Simulation based façade control implemented as a responsive building element

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Smart and Efficient Energy Council (SEEC’2009)

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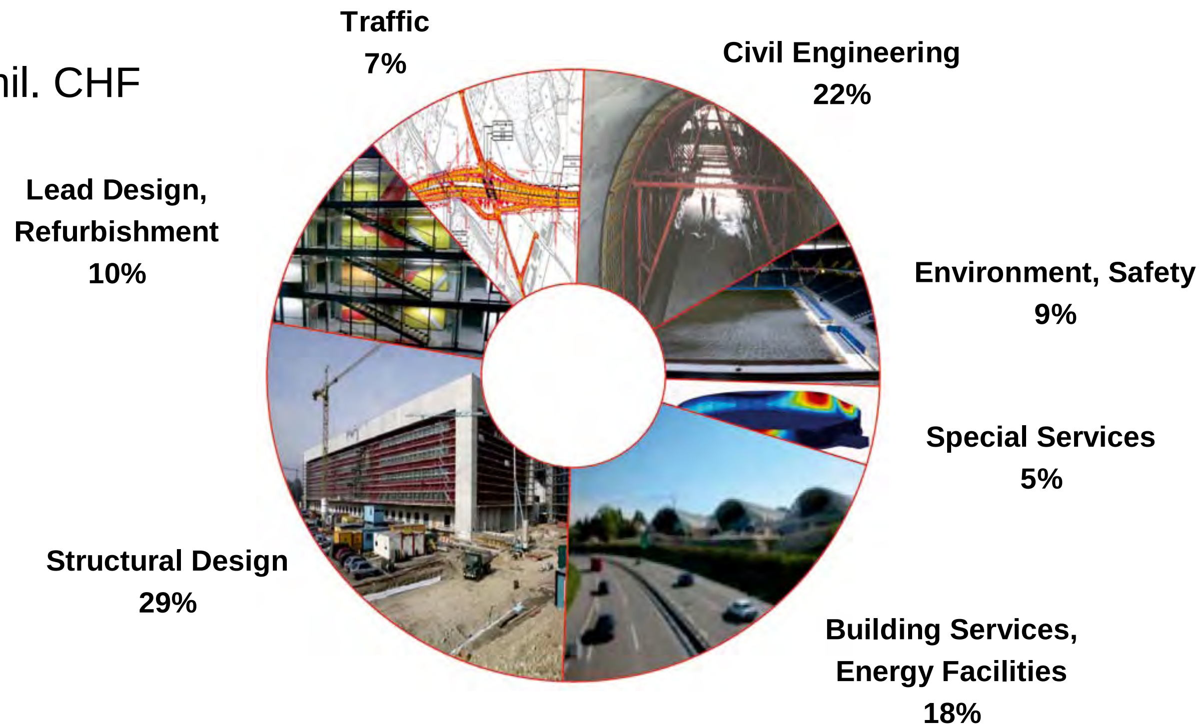
Introduction

> 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

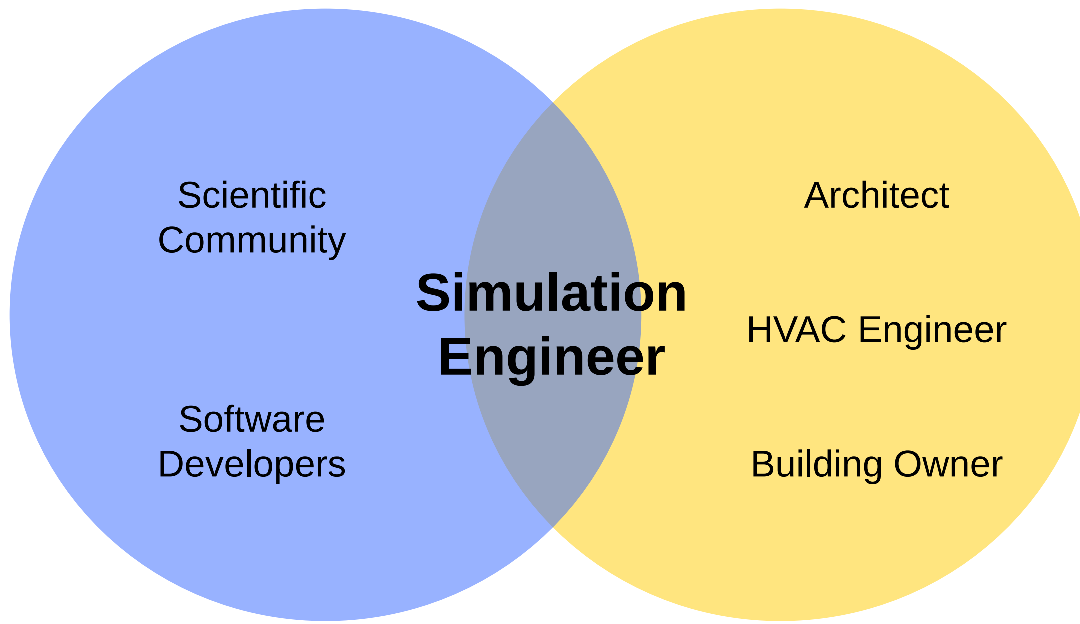


Introduction

> 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 Perfomance Simulation

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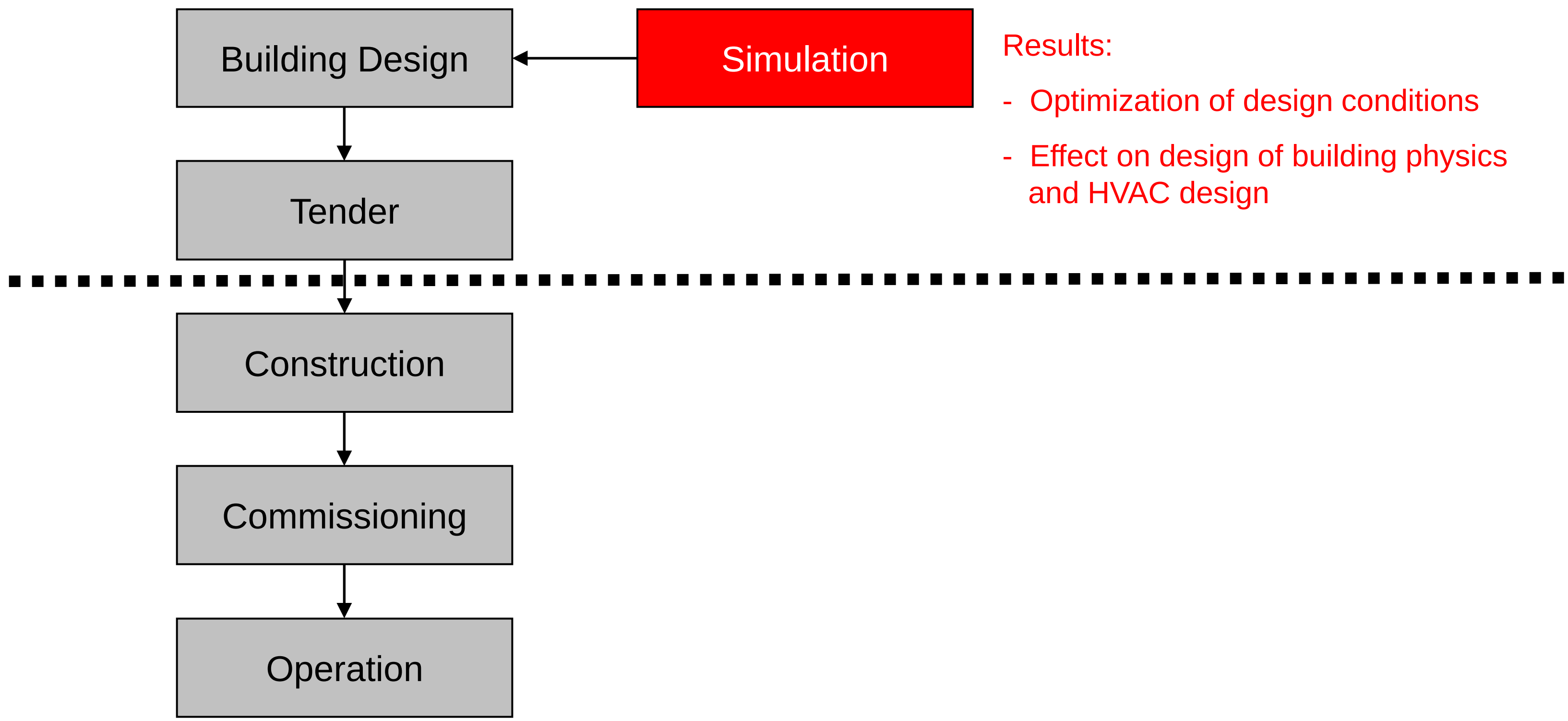
> Simulation primarily used for building and energy design

> Linear approach is commonly used



Results:

- Optimization of design conditions
- Effect on design of building physics and HVAC design

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Integrated Building Energy Perfomance Simulation

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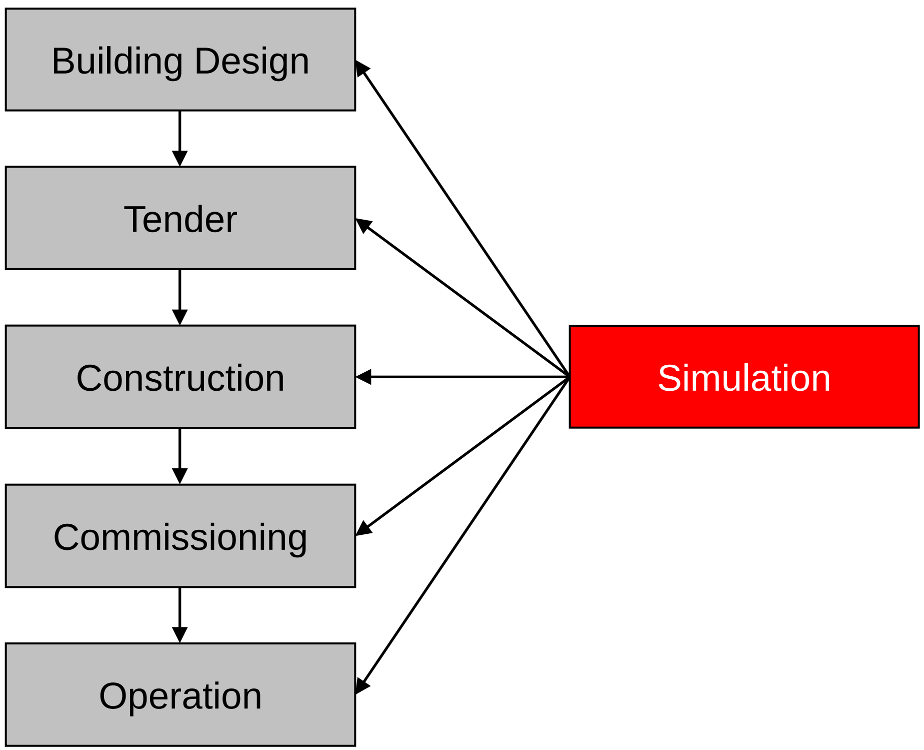
> Simulation used for building and energy design (integrated approach)

> 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

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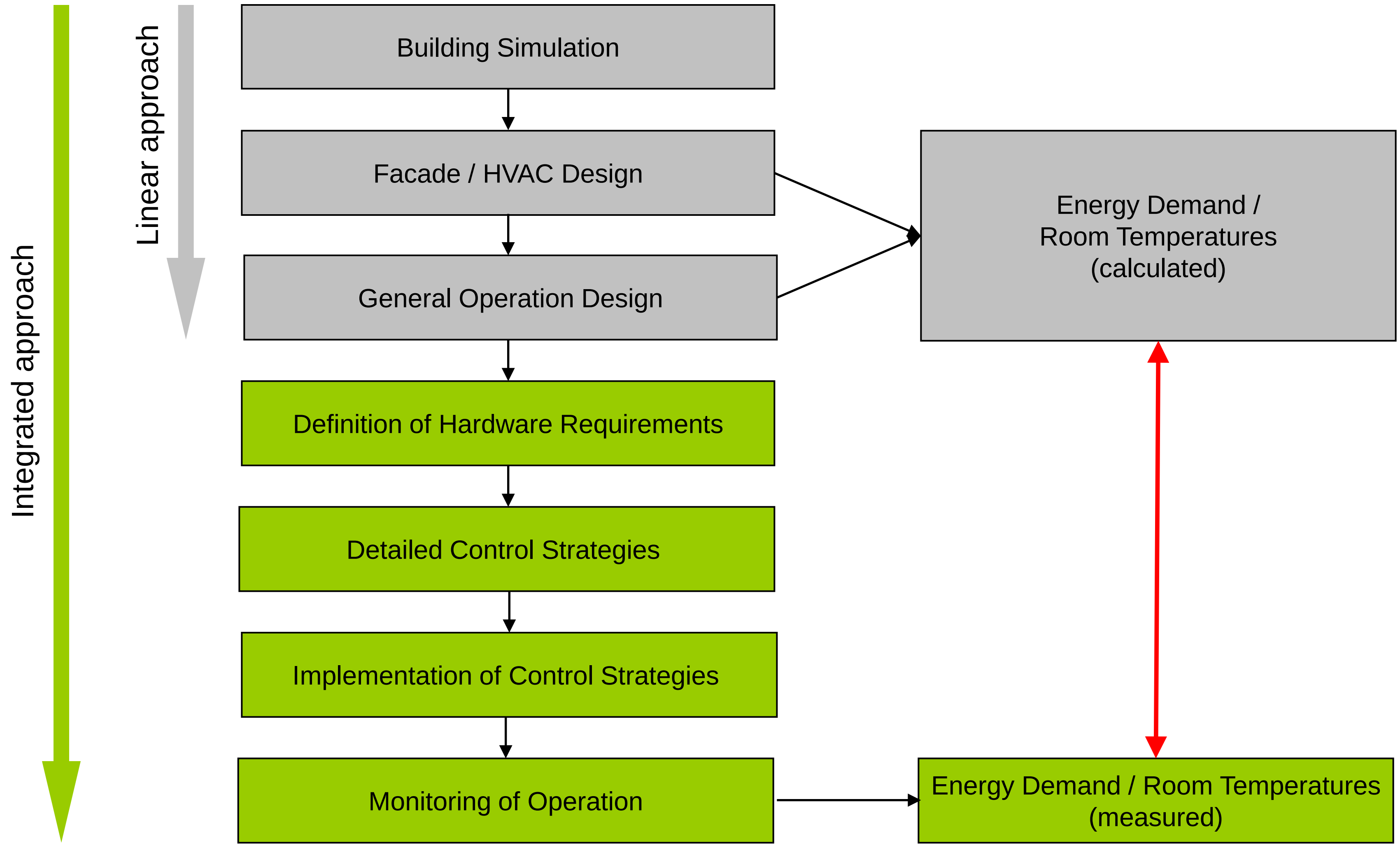
Integrated Building Energy Perfomance Simulation



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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
- IEA Annex 44 (2005 - 2008)
- 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 m^3/h
- Energy:
  - Heating 805 MWh/a, 550 kW
  - Cooling 630 MWh/a, 492 kW

- Construction started in 2009

Floor Plan

> Layout of a typical floor

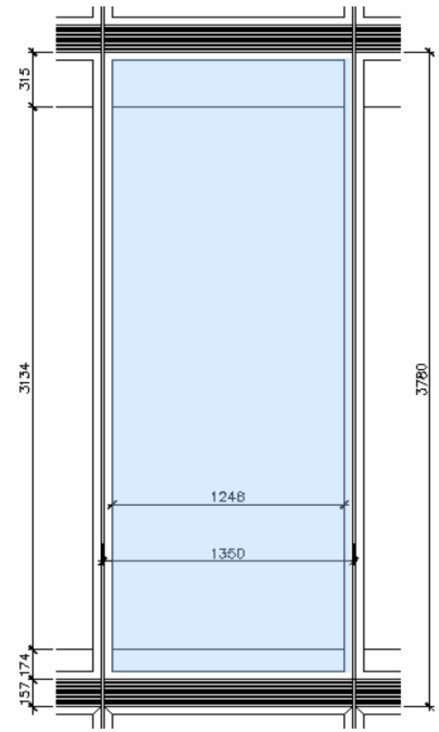
Red areas indicate zoning for thermal simulation.

The typical floor layout shifts 90 degrees on each floor.

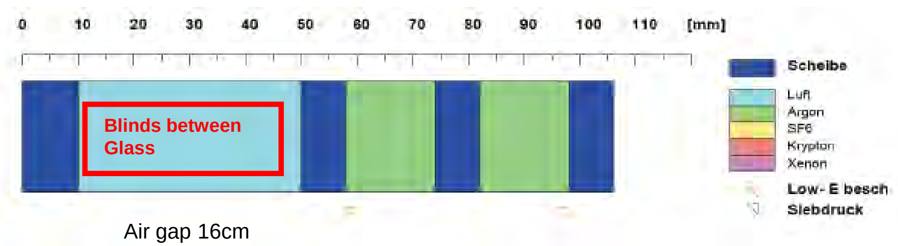
In order to capture all orientations the model was rotated three times.

Building Constructions

- > Facade: modular, non-ventilated facade elements (panels, windows)
  - > Window / Wall ratio 0.77
  - > Wall panels U = 0.55 W/m^{2}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



Cross-section of glass facade elements:



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Building Energy Performance Analysis

- > 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

Simulation-based Blind Control

- 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

Controls in theory (model) ⟷ Controls in real life (applied model) ⟷ Controls in real life (actual controller)

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Simulation-based Blind Control

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Controls in theory (model) ⟷ Controls in real life (applied model) ⟷ Controls in real life (actual controller)

> Example: EnergyPlus Shading Control Types

Reducing Zone Cooling Load due to Window Solar Heat Gain		Reducing Zone Heating Load by reducing Window Conductive Heat Loss	Reducing Zone Heating and Cooling Load
On If Schedule Allows	On If High Solar On Window	On Night If Low Outdoor Temperature and Off Day	On Night If Low Outdoor Temperature and On Day If Cooling
On If High Glare	Meet Daylight Illuminance Setpoint	On Night If Low Inside Temperature and Off Day	On Night If Heating and On Day If Cooling
Off Night and On Day If Cooling and High Solar On Window	On If High Outdoor Temperature and High Solar On Window	On Night If Heating and Day Off	
On If High Outdoor Temperature	On If High Zone Air Temperature		
On If High Zone Cooling Load			

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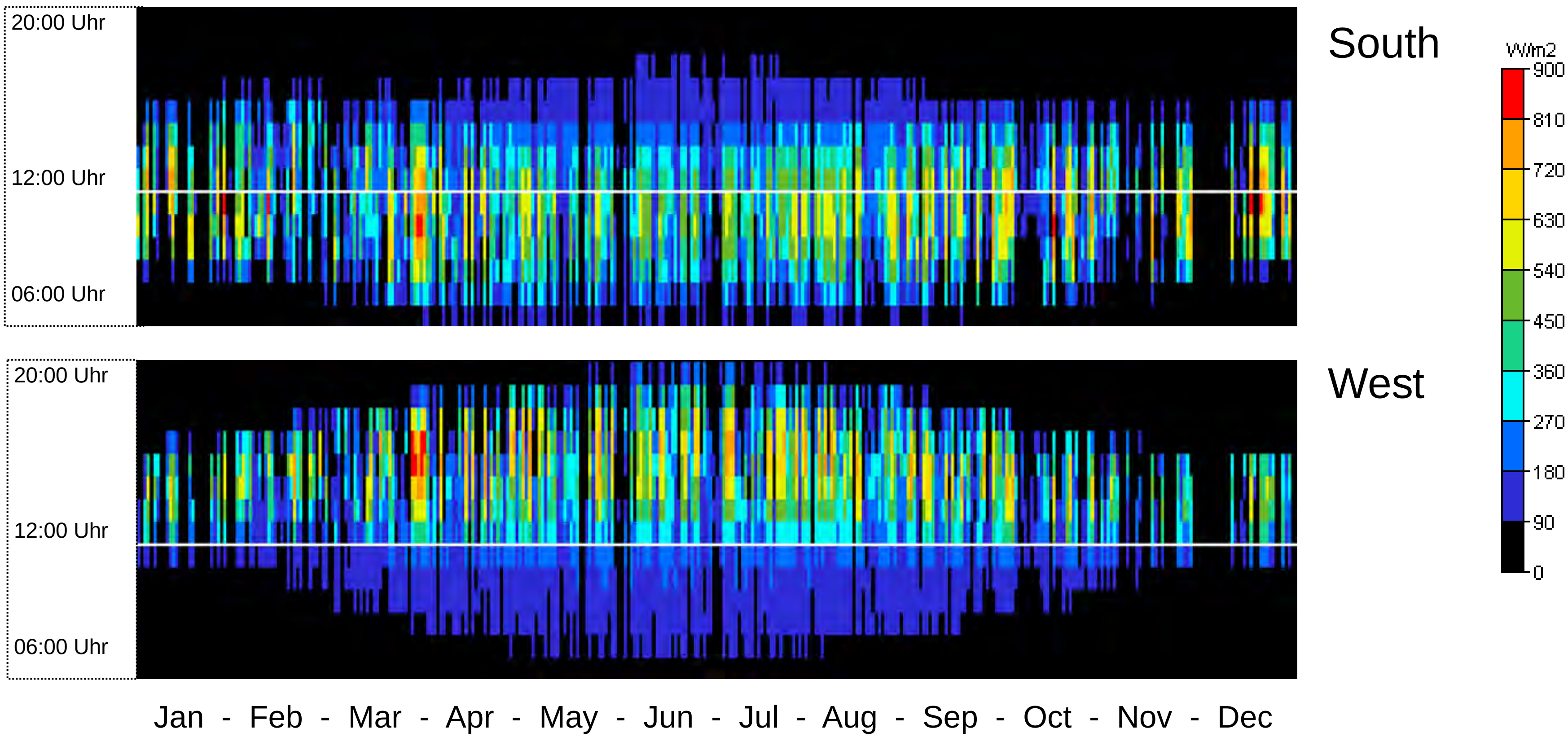
Simulating Blind Control - Step 1

- Simulated Blind Control: **ON If High Solar Radiation On Window**
- Total exterior solar beam on facade surface (W/m^2_{Facade})



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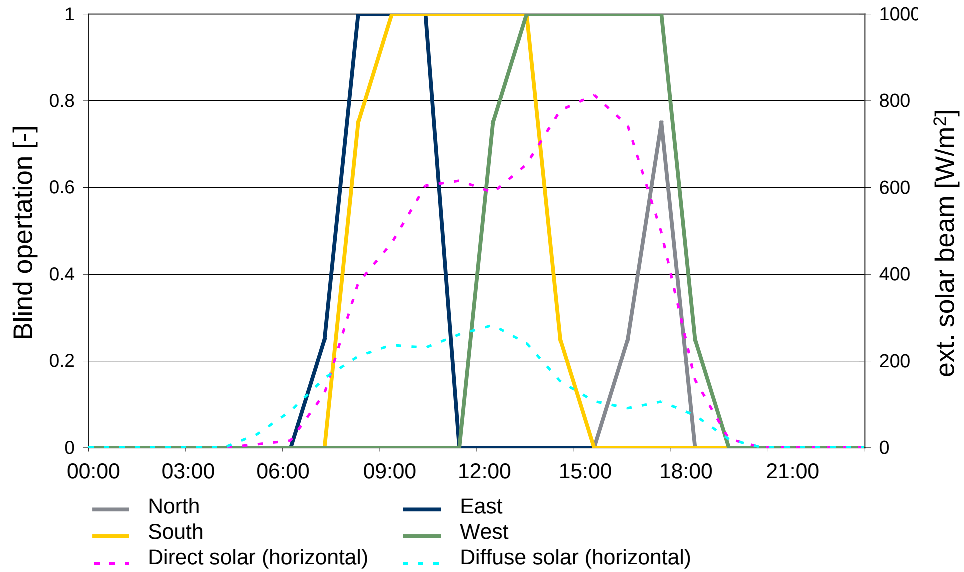
Simulating Blind Control - Step 1

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

> Annual blind usage per facade

Zone	Facade	Blinds closed (office hours)	% of office hours
1	North	83 hrs	2 %
1	West	957 hrs	22 %
2	North	83 hrs	2 %
3	West	957 hrs	22 %
4	South	1150 hrs	26 %
5	East	377 hrs	9 %
5	South	1150 hrs	26 %

> Blind usage (summer day)



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Simulating Blind Control - Step 1

> **Annual operating hours of blinds** (Set-point: ext. solar beam 300 W/m^2)

Simulating Blind Control - Step 2

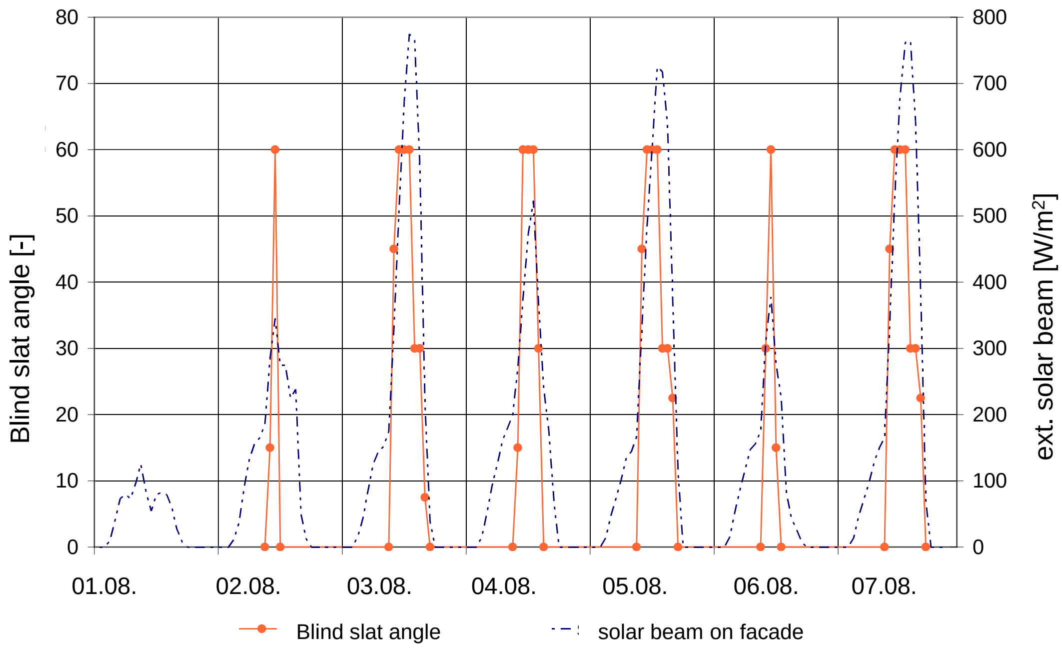
> **Adding dynamic blind slat angle control**

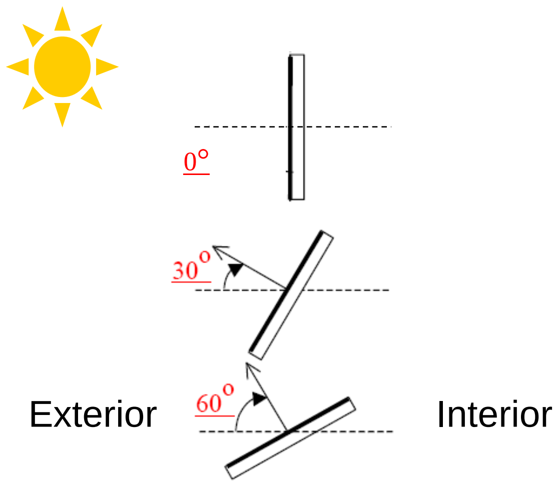
> Blind slat angle adjusts depending on solar radiation and sun position

➔ block direct solar radiation

> Blind slat angle was scheduled during the day

> Example: Western facade (summer week)





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Simulating Blind Control - Progress

Controls in theory (model) ⟷ **Controls in real life (applied model)** ⟷ Controls in real life (actual controller)

> 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 ➔ 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)

Simulating Blind Control - Step 3

> Integrated Blind Control

> Takes into account external solar radiation and zone cooling load

➔ Blinds are closed when there is high zone cooling load

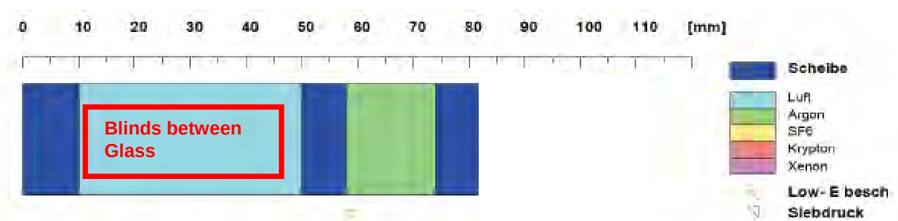
➔ thermal properties of facade thus influence blind usage

> Two different glazing types were compared:

- > thermal insulating glass (3 layers)
- > thermal insulating glass (2 layers)

	3 Layers	2 Layers
U_g [W/m^2K]	0.51	0.75
U_W [W/m^2K]	0.92	1.11
g [ ]	0.41	0.51

Cross-section of glass facade elements:



Air gap 16cm

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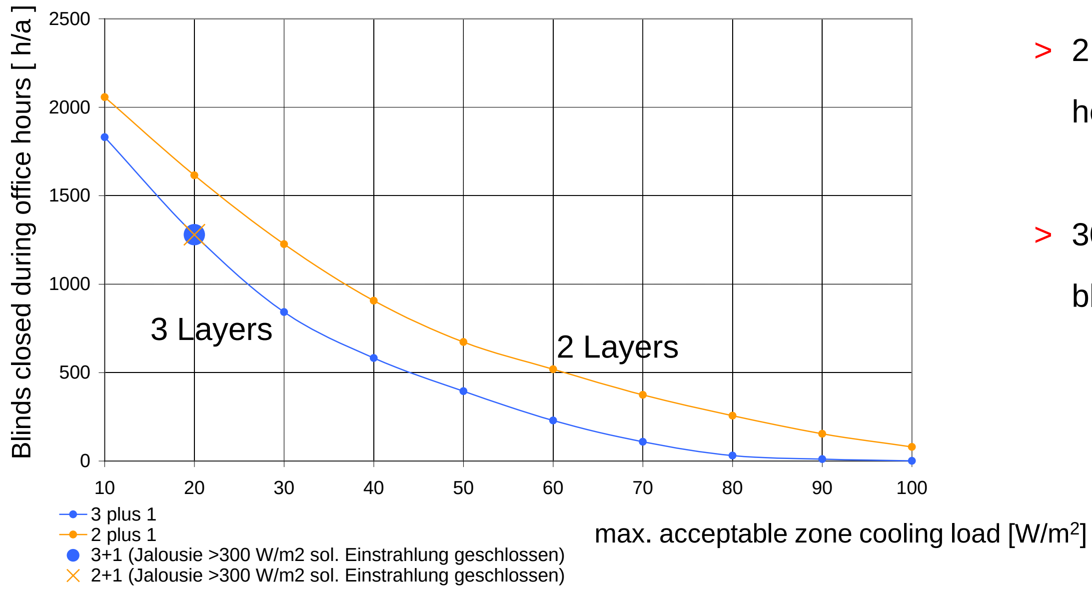
Simulating Blind Control - Step 3

> **Annual operating hours of Blinds** (South-facing facade)

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



> 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

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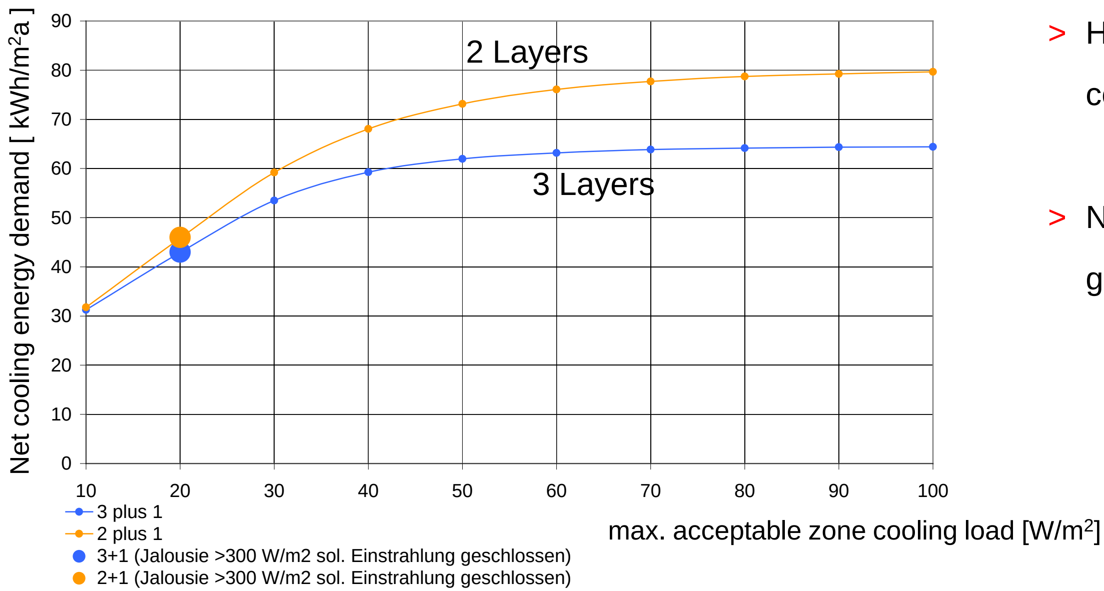
Simulating Blind Control - Step 3

> **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

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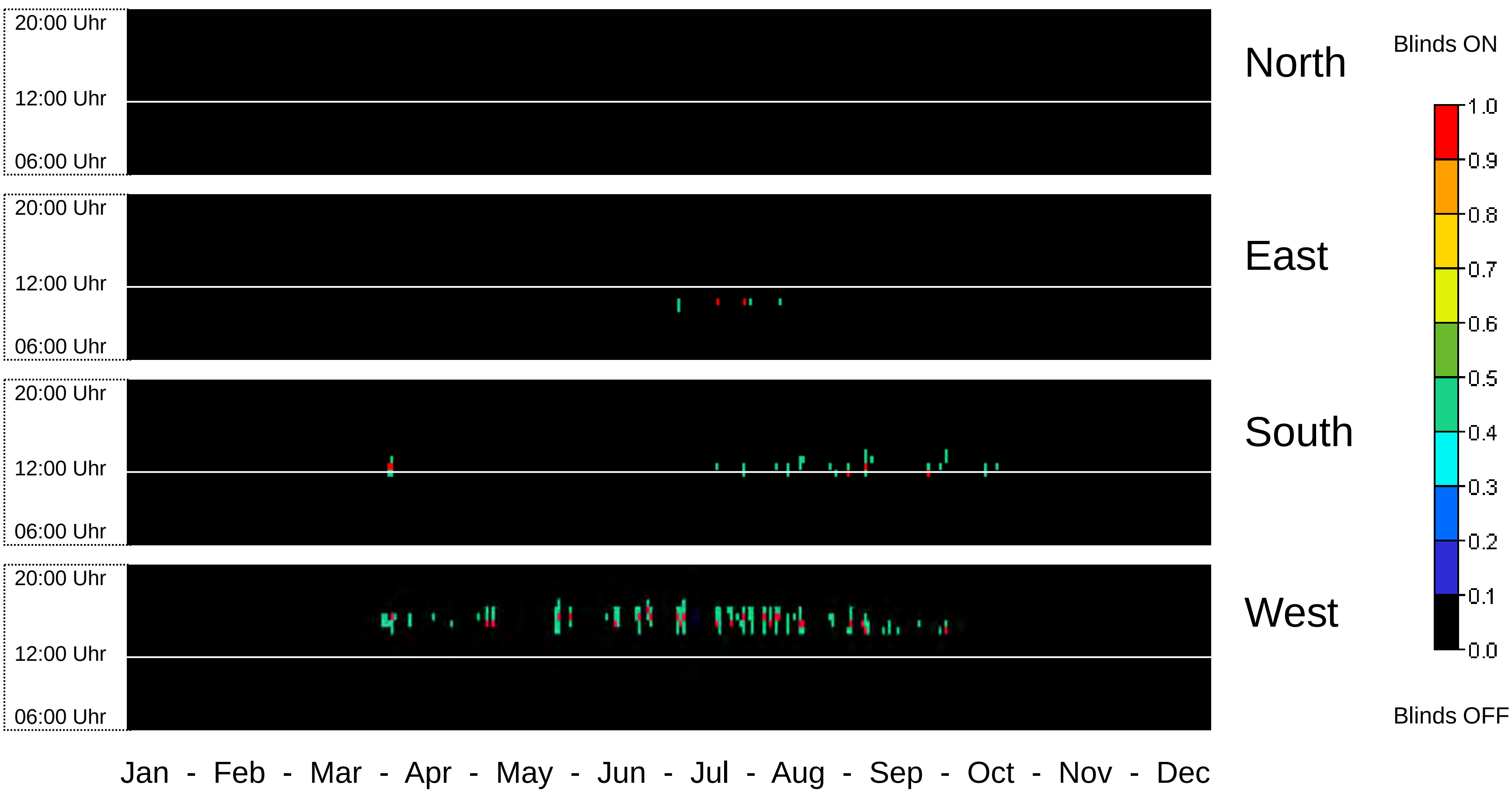
Simulating Blind Control - Step 3

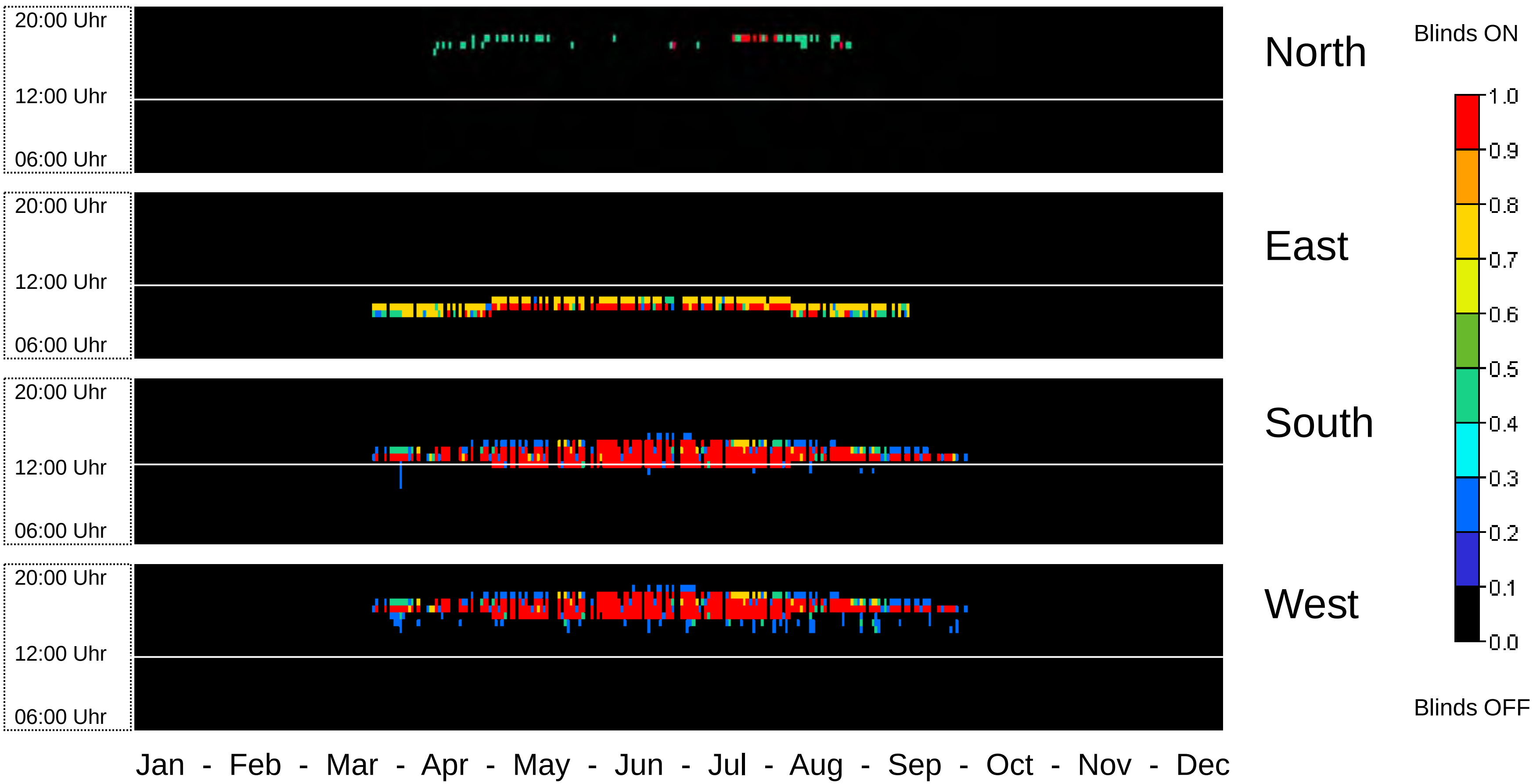
> **Annual operating hours of blinds** (3-layered glazing)
>
> > Blinds are closed at 80 W/m² max. acceptable zone cooling load



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



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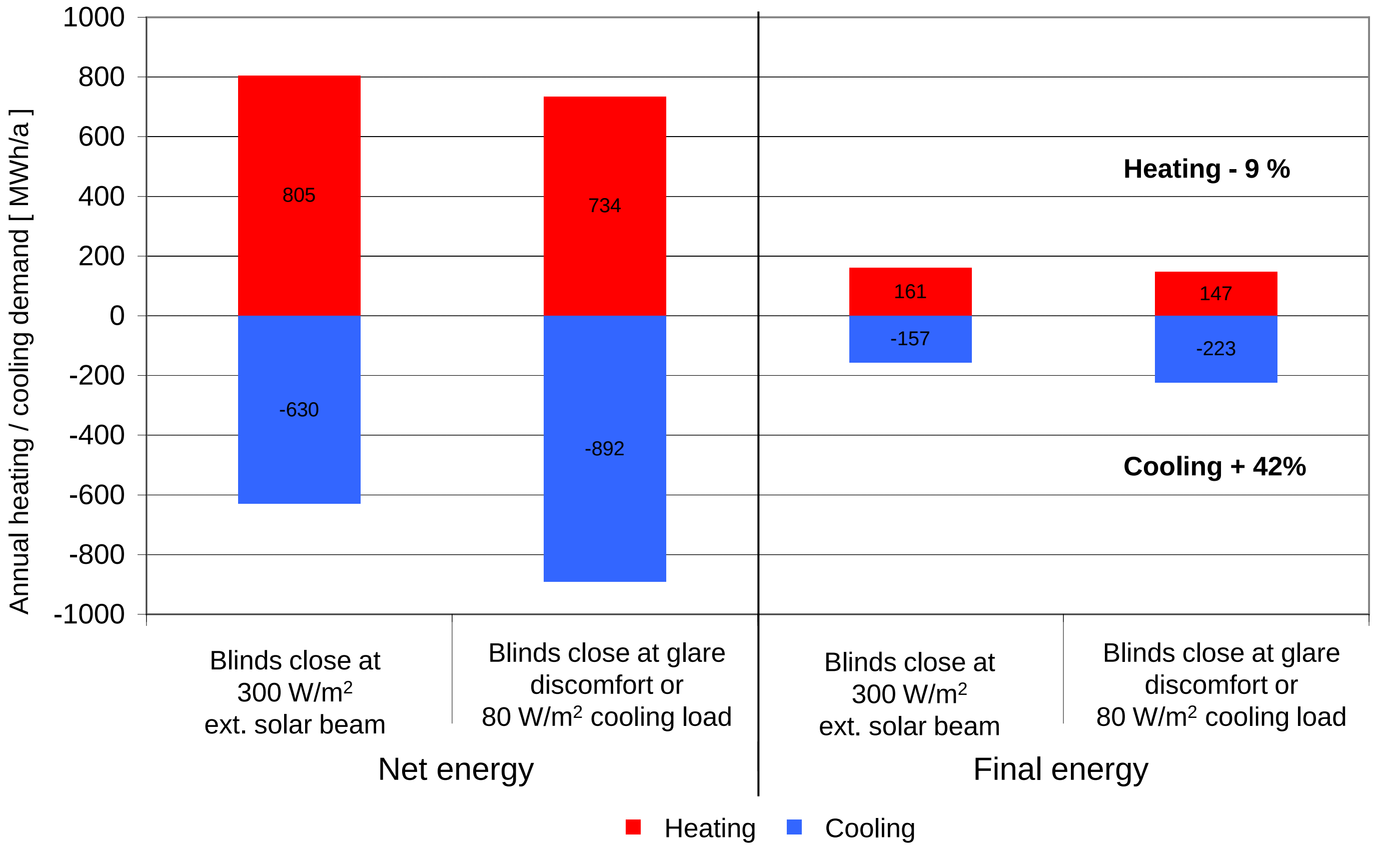
Simulating Blind Control - Step 3

> Blind control influences building energy demand

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



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Simulating Blind Control - Progress

Controls in Theory (Model) ↔ Controls in real life (Applied model) ↔ Controls in real life (actual controller)

> 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

Conventional Blind Control	Partially integrated Blind Control	Fully Integrated Blind Control (BAS)

> Example: EnergyPlus Shading Control Types

Reducing Zone Cooling Load due to Window Solar Heat Gain		Reducing Zone Heating Load by reducing Window Conductive Heat Loss	Reducing Zone Heating and Cooling Load
On If Schedule Allows	On If High Solar On Window	On Night If Low Outdoor Temperature and Off Day	On Night If Low Outdoor Temperature and On Day If Cooling
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Off Night and On Day If Cooling and High Solar On Window	On If High Outdoor Temperature and High Solar On Window	On Night If Heating and Day Off	
On If High Outdoor Temperature	On If High Zone Air Temperature		
On If High Zone Cooling Load			

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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

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Results & Ongoing Work

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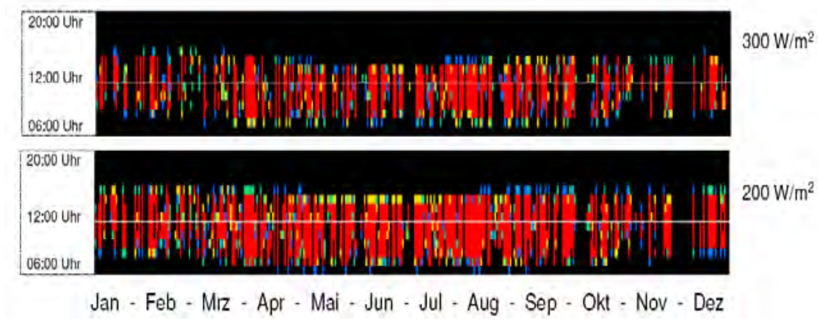
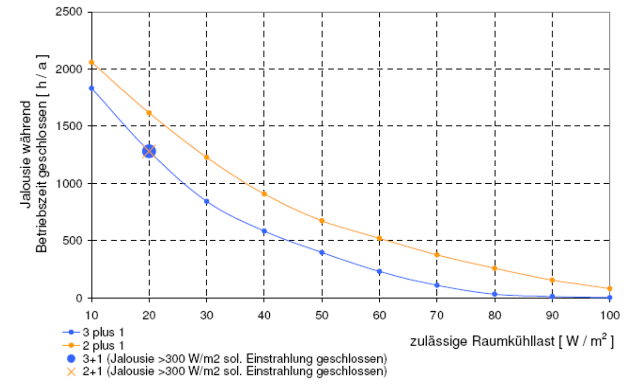
> Building energy perfomance analysis during design phase



> **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)

Results & Ongoing Work

- Implementation of simulation results for integrated blind control
  - **Goals**:

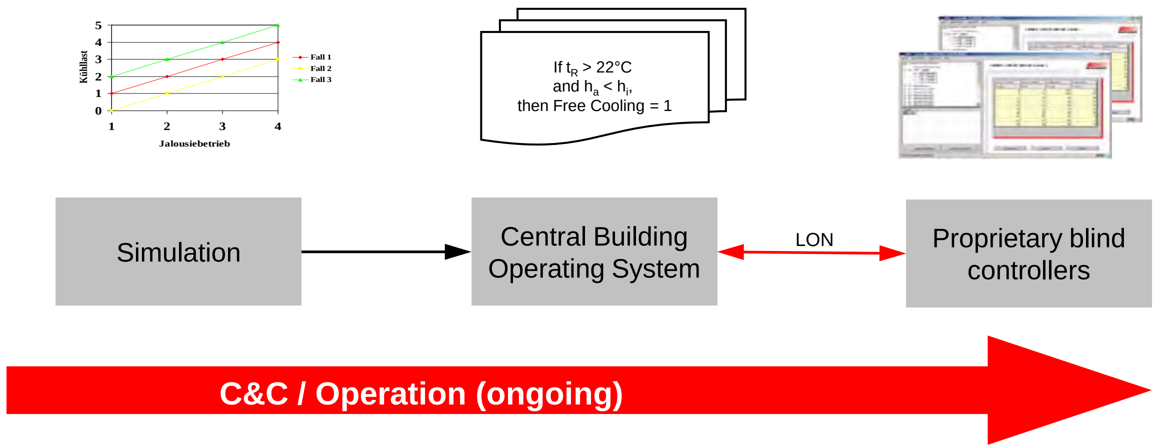
    Conversion of simulation results to proprietary blind controllers

    (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



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