Building performance simulation
For energy efficient buildings and communities
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Indoor environment

- We spend ~ 90% of our lifetime indoors
- Increasing comfort expectations
- Productivity awareness
- Health concerns

Economic impact:
- € energy
- € € productivity
- € € € health
Ongezonde luchtkwaliteit leidt in Nederlandse steden tot:

12.000 ziekenhuisopnames ✦ en 5.600 sterfgevallen. †

Om de gezondheid te bevorderen, wordt er in een gebouw rekening gehouden met deze factoren:
Some other building challenges

- Buildings range from tiny to gigantic
- Built environment has many different stakeholders
- Buildings are (mostly) one-off designed, built and operated
- Each building is a compromise/”optimization” depending on available resources and stakeholder “wishes”
- Construction ranges from DIY to industrial
- Buildings have a long (expected) lifetime
- Buildings need to be flexible (organizations change)
- Building systems need to be robust (climate change)
- Buildings are (becoming more) complex
- Buildings are (becoming more) interconnected
- …
Global environment

Possible 80% cut in greenhouse gas emissions in the EU (100% = 1990)

https://ec.europa.eu/clima/policies/strategies/2050_en
Innovative building solutions

» Integrated electricity production
» Energy storage systems
» Adaptive building skins
» Heat recovery windows
» Hybrid ventilation
» Switchable glazing
» Super-insulation
» Micro co-generation
» Demand response
» …

[ARUP, imagining buildings of the future:
http://www.arup.com/Homepage_Imagining_buildings_of_the_future.aspx]
Smart energy buildings & cities

[http://solutions.3m.com]
Smart energy buildings & cities

Wertschöpfungskette Power to Gas
Quelle: cesa (2013)
Smart energy buildings & cities

http://www.districtenergyinitiative.org/resources
Goal and vision

• A zero-carbon built environment with indoor environment optimized for health, comfort and/or productivity

• Requires a multiscale/multiphysics and transdisciplinary performance based approach

• Computational building performance simulation can play an important role
Building performance simulation

Using a (computer) model (= virtual building(s) / digital twin) to predict what will happen in the real world
Building performance simulation

Using a (computer) model (= virtual building(s) / digital twin) to predict what will happen in the real world

Iterative process, involving:

• Problem formulation and objectives definition
• Model development, including analysis of building (existing or new) and model verification, validation and testing
• Simulation (experiments) with (design) relevant boundary conditions
• Multi-variate analysis of simulation results and extraction of relevant (design) information
Building performance simulation

- Energy Performance
- Thermal comfort
- Daylight
- Airflow
- Heat transfer
- HVAC system operation
- ...
Building performance simulation “opportunities”

- Product R&D support
  - Modelling innovative system/components
  - …

- Design support
  - Risk management/optimization under (use) uncertainty
  - Multi-physics (power flow modeling, …)
  - …

- Building operation and management support
  - Relevant in-use energy consumption prediction
  - Model predictive (supervisory mimo) control
  - …
Building simulation for R&D support

Experimentation as four-step iterative cycles (Thomke 2003)

Step 1: Design
- Conceive new ideas and concepts (the experiments)
- Refined concepts using information from last cycle

Step 2: Build
- Build virtual models or physical prototypes to be used in experiments
- Prepare testing set up

Step 3: Run
- Run tests using models or prototypes
- Test environment, conditions, and cases correspond to real or simulated use conditions

Step 4: Analyse
- Carefully analyse observations
- Develop or modify understanding about cause and effect

SolarBeat outdoor test facility
Smart energy glazing

Total energy savings
Useful daylight illuminance
Glare discomfort
Overheating hours

Relative performance gains [%]

- Total energy savings
- Useful daylight illuminance
- Glare discomfort
- Overheating hours

[Graph showing relative performance gains for different conditions]
Smart energy glazing

<table>
<thead>
<tr>
<th></th>
<th>Reference</th>
<th>Smart Energy Glass</th>
<th>Alternative Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting</td>
<td>8.38 kwh</td>
<td>27.73 %</td>
<td>-6.75 %</td>
</tr>
<tr>
<td>Cooling</td>
<td>23.15 kwh</td>
<td>-280.76 %</td>
<td>-5.9 %</td>
</tr>
<tr>
<td>Heating</td>
<td>224.03 kwh</td>
<td>-37.18 %</td>
<td>-46.55 %</td>
</tr>
<tr>
<td>Totals</td>
<td>255.56 kwh</td>
<td>180.99 kwh</td>
<td>175.28 kwh</td>
</tr>
</tbody>
</table>

The total of Lighting, Cooling, and Heating over 12 months for each glass type.
Climate adaptive greenhouse shells

- Thermal and optical properties of greenhouse shells
- Optimization of photosynthesis and energy performance
- Sensitivity | uncertainty | robustness

On the use of building energy simulation programs in the performance assessment of agricultural greenhouses
Proceedings of IBPSA Asia Conference 2012

Agentschap NL
Ministerie van Economische Zaken,
Landbouw en Innovatie
Climate adaptive greenhouse shells

< Yearly optimum properties >

< Monthly optimum properties >

< Hourly optimum properties – Daytime >

< Hourly optimum properties – Nighttime >
Climate adaptive greenhouse shells

Crop growers
Dutch government
Material developer
... etc.
Building simulation for design
E+ industrial halls

- Comprehensive Design Space Exploration
- Robust Design Optimization
- Life-cycle Energy Analysis

Energy performance and life cycle analysis:
TRNSYS, DAYSIM, Matlab

Climate change - robustness

  1% - 44+ 30 jaar
  5% - 94+ 30 jaar

Computational performance prediction of the potential of hybrid adaptable thermal storage concepts for lightweight houses

- Make smart use of thermal storage to reduce energy demand and increase thermal comfort in lightweight residential houses

  e.g. in winter: low thermal storage capacity (short pre-heating period)
  e.g. in summer: high thermal storage capacity (reduce peak temperatures)

- Design optimization under uncertainty
- Robust building performance

Towards robust energy efficient buildings

A computational methodology for performance robustness assessment of energy efficient buildings for future scenarios

**Methodology:**

<table>
<thead>
<tr>
<th>Designs</th>
<th>Future scenarios</th>
<th>Multi-criteria performance robustness assessment</th>
<th>Selection of robust design</th>
</tr>
</thead>
<tbody>
<tr>
<td>GA based optimization</td>
<td>Latin hypercube sampling</td>
<td>Min-max regret method</td>
<td>Savage MCDM method</td>
</tr>
</tbody>
</table>

**Highlights:**

- Multi-criteria performance assessment
- Min-max regret method for robustness assessment
- Multi-criteria decision making
- Robust designs for different decision makers

**Key findings:**

- Active solutions are more robust compared to passive solutions
- Buildings with low insulations and large PV systems are cost optimal robust solutions
- Buildings with very high insulation levels are prone to overheating risks in the future

Global cost

- Cost of investment, replacement and operational
- Calculated for period of 30 years – service life span of energy systems
**CO₂ emissions**

\[ CO₂ \text{ emissions} = \text{Energy consumption} \times \text{EF} - \text{Energy generation} \times \text{EF} \]

- EF = CO₂ emission factor
- Embodied emissions are not taken into account

Performance variation across all scenarios

Performance robustness across all scenarios
Isabella Gaetani

A strategy for fit-for-purpose occupant behavior modeling when predicting building energy and comfort performance

Increasing modeling complexity does not necessarily produce more accurate results

The modeling complexity of each uncertain OB aspect should depend on the sensitivity of the results

Design of a Modelica based evaluation model for district energy systems.

Figure 1: Illustration of a typical district energy system, combining CHP with thermal storage and distribution and delivering electricity to the grid.
Fit-for-purpose simulation testbed for new generation district heating systems (DHS)

**Different Perspectives**

- Project Phases
- Stakeholders

**Components in DHS**

- DH - District heating
- DHW - Domestic Hot Water
- IWH - Industrial Waste Heat
- STS - Solar Thermal System
- BETS - Borehole Thermal Energy Storage

**Model Complexity**

- Model Complexity vs. Increasing Model Complexity
- Uncertainty vs. Total Uncertainty

**Preliminary System Performance Assessment**

- Designed case
  - On-site generation covered 30%-80%
- No extra heat supply during winter
  - 31% of heating hours lower than 20 °C
  - Monthly heat demand

• Case 1: no seasonal heat storage
Building simulation for O&M

[Image credit: Autodesk]
Energy optimization of (geographically distributed) data centres

- Workload Actuators
- Thermal Actuators
- Power Actuators
- VM Allocation
- VM Migration
- Supervisory intelligence
- WSN Design Tool
- Fault Detection & Diagnostics (FDD)
- Decision Support for RES Integration
- Multi data center intelligence
- Simulators
- Workload Prediction
- Thermal Prediction
- Power Prediction
- Workload Monitoring
- Thermal Monitoring
- Power Monitoring
- Visualization / Human-Machine Interface
- Supervisory intelligence
- WSN Design Tool
- Fault Detection & Diagnostics (FDD)
- Decision Support for RES Integration
- Multi data center intelligence
- Simulators
- Workload Prediction
- Thermal Prediction
- Power Prediction
- Workload Monitoring
- Thermal Monitoring
- Power Monitoring
Towards data centre holistically optimized operation: Methodology for testing and commissioning of control algorithms for mission critical environment

- Testing and commissioning of advance control strategies is **extremely limited** in the data centre case
- Development of the control strategies is often **slowed down** or even **discarded** due to the lack of testing possibilities

- **Virtual testing** can offer a **safe testing environment** to quantify the impact of the control strategies

- The virtual DC environment allows testing in a **closed-loop** fashion. The performance of algorithms may be evaluated at several scales and domains.

**RESULTS AT ROOM/RACK/SERVER SCALE** – temperature distribution

**RESULTS AT BUILDING SCALE** – Demand vs On-site Production analysis

Funded by The European Union
Summary

- Major challenges and opportunities ahead
- Need intelligent people and smart approaches
- Building performance simulation is a very powerful engineering technique to help you with this
IBPSA,

the International Building Performance Simulation Association, is a non-profit international society of building performance simulation researchers, developers and practitioners, dedicated to improving the built environment.

Building Simulation 2017

An exciting new feature of the Building Simulation conference is the opportunity to present alternative sessions that complement the traditional peer-reviewed paper sessions (abstract acceptance for peer-reviewed papers to be announced October 19, 2016). These new sessions provide opportunities for practitioners to report on their work, for researchers to present more timely results, and for [...]
Thank you!

or http://www.tue.nl/staff/j.hensen/