ADAPTIVE FAÇADE DESIGN FOR THE REGULATION OF VISUAL COMFORT

Shirin Masoudi
Overview

SUSTAINABILITY & ENERGY PERFORMANCE
Overview

SUSTAINABILITY & ENERGY PERFORMANCE

ARCHITECTS

DESIGN
Overview

SUSTAINABILITY & ENERGY PERFORMANCE

CONSTRUCTION COMPANY

ARCHITECTS

PRODUCT Innovation DESIGN
Overview

SUSTAINABILITY & ENERGY PERFORMANCE

CONSTRUCTION COMPANY

ARCHITECTS

PRODUCT

DESIGN

BUILDING ENERGY PERFORMANCE

OFFICE BUILDINGS

44% energy consumption for LIGHTING

Innovation
Overview

SUSTAINABILITY & ENERGY PERFORMANCE

CONSTRUCTION COMPANY

ARCHITECTS

BUILDING ENERGY PERFORMANCE

PRODUCT

DESIGN

INNOVATION

ADAPTIVE FACADES

OFFICE BUILDINGS

44% energy consumption for LIGHTING
Overview

SUSTAINABILITY & ENERGY PERFORMANCE

CONSTRUCTION COMPANY

ARCHITECTS

BUILDING ENERGY PERFORMANCE

PRODUCT

DESIGN

44% energy consumption for LIGHTING

OFFICE BUILDINGS

ADAPTIVE FACADES
Adaptive façades are envelopes that respond both to indoor and outdoor stimuli and change configuration – both physically or chemically - to take advantage of the outdoor climate and offer a systematic flexibility that responds situationally in relation to specific points in time with the aim to improve both the building performance and the user comfort.

**Adaptive façades**

- **Exterior**
  - Solar radiation
  - Temperature
  - Humidity
  - Wind
  - Precipitation
  - Noise

- **Interior**
  - Light
  - Temperature
  - Humidity
  - Sound level
  - Air exchange rate

What is an adaptive facade?
Adaptive façades are envelopes that respond both to indoor and outdoor stimuli and change configuration – both physically or chemically - to take advantage of the outdoor climate and offer a systematic flexibility that responds situationally in relation to specific points in time with the aim to improve both the building performance and the user comfort.
Adaptive façades are envelopes that respond both to indoor and outdoor stimuli and change configuration – both physically or chemically - to take advantage of the outdoor climate and offer a systematic flexibility that responds situationally in relation to specific points in time with the aim to improve both the building performance and the user comfort.

<table>
<thead>
<tr>
<th>Adaptive facades</th>
<th>Exterior</th>
<th>Response</th>
<th>Control</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Solar radiation</td>
<td>Dynamic</td>
<td>Manual</td>
<td>Thermal comfort</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td>Static</td>
<td>Mechanical</td>
<td>Visual Comfort</td>
</tr>
<tr>
<td></td>
<td>Humidity</td>
<td></td>
<td>Smart</td>
<td>IAQ</td>
</tr>
<tr>
<td></td>
<td>Wind</td>
<td></td>
<td></td>
<td>Acoustic comfort</td>
</tr>
<tr>
<td></td>
<td>Precipitation</td>
<td></td>
<td></td>
<td>Energy</td>
</tr>
<tr>
<td></td>
<td>Noise</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Interior</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Light</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Humidity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sound level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Air exchange rate</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

What is an adaptive facade?
Reference projects

Buildings
- Al Bahr Towers
  Aedas Architects
  Abu Dhabi, United Arab Emirates
  2012

Products
- Smart Window and Power Window
  PHYSEE
  Delft, Netherlands
  2014

Research projects
- Adaptive Solar Facade
  ETH Foundation
  House of Natural Resources (HoNR), Campus ETH Honggerberg, Zurich, Switzerland
  2015
Reference projects

Adaptive facades

Exterior
- Solar radiation
- Temperature
- Humidity
- Wind
- Precipitation
- Noise

Response
- Dynamic
- Static

Control
- Manual
- Mechanical
- Smart

Purpose
- Thermal comfort
- Visual Comfort
- IAQ
- Acoustic comfort
- Energy

Response time
- Seconds
- Minutes
- Hours
- Days
- Seasons

Interior
- Light
- Temperature
- Humidity
- Sound level
- Air exchange rate

Buildings

Products

Research projects
Solar radiation

Irradiance (W/m²/nm)

Wavelength (nm)

- UV
- Visible
- Infrared
Solar radiation - Control

Summer - visual discomfort

Irradiance (W/m²/nm)

UV, Visible, Infrared

Wavelength (nm)

0 0.5 1 1.5 2 2.5

out

in
Solar radiation - Control

Winter - visual comfort

- UV
- Visible
- Infrared

Irradiance (W/m²/nm)

Wavelength (nm)

0 0.5 1 1.5 2 2.5

250 500 750 1000 1250 1500 1750 2000 2250 2500

Winter - visual comfort
Winter - visual discomfort

Solar radiation - Control

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>Irradiance (W/m²/nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UV</td>
<td>2</td>
</tr>
<tr>
<td>Visible</td>
<td>1</td>
</tr>
<tr>
<td>Infrared</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Winter - visual discomfort
Summer - visual comfort

Solar radiation - Control

- UV
- Visible
- Infrared

Irradiance (W/m²/nm)

Wavelength (nm)

2.5
2
1.5
1
0.5
0
250 500 750 1000 1250 1500 1750 2000 2250 2500

out
in
Comfort

**Visual Comfort**

Illuminance: 300-500 lux

Daylight Glare Probability (DGP) < 0.35

High quality light (daylight)

View to the outside environment

**Thermal Comfort**

Temperature winter: 20-23 °C

Temperature summer: 23-26°C
Biomimicry
Smart materials
Nanotechnology

Sensors
Integrated system
Layers

Low-tech
Aesthetics
Kinetics

Soft robotics
High transparency
Energy generator

Concept of Adaptivity
Concept of Adaptivity

- Biomimicry
- Smart materials
- Nanotechnology
- Sensors
- Integrated system
- Layers
- Low-tech
- Aesthetics
- Kinetics
- Soft robotics
- High transparency
- Energy generator
Improve Visual Comfort of an Office Space by:

- Reducing Daylight Glare Probability
- Increasing daylight and DA
- Assuring view
Facade subdivision
Independent control of each panel to improve daylight and view

Design strategies

Top
Middle
Bottom
Design strategies

Facade subdivision
Independent control of each panel to improve daylight and view

Measurement of indoor and outdoor conditions to optimize the facade response

Top
Middle
Bottom

Sensors
Facade subdivision
Independent control of each panel to improve daylight and view

Adaptive solution that reacts independently from each panel according to the information received by the sensors

Measurement of indoor and outdoor conditions to optimize the facade response

Design strategies
Adaptive technologies

Requirements:
- Daylight control
- Thermal control
- Fast adaptation
- View preservation
- Neutral colour
- Low energy demand

Adaptive solution
Adaptive solutions

- Roller shading
- Venetian blinds
- Smart glass

Traditional solutions

Passive solutions
- Photochromic
- Thermochromic

Active solutions

- Liquid Crystals (LC)
- Electrochromic Polymer Glazing
- Suspended-particle Device (SPDs)

Cholesteric Liquid Crystals (Ch-LC)
- Gasochromic Windows
Different portions of the spectrum are regulated by different layers and materials.

Visible Light

Liquid Crystals (LC)

Cholesteric Liquid Crystals (Ch-LC)

Infrared

Nematic

Smectic

Cholesteric

Pitch
Case studies

licrivision™, Merck

SageGlass, Saint-Gobain

iSolar Blinds, LCG

ECONTROL®, EControl-Glas

Polyarch, TU Delft and TU/e

CONTROLITE®, Danpal®

PowerWindow, Physee

LCG® Films, Gauzy

Kindow Binds, Kindow
Design concept

Reference project 1
Roller shading

Reference project 2
Venetian blinds

Design option
Ch-LC + LC

Ch-LC

LC
Simulation

South facing facade

User 1

User 2
Annual DGP (User 1)
Annual DGP (User 1)

The facade responds changing light transmittance

Shading schedule
Simulation

Annual DGP (User 1)

The facade responds changing light transmittance

Influence on Illuminance DA

Shading schedule
Annual DGP (User 1)

The facade responds changing light transmittance

Influence on Illuminance

Electric lighting on when illuminance < 500 lux on task

Shading schedule

Energy balance
Simulation

DIVA (Radiance)

Annual DGP
(User 1)

The facade responds changing light transmittance

Influence on Illuminance DA

Electric lighting on when illuminance < 500 lux on task

Shading schedule

Energy balance
Simulation

Annual DGP (User 1)
The facade responds changing light transmittance

Influence on Illuminance DA

Electric lighting on when illuminance < 500 lux on task

Shading schedule

Energy balance

Influence on the Heating & Cooling

T < 20°C
T > 26°C

IR reflected
IR transmitted

DIVA (Radiance)
Simulation

Annual DGP (User 1)

The facade responds changing light transmittance

Influence on Illuminance DA

Electric lighting on when illuminance < 500 lux on task

Shading schedule

Energy balance

IR reflected

IR transmitted

DesignBuilder (Energy Plus)

Influence on the Heating & Cooling

don when T < 20°C

T > 26°C
Simulation

DIVA (Radiance)

Annual DGP (User 1)

The facade responds changing light transmittance

Influence on Illuminance DA

Electric lighting on when illuminance < 500 lux on task

Shading schedule

Energy balance

DesignBuilder (Energy Plus)

IR reflected

IR transmitted

Influence on the Heating & Cooling

on when

T < 20°C

T > 26°C

Ventilation

Equipment & Users

Do not vary between the different cases
Simulation

Roller shading

**Glare control**
Shading control:

- base: clear facade
- shading state 1: top
- shading state 2: middle
- shading state 3: top & middle

Venetian blinds

**Glare control**
2 independent shading groups: Top & middle

- base: clear facade
- shading state 1: 0°
- shading state 2: 45°
- shading state 3: 90°

**Thermal control**
The shading control is activated by the glare perception. Therefore, the influence of the shading system on the thermal balance is due to this factor.
**Glare control**

LC

base: clear facade

shading state 1: 30% VT

shading state 2: 2% VT

**Thermal control**

Ch-LC

transparent insulation

base: 95% ST = 100% Ch-LC

state 1: 60% ST = 50% Ch-LC

state 2: 22% ST = 0% Ch-LC

---

**Simulation**

Shading combinations
Results

Roller shading
Venetian blinds
Smart window

21st March 9:00

Infrared control: 100%

200 lux
200 lux
200 lux

24.5 °C
24.5 °C
21.5 °C

0.33 kW
0.32 kW
0.14 kW
**Results**

<table>
<thead>
<tr>
<th>Roller shading</th>
<th>Venetian blinds</th>
<th>Smart window</th>
</tr>
</thead>
<tbody>
<tr>
<td>400-500 lux</td>
<td>400-500 lux</td>
<td>400-500 lux</td>
</tr>
<tr>
<td>24.5 °C</td>
<td>24.5 °C</td>
<td>21.5 °C</td>
</tr>
<tr>
<td>0.32 kWh</td>
<td>0.32 kWh</td>
<td>0.21 kWh</td>
</tr>
</tbody>
</table>

**21st March 10:00**

Infrared control: 100%
Results

Roller shading

Venetian blinds

Smart window

21st March 11:00

100-200 lux

24.5 °C

0.32 kWh

Infrared control: 100%

100-200 lux

24.5 °C

0.31 kWh

100-200 lux

21.5 °C

0.22 kWh
Results

Roller shading
Venetian blinds
Smart window

Infrared control:

21st March 12:00

- Roller shading: 700-900 lux, 25.5 °C, 0.34 kWh
- Venetian blinds: 200-700 lux, 25 °C, 0.35 kWh
- Smart window: 900-1000 lux, 22 °C, 0.27 kWh

Infrared control:
Results

Roller shading  Venetian blinds  Smart window

21st March 13:00

Infrared control: 100%

<table>
<thead>
<tr>
<th></th>
<th>500-700 lux</th>
<th>100-300 lux</th>
<th>500-700 lux</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>25.5 °C</td>
<td>25.5 °C</td>
<td>22.5 °C</td>
</tr>
<tr>
<td>Electric usage</td>
<td>0.40 kWh</td>
<td>0.40 kWh</td>
<td>0.27 kWh</td>
</tr>
</tbody>
</table>
Results

21st March 14:00

Roller shading
Venetian blinds
Smart window

500-700 lux
100-300 lux
500-700 lux

Infrared control: 100%

500-700 lux
100-300 lux
500-700 lux

25.5 ºC
25.5 ºC
23 ºC

0.42 kWh
0.41 kWh
0.27 kWh
Results

21st March 15:00

Roller shading
Venetian blinds
Smart window

200-300 lux
200-300 lux
200-300 lux

Infrared control: 100%

25.5 °C
25.5 °C
22.5 °C

0.38 kWh
0.31 kWh
0.26 kWh

50
Results

Roller shading
Venetian blinds
Smart window

21st March 16:00

100-300 lux
100-200 lux
300-500 lux

Infrared control: 100%

100-300 lux
100-200 lux
300-500 lux

25.5 ºC
25.5 ºC
22.5 ºC

0.40 kWh
0.34 kWh
0.26 kWh
Results

Roller shading | Venetian blinds | Smart window

21st March 17:00

300 lux  | 300 lux  | 300 lux

25.5 °C  | 25.4 °C  | 22.6 °C

0.38 kWh | 0.31 kWh | 0.26 kWh

Infrared control: 100%
Results

21st March 18:00

Roller shading
Venetian blinds
Smart window

100-200 lux
100-200 lux
100-200 lux

25.5 °C
25 °C
22 °C

0.32 kWh
0.30 kWh
0.26 kWh

Infrared control: 100%
### Shading Schedule

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00</td>
<td>-</td>
<td>500</td>
<td>25,5</td>
<td>0,4</td>
</tr>
<tr>
<td>10:00</td>
<td>-</td>
<td>600</td>
<td>25,5</td>
<td>0,4</td>
</tr>
<tr>
<td>11:00</td>
<td>-</td>
<td>600</td>
<td>25,5</td>
<td>0,5</td>
</tr>
<tr>
<td>12:00</td>
<td>-</td>
<td>500</td>
<td>24</td>
<td>0,6</td>
</tr>
<tr>
<td>13:00</td>
<td>-</td>
<td>700</td>
<td>26</td>
<td>0,7</td>
</tr>
<tr>
<td>14:00</td>
<td>-</td>
<td>200</td>
<td>24</td>
<td>0,6</td>
</tr>
<tr>
<td>15:00</td>
<td>full 45°</td>
<td>100</td>
<td>26</td>
<td>0,7</td>
</tr>
<tr>
<td>16:00</td>
<td>half-top</td>
<td>100</td>
<td>26</td>
<td>0,7</td>
</tr>
<tr>
<td>17:00</td>
<td>top 0°</td>
<td>100</td>
<td>26</td>
<td>0,7</td>
</tr>
<tr>
<td>18:00</td>
<td>-</td>
<td>200</td>
<td>25,5</td>
<td>0,1</td>
</tr>
</tbody>
</table>
```
<table>
<thead>
<tr>
<th>Time</th>
<th>Shading Schedule</th>
<th>Illuminance [lux]</th>
<th>Temperature [°C]</th>
<th>Energy Demand [kWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00</td>
<td>-</td>
<td>500</td>
<td>25.5</td>
<td>0.4</td>
</tr>
<tr>
<td>10:00</td>
<td>-</td>
<td>600</td>
<td>25.5</td>
<td>0.4</td>
</tr>
<tr>
<td>11:00</td>
<td>-</td>
<td>600</td>
<td>25.5</td>
<td>0.5</td>
</tr>
<tr>
<td>12:00</td>
<td>-</td>
<td>500</td>
<td>25.5</td>
<td>0.6</td>
</tr>
<tr>
<td>13:00</td>
<td>-</td>
<td>700</td>
<td>26</td>
<td>0.6</td>
</tr>
<tr>
<td>14:00</td>
<td>-</td>
<td>200</td>
<td>26</td>
<td>0.7</td>
</tr>
<tr>
<td>15:00</td>
<td>full 45°45° half-full</td>
<td>100 200 500</td>
<td>26</td>
<td>0.7</td>
</tr>
<tr>
<td>16:00</td>
<td>top 0° 0° half-top</td>
<td>300 400 400</td>
<td>26</td>
<td>0.7</td>
</tr>
<tr>
<td>17:00</td>
<td>-</td>
<td>200</td>
<td>26</td>
<td>0.6</td>
</tr>
<tr>
<td>18:00</td>
<td>-</td>
<td>200</td>
<td>26</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>200</td>
<td>26</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>200</td>
<td>26</td>
<td>0.1</td>
</tr>
</tbody>
</table>
```
Results

21st June

<table>
<thead>
<tr>
<th>Time</th>
<th>Shading Schedule</th>
<th>Illuminance [lux]</th>
<th>Temperature [°C]</th>
<th>Energy demand [kWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00</td>
<td>-</td>
<td>500</td>
<td>25.5</td>
<td>0.4</td>
</tr>
<tr>
<td>10:00</td>
<td>-</td>
<td>600</td>
<td>25.5</td>
<td>0.4</td>
</tr>
<tr>
<td>11:00</td>
<td>-</td>
<td>600</td>
<td>25.5</td>
<td>0.5</td>
</tr>
<tr>
<td>12:00</td>
<td>-</td>
<td>500</td>
<td>25.5</td>
<td>0.6</td>
</tr>
<tr>
<td>13:00</td>
<td>-</td>
<td>700</td>
<td>26</td>
<td>0.7</td>
</tr>
<tr>
<td>14:00</td>
<td>-</td>
<td>200</td>
<td>26</td>
<td>0.6</td>
</tr>
<tr>
<td>15:00</td>
<td>full 45°</td>
<td>100</td>
<td>26</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>half-full 45°</td>
<td>200</td>
<td>26</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>half-full 0°</td>
<td>500</td>
<td>26</td>
<td>0.7</td>
</tr>
<tr>
<td>16:00</td>
<td>top 0°</td>
<td>300</td>
<td>26</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>half-top 0°</td>
<td>400</td>
<td>26</td>
<td>0.7</td>
</tr>
<tr>
<td>17:00</td>
<td>-</td>
<td>200</td>
<td>26</td>
<td>0.7</td>
</tr>
<tr>
<td>18:00</td>
<td>-</td>
<td>200</td>
<td>26</td>
<td>0.7</td>
</tr>
</tbody>
</table>
### Shading schedule

<table>
<thead>
<tr>
<th>Time</th>
<th>Full 45°</th>
<th>45° half-full</th>
<th>Top 0°</th>
<th>0° half-top</th>
<th>Energy demand [kWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00</td>
<td>-</td>
<td>100%</td>
<td>-</td>
<td>-</td>
<td>0.4</td>
</tr>
<tr>
<td>10:00</td>
<td>-</td>
<td>100%</td>
<td>-</td>
<td>-</td>
<td>0.4</td>
</tr>
<tr>
<td>11:00</td>
<td>-</td>
<td>100%</td>
<td>-</td>
<td>-</td>
<td>0.4</td>
</tr>
<tr>
<td>12:00</td>
<td>-</td>
<td>100%</td>
<td>-</td>
<td>-</td>
<td>0.4</td>
</tr>
<tr>
<td>13:00</td>
<td>-</td>
<td>100%</td>
<td>-</td>
<td>-</td>
<td>0.4</td>
</tr>
<tr>
<td>14:00</td>
<td>-</td>
<td>100%</td>
<td>-</td>
<td>-</td>
<td>0.4</td>
</tr>
<tr>
<td>15:00</td>
<td>full</td>
<td>100%</td>
<td>45°</td>
<td>100%</td>
<td>0.4</td>
</tr>
<tr>
<td>16:00</td>
<td>top</td>
<td>100%</td>
<td>0°</td>
<td>100%</td>
<td>0.4</td>
</tr>
<tr>
<td>17:00</td>
<td>-</td>
<td>100%</td>
<td>200</td>
<td>200</td>
<td>0.4</td>
</tr>
<tr>
<td>18:00</td>
<td>-</td>
<td>50%</td>
<td>200</td>
<td>200</td>
<td>0.4</td>
</tr>
</tbody>
</table>

### Illuminance [lux]

<table>
<thead>
<tr>
<th>Time</th>
<th>Full 45°</th>
<th>45° half-full</th>
<th>Top 0°</th>
<th>0° half-top</th>
<th>Energy demand [kWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00</td>
<td>-</td>
<td>100%</td>
<td>-</td>
<td>-</td>
<td>0.4</td>
</tr>
<tr>
<td>10:00</td>
<td>-</td>
<td>100%</td>
<td>-</td>
<td>-</td>
<td>0.4</td>
</tr>
<tr>
<td>11:00</td>
<td>-</td>
<td>100%</td>
<td>-</td>
<td>-</td>
<td>0.4</td>
</tr>
<tr>
<td>12:00</td>
<td>-</td>
<td>100%</td>
<td>-</td>
<td>-</td>
<td>0.4</td>
</tr>
<tr>
<td>13:00</td>
<td>-</td>
<td>100%</td>
<td>-</td>
<td>-</td>
<td>0.4</td>
</tr>
<tr>
<td>14:00</td>
<td>-</td>
<td>100%</td>
<td>-</td>
<td>-</td>
<td>0.4</td>
</tr>
<tr>
<td>15:00</td>
<td>full</td>
<td>100%</td>
<td>45°</td>
<td>100%</td>
<td>0.4</td>
</tr>
<tr>
<td>16:00</td>
<td>top</td>
<td>100%</td>
<td>0°</td>
<td>100%</td>
<td>0.4</td>
</tr>
<tr>
<td>17:00</td>
<td>-</td>
<td>100%</td>
<td>200</td>
<td>200</td>
<td>0.4</td>
</tr>
<tr>
<td>18:00</td>
<td>-</td>
<td>50%</td>
<td>200</td>
<td>200</td>
<td>0.4</td>
</tr>
</tbody>
</table>

### Temperature [°C]

<table>
<thead>
<tr>
<th>Time</th>
<th>Full 45°</th>
<th>45° half-full</th>
<th>Top 0°</th>
<th>0° half-top</th>
<th>Energy demand [kWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00</td>
<td>-</td>
<td>100%</td>
<td>-</td>
<td>-</td>
<td>0.4</td>
</tr>
<tr>
<td>10:00</td>
<td>-</td>
<td>100%</td>
<td>-</td>
<td>-</td>
<td>0.4</td>
</tr>
<tr>
<td>11:00</td>
<td>-</td>
<td>100%</td>
<td>-</td>
<td>-</td>
<td>0.4</td>
</tr>
<tr>
<td>12:00</td>
<td>-</td>
<td>100%</td>
<td>-</td>
<td>-</td>
<td>0.4</td>
</tr>
<tr>
<td>13:00</td>
<td>-</td>
<td>100%</td>
<td>-</td>
<td>-</td>
<td>0.4</td>
</tr>
<tr>
<td>14:00</td>
<td>-</td>
<td>100%</td>
<td>-</td>
<td>-</td>
<td>0.4</td>
</tr>
<tr>
<td>15:00</td>
<td>full</td>
<td>100%</td>
<td>45°</td>
<td>100%</td>
<td>0.4</td>
</tr>
<tr>
<td>16:00</td>
<td>top</td>
<td>100%</td>
<td>0°</td>
<td>100%</td>
<td>0.4</td>
</tr>
<tr>
<td>17:00</td>
<td>-</td>
<td>100%</td>
<td>200</td>
<td>200</td>
<td>0.4</td>
</tr>
<tr>
<td>18:00</td>
<td>-</td>
<td>50%</td>
<td>200</td>
<td>200</td>
<td>0.4</td>
</tr>
</tbody>
</table>

### Energy demand

<table>
<thead>
<tr>
<th>Time</th>
<th>Full 45°</th>
<th>45° half-full</th>
<th>Top 0°</th>
<th>0° half-top</th>
<th>Energy demand [kWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00</td>
<td>-</td>
<td>100%</td>
<td>-</td>
<td>-</td>
<td>0.4</td>
</tr>
<tr>
<td>10:00</td>
<td>-</td>
<td>100%</td>
<td>-</td>
<td>-</td>
<td>0.4</td>
</tr>
<tr>
<td>11:00</td>
<td>-</td>
<td>100%</td>
<td>-</td>
<td>-</td>
<td>0.4</td>
</tr>
<tr>
<td>12:00</td>
<td>-</td>
<td>100%</td>
<td>-</td>
<td>-</td>
<td>0.4</td>
</tr>
<tr>
<td>13:00</td>
<td>-</td>
<td>100%</td>
<td>-</td>
<td>-</td>
<td>0.4</td>
</tr>
<tr>
<td>14:00</td>
<td>-</td>
<td>100%</td>
<td>-</td>
<td>-</td>
<td>0.4</td>
</tr>
<tr>
<td>15:00</td>
<td>full</td>
<td>100%</td>
<td>45°</td>
<td>100%</td>
<td>0.4</td>
</tr>
<tr>
<td>16:00</td>
<td>top</td>
<td>100%</td>
<td>0°</td>
<td>100%</td>
<td>0.4</td>
</tr>
<tr>
<td>17:00</td>
<td>-</td>
<td>100%</td>
<td>200</td>
<td>200</td>
<td>0.4</td>
</tr>
<tr>
<td>18:00</td>
<td>-</td>
<td>50%</td>
<td>200</td>
<td>200</td>
<td>0.4</td>
</tr>
</tbody>
</table>

21st June
### Shading schedule

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00</td>
<td>-</td>
<td>100%</td>
<td>25,5</td>
<td>0,4</td>
</tr>
<tr>
<td>10:00</td>
<td>-</td>
<td>100%</td>
<td>25,5</td>
<td>0,4</td>
</tr>
<tr>
<td>11:00</td>
<td>-</td>
<td>100%</td>
<td>25,5</td>
<td>0,5</td>
</tr>
<tr>
<td>12:00</td>
<td>-</td>
<td>100%</td>
<td>25,5</td>
<td>0,6</td>
</tr>
<tr>
<td>13:00</td>
<td>-</td>
<td>100%</td>
<td>26</td>
<td>0,7</td>
</tr>
<tr>
<td>14:00</td>
<td>-</td>
<td>100%</td>
<td>26</td>
<td>0,6</td>
</tr>
<tr>
<td>15:00</td>
<td>full 45°</td>
<td>100%</td>
<td>26</td>
<td>0,7</td>
</tr>
<tr>
<td></td>
<td>45° half-full</td>
<td>100%</td>
<td>26</td>
<td>0,6</td>
</tr>
<tr>
<td>16:00</td>
<td>top 0°</td>
<td>100%</td>
<td>26</td>
<td>0,7</td>
</tr>
<tr>
<td>17:00</td>
<td>-</td>
<td>100%</td>
<td>26</td>
<td>0,7</td>
</tr>
<tr>
<td>18:00</td>
<td>-</td>
<td>50%</td>
<td>26</td>
<td>0,6</td>
</tr>
</tbody>
</table>

### Results

- **21st June**
- **Temperature**: 25,5 / 23,5°C
- **Energy demand**: 0,4 / 0,2 kWh

**Note**: The shading schedule is adjusted to maintain a temperature range of 23.5°C to 25.5°C, with energy demand ranging from 0.2 to 0.7 kWh.
## 23rd December

### Shading Schedule

<table>
<thead>
<tr>
<th>Time</th>
<th>Shading</th>
<th>Illuminance [lux]</th>
<th>Temperature [°C]</th>
<th>Energy Demand [kWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00</td>
<td>-</td>
<td>100</td>
<td>20</td>
<td>0,2</td>
</tr>
<tr>
<td>10:00</td>
<td>-</td>
<td>100</td>
<td>20</td>
<td>0,2</td>
</tr>
<tr>
<td>11:00</td>
<td>-</td>
<td>100</td>
<td>20,0</td>
<td>0,2</td>
</tr>
<tr>
<td>12:00</td>
<td>-</td>
<td>200</td>
<td>20,5</td>
<td>0,1</td>
</tr>
<tr>
<td>13:00</td>
<td>-</td>
<td>300</td>
<td>20,5</td>
<td>0,01</td>
</tr>
<tr>
<td>14:00</td>
<td>-</td>
<td>300</td>
<td>20,5</td>
<td>0,02</td>
</tr>
<tr>
<td>15:00</td>
<td>-</td>
<td>200</td>
<td>20,5</td>
<td>0,04</td>
</tr>
<tr>
<td>16:00</td>
<td>-</td>
<td>100</td>
<td>20,5</td>
<td>0,01</td>
</tr>
<tr>
<td>17:00</td>
<td>-</td>
<td>100</td>
<td>20,5</td>
<td>0,03</td>
</tr>
<tr>
<td>18:00</td>
<td>-</td>
<td>100</td>
<td>20,5</td>
<td>0,01</td>
</tr>
</tbody>
</table>

**Notes:**
- Numbers in the table represent the percentage of shading for each time slot.
- Illuminance and temperature values are given in the respective columns.
- Energy demand values are estimated for each hour.
### Shading schedule

<table>
<thead>
<tr>
<th>Time</th>
<th>Shading</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00</td>
<td>-</td>
</tr>
<tr>
<td>10:00</td>
<td>-</td>
</tr>
<tr>
<td>11:00</td>
<td>-</td>
</tr>
<tr>
<td>12:00</td>
<td>-</td>
</tr>
<tr>
<td>13:00</td>
<td>-</td>
</tr>
<tr>
<td>14:00</td>
<td>-</td>
</tr>
<tr>
<td>15:00</td>
<td>-</td>
</tr>
<tr>
<td>16:00</td>
<td>-</td>
</tr>
<tr>
<td>17:00</td>
<td>-</td>
</tr>
<tr>
<td>18:00</td>
<td>-</td>
</tr>
</tbody>
</table>

### Illuminance [lux]

<table>
<thead>
<tr>
<th>Time</th>
<th>0%</th>
<th>50%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10:00</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11:00</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12:00</td>
<td>200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13:00</td>
<td>300</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14:00</td>
<td>300</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15:00</td>
<td>200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16:00</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17:00</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18:00</td>
<td>100</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Temperature [°C]

<table>
<thead>
<tr>
<th>Time</th>
<th>20</th>
<th>20,5</th>
<th>20,5</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00</td>
<td>20</td>
<td>20,5</td>
<td>20,5</td>
</tr>
<tr>
<td>10:00</td>
<td>20</td>
<td>20,5</td>
<td>20,5</td>
</tr>
<tr>
<td>11:00</td>
<td>20</td>
<td>20,5</td>
<td>20,5</td>
</tr>
<tr>
<td>12:00</td>
<td>20</td>
<td>20,5</td>
<td>20,5</td>
</tr>
<tr>
<td>13:00</td>
<td>20</td>
<td>20,5</td>
<td>20,5</td>
</tr>
<tr>
<td>14:00</td>
<td>20</td>
<td>20,5</td>
<td>20,5</td>
</tr>
<tr>
<td>15:00</td>
<td>20</td>
<td>20,5</td>
<td>20,5</td>
</tr>
<tr>
<td>16:00</td>
<td>20</td>
<td>20,5</td>
<td>20,5</td>
</tr>
<tr>
<td>17:00</td>
<td>20</td>
<td>20,5</td>
<td>20,5</td>
</tr>
<tr>
<td>18:00</td>
<td>20</td>
<td>20,5</td>
<td>20,5</td>
</tr>
</tbody>
</table>

### Energy demand [kWh]

<table>
<thead>
<tr>
<th>Time</th>
<th>0,2</th>
<th>0,2</th>
<th>0,2</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00</td>
<td>0,2</td>
<td>0,2</td>
<td>0,2</td>
</tr>
<tr>
<td>10:00</td>
<td>0,2</td>
<td>0,2</td>
<td>0,2</td>
</tr>
<tr>
<td>11:00</td>
<td>0,2</td>
<td>0,1</td>
<td>0,1</td>
</tr>
<tr>
<td>12:00</td>
<td>0,1</td>
<td>0,02</td>
<td>0,03</td>
</tr>
<tr>
<td>13:00</td>
<td>0,01</td>
<td>0,04</td>
<td>0,01</td>
</tr>
<tr>
<td>14:00</td>
<td>0,02</td>
<td>0,1</td>
<td>0,01</td>
</tr>
<tr>
<td>15:00</td>
<td>0,03</td>
<td>0,04</td>
<td>0,01</td>
</tr>
<tr>
<td>16:00</td>
<td>0,03</td>
<td>0,01</td>
<td>-</td>
</tr>
<tr>
<td>17:00</td>
<td>0,03</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>18:00</td>
<td>0,03</td>
<td>-</td>
<td>0,01</td>
</tr>
</tbody>
</table>
## 23rd December

<table>
<thead>
<tr>
<th>Time</th>
<th>Shading Schedule</th>
<th>Illuminance [lux]</th>
<th>Temperature [°C]</th>
<th>Energy Demand [kWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00</td>
<td>-</td>
<td>0%</td>
<td>100</td>
<td>0,2, 0,2, 0,2</td>
</tr>
<tr>
<td>10:00</td>
<td>-</td>
<td>0%</td>
<td>100</td>
<td>0,2, 0,2, 0,1</td>
</tr>
<tr>
<td>11:00</td>
<td>-</td>
<td>0%</td>
<td>100</td>
<td>0,2, 0,1, 0,1</td>
</tr>
<tr>
<td>12:00</td>
<td>-</td>
<td>0%</td>
<td>200</td>
<td>0,1, 0,02, 0,03</td>
</tr>
<tr>
<td>13:00</td>
<td>-</td>
<td>50%</td>
<td>300</td>
<td>0,01, 0,04, 0,01</td>
</tr>
<tr>
<td>14:00</td>
<td>-</td>
<td>100%</td>
<td>300</td>
<td>0,02, 0,1, 0,01</td>
</tr>
<tr>
<td>15:00</td>
<td>-</td>
<td>100%</td>
<td>200</td>
<td>0,03, 0,04, 0,01</td>
</tr>
<tr>
<td>16:00</td>
<td>-</td>
<td>100%</td>
<td>100</td>
<td>0,03, 0,01, -</td>
</tr>
<tr>
<td>17:00</td>
<td>-</td>
<td>100%</td>
<td>100</td>
<td>0,03, -, -</td>
</tr>
<tr>
<td>18:00</td>
<td>-</td>
<td>50%</td>
<td>100</td>
<td>0,03, -, 0,01</td>
</tr>
</tbody>
</table>
# Results

<table>
<thead>
<tr>
<th>Time</th>
<th>Shading Schedule</th>
<th>Illuminance [lux]</th>
<th>Temperature [°C]</th>
<th>Energy Demand [kWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00</td>
<td></td>
<td>100</td>
<td>20</td>
<td>0.2, 0.2, 0.2</td>
</tr>
<tr>
<td>10:00</td>
<td></td>
<td>100</td>
<td>20</td>
<td>0.2, 0.2, 0.1</td>
</tr>
<tr>
<td>11:00</td>
<td></td>
<td>100</td>
<td>20</td>
<td>0.2, 0.1, 0.1</td>
</tr>
<tr>
<td>12:00</td>
<td></td>
<td>200</td>
<td>20, 20.5, 20.5</td>
<td>0.1, 0.02, 0.03, 0.01, 0.02, 0.1, 0.01, 0.03, 0.01, 0.03</td>
</tr>
<tr>
<td>13:00</td>
<td></td>
<td>300</td>
<td>20,5, 20,5</td>
<td>0.01, 0.04, 0.01, 0.02, 0.1, 0.04, 0.01, 0.03, 0.01, 0.03</td>
</tr>
<tr>
<td>14:00</td>
<td></td>
<td>300</td>
<td>20,5, 21, 20.5</td>
<td>0.03, 0.04, 0.01, 0.03, 0.04, 0.01, 0.03, 0.01, 0.03</td>
</tr>
<tr>
<td>15:00</td>
<td></td>
<td>200</td>
<td>20,5, 21, 20.5</td>
<td>0.03, 0.01, -</td>
</tr>
<tr>
<td>16:00</td>
<td></td>
<td>100</td>
<td>20,5, 21, 21</td>
<td>0.03, -, -</td>
</tr>
<tr>
<td>17:00</td>
<td></td>
<td>100</td>
<td>20,5, 21, 21</td>
<td>0.03, -, -</td>
</tr>
<tr>
<td>18:00</td>
<td></td>
<td>100</td>
<td>20,5, 21, 21</td>
<td>0.03, -, 0.01</td>
</tr>
</tbody>
</table>

Shading schedule: 9:00 - 11:00: 0%, 12:00 - 13:00: 0%, 13:00 - 14:00: 50%, 14:00 - 15:00: 100%, 15:00 - 16:00: 100%, 16:00 - 18:00: 50%.

23rd December
### Results overview

<table>
<thead>
<tr>
<th></th>
<th>Reference project 1</th>
<th>Reference project 2</th>
<th>Design option</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Roller shading</td>
<td>Venetian blinds</td>
<td>Ch-LC + LC</td>
</tr>
<tr>
<td><strong>Daylight</strong></td>
<td>83%</td>
<td>86%</td>
<td>85%</td>
</tr>
<tr>
<td><strong>Autonomy</strong></td>
<td>low</td>
<td>medium</td>
<td>high</td>
</tr>
<tr>
<td><strong>View availability</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Energy consumption</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lighting</td>
<td>45.5 kWh/y</td>
<td>37.5 kWh/y</td>
<td>38.2 kWh/y</td>
</tr>
<tr>
<td><strong>Energy heating &amp; cooling</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>127.1 kWh/y</td>
<td>113.7 kWh/y</td>
<td>41.3 kWh/y</td>
</tr>
</tbody>
</table>
### Results overview

<table>
<thead>
<tr>
<th>Daylight Autonomy</th>
<th>View availability</th>
<th>Energy consumption lighting</th>
<th>Energy heating &amp; cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roller shading</td>
<td>low</td>
<td>45.5 kWh/y</td>
<td>127.1 kWh/y</td>
</tr>
<tr>
<td>83%</td>
<td>medium</td>
<td>37.5 kWh/y</td>
<td>113.7 kWh/y</td>
</tr>
<tr>
<td>Reference project 1</td>
<td>high</td>
<td>38.2 kWh/y</td>
<td>41.3 kWh/y</td>
</tr>
<tr>
<td>Venetian blinds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>86%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reference project 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ch-LC + LC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>85%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Results overview

<table>
<thead>
<tr>
<th></th>
<th>Reference project 1</th>
<th>Reference project 2</th>
<th>Design option</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Roller shading</strong></td>
<td>83%</td>
<td>86%</td>
<td>85%</td>
</tr>
<tr>
<td><strong>Venetian blinds</strong></td>
<td>low</td>
<td>medium</td>
<td><strong>high</strong></td>
</tr>
<tr>
<td><strong>Energy consumption lighting</strong></td>
<td>45.5 kWh/y</td>
<td>37.5 kWh/y</td>
<td>38.2 kWh/y</td>
</tr>
<tr>
<td><strong>Energy heating &amp; cooling</strong></td>
<td>127.1 kWh/y</td>
<td>113.7 kWh/y</td>
<td>41.3 kWh/y</td>
</tr>
</tbody>
</table>
## Results overview

<table>
<thead>
<tr>
<th>Design option</th>
<th>Roller shading</th>
<th>Venetian blinds</th>
<th>Ch-LC + LC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Daylight Autonomy</strong></td>
<td>83%</td>
<td>86%</td>
<td>85%</td>
</tr>
<tr>
<td><strong>View availability</strong></td>
<td>low</td>
<td>medium</td>
<td>high</td>
</tr>
<tr>
<td><strong>Energy consumption</strong></td>
<td>45.5 kWh/y</td>
<td>37.5 kWh/y</td>
<td>38.2 kWh/y</td>
</tr>
<tr>
<td><strong>Lighting</strong></td>
<td>127.1 kWh/y</td>
<td>113.7 kWh/y</td>
<td>41.3 kWh/y</td>
</tr>
</tbody>
</table>
Pros & cons

2 levels of adaptation
Low maintenance

Roller shading
Venetian blinds
Ch-LC + LC
Pros & cons

- Roller shading
- Venetian blinds
- Ch-LC + LC

2 levels of adaptation
Low maintainance

Transparency
Independendnt control of visible light and infrared
Design freedom
Minimal impact
Pros & cons

- Roller shading
  - 2 levels of adaptation
  - Low maintenance

- Venetian blinds
  - Ch-LC + LC
  - Transparency
  - Independent control of visible light and infrared
  - Design freedom
  - Minimal impact

- Ch-LC + LC

- Consumption of energy during the clear state
  - High cost
  - Long development phase
Unitised system → standard product

Layer of LC

Increase daylight

Increase daylight and view

Increase view
Unitised system

→

standard product

Layer of Ch-LC

Layer of LC

Increase daylight

Increase daylight and view

Increase view

Infrared control
Design

Unitised system

standard product

Glass cladding or PV panel

Energy production

Increase daylight

Increase daylight and view

Infrared control

Increase view

Layer of LC

Layer of Ch-LC
Design

Unitised system

standard product
Further developments

Different facade systems
Different dimension
Different shapes
Different colours
Different functions
Further developments

- Different facade systems
- Different dimension
- Different shapes
- Different colours
- Different functions

Integrated PV cells

Energy
Further developments

Different facade systems
Different dimension
Different shapes
Different colours
Different functions

integrated PV cells

energy

projection

outdoor

Advertisment
interesting for leasing facade

indoor

Presentation
or group work flexibility of interiors
THANK YOU