Simulation based façade control implemented as a responsive building element

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Smart and Efficient Energy Council (SEEC’2009)
Trento / Italy, October 8 - 9, 2009
Table of Content

> Introduction

> Integrated Building Energy Performance Simulation

> Responsive Building Elements

> Case Study: Swiss Office Building

> Ongoing Work / Perspectives
Introduction

> one of the most important groups of engineering companies in Switzerland

> founded in: 1862, limited company since 1970

> number of staff: 548

> annual turnover: 79.3 mil. CHF
Introduction

> Building Simulation

> from scientific point of view: research focuses on methodical search for new conclusions and systematic documentation and dissemination

> from engineering point of view: generating practical solutions on time (pragmatic approach)
Integrated Building Energy Performance Simulation

> Simulation primarily used for building and energy design

> Linear approach is commonly used

Results:
- Optimization of design conditions
- Effect on design of building physics and HVAC design
Integrated Building Energy Performance Simulation

> Simulation used for building and energy design (integrated approach)

> Simulation results are transferred to building operation phase

Results:
- Optimization of design conditions
- Effect on design of building physics, and HVAC engineering
- Effect on Building controls strategy
- Preconditioning for commissioning (set-up with arbitrary values)
- Simplified set-up of energy monitoring
Integrated Building Energy Performance Simulation

Building Simulation

Facade / HVAC Design

General Operation Design

Definition of Hardware Requirements

Detailed Control Strategies

Implementation of Control Strategies

Monitoring of Operation

Energy Demand / Room Temperatures (calculated)

Energy Demand / Room Temperatures (measured)

Linear approach

Integrated approach
Responsive Building Elements

- Active Building Construction Components used for
  - transfer or storage of heat, light, water and air
- Functions, features and thermophysical behaviour of responsive building components
  adapt to different building requirements
- Examples of responsive building elements
  - Foundations (earth coupling systems e.g.)
  - Energy storage (active use of thermal mass)
  - Phase changing materials (PCM’s)
  - Facade systems (ventilated facades, adaptable facades e.g.)
Responsive Building Elements

> Active Facade Systems

> building envelope with dynamic behaviour (blinds, ventilation, glazing)

> adaptive to outdoor conditions and indoor requirements

> goal is to actively help minimize building energy consumption while also meeting static building envelope functions

> Case Study: Swiss Office Tower

Transition of a common double skin facade into a responsive building element with conventional hardware
Case Study: Swiss Office Tower

- Newly designed 15 story office building
- Skeleton-type building
- Double-skin glass facade
- Ground-coupled heat-pump
- Ventilation: Supply Air 50,000 m³/h

Energy:
- Heating 805 MWh/a, 550 kW
- Cooling 630 MWh/a, 492 kW

Construction started in 2009
> Layout of a typical floor

Red areas indicate zoning for thermal simulation.

The typical floor layout shifts 90 degrees on each floor.

In order to capture all orientations the model was rotated three times.
> Facade: modular, non-ventilated facade elements (panels, windows)

> Window / Wall ratio 0.77

> Wall panels $U = 0.55 \text{ W/m}^2\text{K}$

> 4 glass layers

> $U_g = 0.51, \ U_w = 0.92$

> $g = 0.45, \ \tau = 0.67$

> Blinds

> Blinds between glass

> Slat width 80mm
> Objectives of Building Energy Performance Analysis

> Comparison of two different glazing types

> Assessment of thermal comfort in selected individual rooms

> Calculation of annual energy performance for total building

> Tools

> EnergyPlus, Window 5, WIS
Due to high glazing ratio the main focus is on control strategies of blinds reducing:

- Zone Cooling Loads
- Glare Discomfort

Simulation models for different control strategies are available.
Control representation in simulation often differs from reality:
- Idealized operation without time delay

Diagram:

- Controls in theory (model)
- Controls in real life (applied model)
- Controls in real life (actual controller)
Simulation-based Blind Control

<table>
<thead>
<tr>
<th>Reducing Zone Cooling Load due to Window Solar Heat Gain</th>
<th>Reducing Zone Heating Load by reducing Window Conductive Heat Loss</th>
<th>Reducing Zone Heating and Cooling Load</th>
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<td>On If Schedule Allows</td>
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</table>
Simulating Blind Control - Step 1

> Simulated Blind Control: **ON If High Solar Radiation On Window**

> Total exterior solar beam on facade surface \( (W/m^2_{Facade}) \)

![Graph showing solar radiation on facade surfaces](image)

- **South**
  - 20:00 Uhr
  - 12:00 Uhr
  - 06:00 Uhr

- **West**
  - 20:00 Uhr
  - 12:00 Uhr
  - 06:00 Uhr

Jan - Feb - Mar - Apr - May - Jun - Jul - Aug - Sep - Oct - Nov - Dec
Simulating Blind Control - Step 1

> Annual operating hours of blinds (Set-point: ext. solar beam 300 W/m²)

> Annual blind usage per facade

<table>
<thead>
<tr>
<th>Zone</th>
<th>Facade</th>
<th>Blinds closed (office hours)</th>
<th>% of office hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>North</td>
<td>83 hrs</td>
<td>2 %</td>
</tr>
<tr>
<td>1</td>
<td>West</td>
<td>957 hrs</td>
<td>22 %</td>
</tr>
<tr>
<td>2</td>
<td>North</td>
<td>83 hrs</td>
<td>2 %</td>
</tr>
<tr>
<td>3</td>
<td>West</td>
<td>957 hrs</td>
<td>22 %</td>
</tr>
<tr>
<td>4</td>
<td>South</td>
<td>1150 hrs</td>
<td>26 %</td>
</tr>
<tr>
<td>5</td>
<td>East</td>
<td>377 hrs</td>
<td>9 %</td>
</tr>
<tr>
<td>5</td>
<td>South</td>
<td>1150 hrs</td>
<td>26 %</td>
</tr>
</tbody>
</table>

> Blind usage (summer day)
Simulating Blind Control - Step 1

> Annual operating hours of blinds (Set-point: ext. solar beam 300 W/m²)

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<th>North</th>
<th>East</th>
<th>South</th>
<th>West</th>
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<tr>
<td>20:00 Uhr</td>
<td></td>
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Adding dynamic blind slat angle control

- Blind slat angle adjusts depending on solar radiation and sun position
  - block direct solar radiation
- Blind slat angle was scheduled during the day

Example: Western facade (summer week)
Not all simulated control strategies are suitable for real life

**Organisational difficulties**
- Different requirements of users, architects and engineers
  - (energy demand vs. operating hours of blinds \(\rightarrow\) building appearance)

**Technical difficulties**
- Control parameters might not be suitable
  - (e.g. total zone cooling load difficult to measure if used as a parameter for blind control)
- Optimization not only of energy demand but also hardware requirements
  - (e.g. choice of electric motor, maintenance)
Integrated Blind Control

- Takes into account external solar radiation and zone cooling load

- Blinds are closed when there is high zone cooling load

- Thermal properties of facade thus influence blind usage

Two different glazing types were compared:

- Thermal insulating glass (3 layers)
- Thermal insulating glass (2 layers)

Cross-section of glass facade elements:

<table>
<thead>
<tr>
<th></th>
<th>3 Layers</th>
<th>2 Layers</th>
</tr>
</thead>
<tbody>
<tr>
<td>$U_g \ [W/m^2K]$</td>
<td>0.51</td>
<td>0.75</td>
</tr>
<tr>
<td>$U_w \ [W/m^2K]$</td>
<td>0.92</td>
<td>1.11</td>
</tr>
<tr>
<td>$g \ [\ ]$</td>
<td>0.41</td>
<td>0.51</td>
</tr>
</tbody>
</table>
> Annual operating hours of Blinds (South-facing facade)

Operating time depending on max. acceptable zone cooling load at which blinds are closed

- 3 Layers
- 2 Layers

> 2 Layer thermal insulating glass: operating hours on average 300 h / a higher

> 30 W/m²: Effect of additional zone cooling on blind operation decreases
Simulating Blind Control - Step 3

> Net cooling energy demand (Total building, excl. HVAC)

depending on max. acceptable zone cooling load at which blinds are closed

> High acceptable cooling loads increase cooling energy demand

> Net cooling energy demand of the 2-layered glazing is approx. 25% higher
> Annual operating hours of blinds (3-layered glazing)

> Blinds are closed at 80 W/m² max. acceptable zone cooling load
Simulating Blind Control - Step 3

> Annual operating hours of blinds (3-layered glazing)

> Blinds are closed for **visual comfort** or at 80 W/m² max. acceptable zone cooling load
Simulating Blind Control - Step 3

> Blind control influences building energy demand

Annual net heating and cooling energy demand (incl. plants, excl. electricity demands)

- Blinds close at 300 W/m² ext. solar beam
  - Net energy: -630
  - Final energy: -892

- Blinds close at glare discomfort or 80 W/m² cooling load
  - Net energy: -800
  - Final energy: -157

- Blinds close at 300 W/m² ext. solar beam
  - Heating: 161
  - Cooling: 147

- Blinds close at glare discomfort or 80 W/m² cooling load
  - Heating: 0
  - Cooling: -223

Heating: -9 %
Cooling: +42%
Integration of blind control strategies in overall building operation

Organizational aspects
- Technical specifications have to be available in time for tendering
- Coordination of engineer - contractor - building operator prerequisite

Technical aspects
- Integration of blinds in building automation systems (BAS)
  - bus systems
  - feedback to / from BAS is needed
- Translation of control algorithms to proprietary blind controllers
  - rule-based, table based e.g.
Simulation-based Blind Control

<table>
<thead>
<tr>
<th>Conventional Blind Control</th>
<th>Partially integrated Blind Control</th>
<th>Fully Integrated Blind Control (BAS)</th>
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> Example: EnergyPlus Shading Control Types

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Implementation of Integrated Facade Control

> Blind operation will be connected to BAS

> Blind control strategies depend on indoor and outdoor conditions

> Energy consumption depending on user requirements and available energy sources
  
  ➔ Free cooling will be used as much as possible
  
  ➔ Described control cycles will be detailed & implemented
Results & Ongoing Work

> Building energy performance analysis during design phase

> Goals:
Optimize design parameters,
analyse building operation at design conditions

> Results:
Evaluation of design alternatives,
Proof of proposed building functions,
Specification of operating modes & measures

Design (completed)
> Implementation of simulation results for integrated blind control

> **Goals:**

Conversion of simulation results to proprietary blind controllers
(specification of measuring points, operating modes e.g.)

> **Results:**

Set of rules and tables ready to program controllers and BAS for all building zones and plants,
Preparation of building energy monitoring

If $t_r > 22^\circ C$ and $h_a < h_i$, then Free Cooling = 1

C&C / Operation (ongoing)
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