRAD + DELPHIN**

- Building geometry
- Construction data + Materials
- Zone activities (user profiles)
- Lighting systems
- HVAC systems
- Climate data

**Discretisation of constructions**
- Durability of constructions
- Moisture & thermal buffering
- Thermo-active systems
- Capillary-active systems
- Panel heating systems
- Emissions from materials
- Micro climate
Thank you for your attention!