High-Performance Facades: Designing Office Building Facades to Enhance Indoor Daylighting Performance

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“A room is not a room without natural light.”

Louis Kahn, 1971
Motivation

Building skins shouldn’t be just designed only for its aesthetics aspects but also as a functioning element in the building.

The research aims to:

- Define guidelines for using daylighting systems to achieve high performance office building facades.

- Explore an integrated framework or methodology for integrating computational and building performance simulation tools.

*Figures copyright: Lecture presentation Prof. G. Z. Brown
1. Shading and Daylight Redirecting Systems: Daylighting Performance Analysis and Guidelines

2. Integrating Daylighting and Energy Consumption Simulations

3. Integrating Computational and Building Performance Simulation Techniques for Optimized Facade Designs
1 Shading and Daylight Redirecting Systems: Daylighting Performance Analysis and Guidelines

Shading Devices Design and Parameters
Location and Context

The case study was chosen to be located in the city of Cairo, Egypt (30° N- 31° E).

Cairo is endowed with a clear sunny sky for almost all the year round.

Base Case Parameters

A typical side-lit office room space 4.00 m wide and 6.00 m deep rectangular space, with 3.00 m clear height. The office space was assumed to have 3.60m wide and 1.80 m high window.

Modeled Cases

Different daylighting systems were investigated for the South, and East/West orientations. Three shading systems and two daylight redirecting systems were studied.
Simulation Parameters and Assumptions

The **Daylight Availability** metric was chosen as evaluating criteria.

**Daylit - Partially daylit - Over lit**

"Low Performance": (50% ≤ daylit area < 65%).
"Medium Performance": (65% ≤ daylit area < 75%).
"High Performance": (75% ≤ daylit area).

**Daylight Glare Probability (DGP)**

Simulation Workflow and Modeling Software

Parametric models were created using **Grasshopper** a plug-in for **Rhinoceros** modeling software. Simulations were conducted using **Diva-for-Rhino** which was used to interface Radiance and Daysim for annual simulation and illuminance computation, and Evalglare for calculating the Daylight Glare Probability (DGP).
Base Case Simulation Results

South Orientation

57% Daylit Area
43% Overlit Area

East Orientation

45% Daylit Area
42% Overlit Area
Sky condition and Sun angles

Cairo, Egypt
30 N, 31.2 E

<table>
<thead>
<tr>
<th></th>
<th>Winter</th>
<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
<th>Annual Mean</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Days with Clear Sky</strong> (Monthly Mean)</td>
<td>23</td>
<td>28</td>
<td>31</td>
<td>28</td>
<td>27</td>
<td>90%</td>
</tr>
<tr>
<td><strong>Days with Cloud Sky</strong> (Monthly Mean)</td>
<td>7</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>10%</td>
</tr>
</tbody>
</table>
Horizontal sun breakers

- Vertical shading angle: 70°, 60°, 50° and 40°
- Rotation angles: 15° downwards, 0°, and 15° upwards
- Number of slats: single, double and triple

South Orientation

East Orientation
Horizontal sun breakers

- Vertical shading angle: 70°, 60°, 50° and 40°
- Rotation angles: 15° downwards, 0°, and 15° upwards
- Number of slats: single, double and triple

South Orientation

Three slats, horizontal with 50° VSA

70% Daylit Area
1% Overlit Area

East Orientation

Two slats, horizontal with 50° VSA

53% Daylit Area
9% Overlit Area
Horizontal sun breakers

- **Vertical shading angle**: 70°, 60°, 50° and 40°
- **Rotation angles**: 15° downwards, 0°, and 15° upwards
- **Number of slats**: single, double and triple

South Orientation

30% Highest DGP

Imperceptible Glare

East Orientation

25% Highest DGP

Imperceptible Glare
Vertical sun breakers

- **Horizontal shading angle:** 70°, 60°, 50° and 40°
- **Rotation angles:** 15° downwards, 0°, and 15° upwards
- **Number of slats:** three, four and five

**South Orientation**

**East Orientation**
Vertical sun breakers

The effect of changing three parameters was studied.

- **Horizontal shading angle**: 70°, 60°, 50° and 40°
- **Rotation angles**: 15° North, 0°, and 15° South
- **Number of slats**: three, four and five

**South Orientation**

- Four slats, 0° rotation, with 70° HSA
- **59%** Daylit Area
- **39%** Overlit Area

**East Orientation**

- Five slats, 15° South, with 70° HSA
- **43%** Daylit Area
- **39%** Overlit Area
Solar Screens

The effect of changing three parameters was studied.

- **Vertical shading angle**: 70°, 60°, 50° and 40°
- **Perforation ratio**: 90%, 80%, and 70%
- **Aspect ratio (Horizontal: Vertical)**: 1:1, 2:1 and 4:1

South Orientation

![South Orientation Chart]

East Orientation

![East Orientation Chart]
Solar Screens

The effect of changing three parameters was studied.

- **Vertical shading angle**: 70°, 60°, 50° and 40°
- **Perforation ratio**: 90%, 80%, and 70%
- **Aspect ratio (Horizontal: Vertical)**: 1:1, 2:1 and 4:1

### South Orientation

- **50% Daylit Area**
- **0% Overlit Area**

- **90% perforation, 4:1, with 70° VSA**

### East Orientation

- **41% Daylit Area**
- **9% Overlit Area**

- **90% perforation, 4:1, with 50° VSA**
Light Shelves

The effect of changing three parameters was studied.

- **External light shelf depth**: 60 cm, 80 cm, 100 cm and 120 cm
- **Internal light shelf depth**: 0, 30 cm, 60 cm, and 80 cm
- **External light shelf rotation angle**: 0°, 10°, 20°, and 30°

### South Orientation

![Graph showing light distribution for South Orientation](image)

### East Orientation

![Graph showing light distribution for East Orientation](image)
Light Shelves

The effect of changing three parameters was studied.

- **External light shelf depth:** 60 cm, 80 cm, 100 cm and 120 cm
- **Internal light shelf depth:** 0, 30 cm, 60 cm, and 80 cm
- **External light shelf rotation angle:** 0°, 10°, 20°, and 30°

### South Orientation

- **82%** Daylit Area
- **16%** Overlit Area

### East Orientation

- **60%** Daylit Area
- **14%** Overlit Area
Louvers and Blinds

The louvers were rotated in two different ways:

The conventional way: all louver slats were rotated in the same direction
The combined way: where every other louver have the same rotation angle.

- Vertical shading angle: 70°, 60°, 50° and 40°
- Rotation angles: 15° downwards, 0°, and 15° upwards

South Orientation

East Orientation
Louvers and Blinds

The louvers were rotated in two different ways:
The conventional way: all louver slats were rotated in the same direction
The combined way: where every other louver have the same rotation angle.

- Vertical shading angle: 70°, 60°, 50° and 40°
- Rotation angles: 15° downwards, 0°, and 15° upwards

South Orientation

Conventional, 15° downwards, 40° VSA

67% Daylit Area
0% Overlit Area

East Orientation

Conventional, 15° downwards, 40° VSA

51% Daylit Area
0% Overlit Area

Radiance Workshop 2013, Golden, Colorado
Comparison between the five systems

South Orientation

East Orientation

Daylit Area %

Percentage of Cases

Daylit Area %

Percentage of Cases

Base Case

Horizonal Sun Breakers  Light shelves  Vertical Louvers  Louvers  Solar Screen

Base Case

Horizonal Sun Breakers  Light shelves  Vertical Louvers  Louvers  Solar Screen

Radiance Workshop 2013, Golden, Colorado
Integrating Daylighting and Energy Consumption Simulations

Methodology

<table>
<thead>
<tr>
<th>Studied cases for February/October cut-off angle (40°)</th>
<th>Number of slats</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>15° downwards A</td>
<td><img src="image1.png" alt="Image" /></td>
</tr>
<tr>
<td>0° B</td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td>15° upwards C</td>
<td><img src="image3.png" alt="Image" /></td>
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</table>
“Integrating Computational and Building Performance Simulation Techniques for Optimized Facade Designs”
Generative Design, Optimization and Form Finding

Generative Design

Optimization and Form finding
Generative Design, Optimization and Form Finding

Optimization Methodology

Simulation Inputs
- Weather File
- Occupancy Schedule
- Illuminance Threshold
- Analysis Grid

Parametric Model
- Model Geometry and Materials
- Parametric Model Geometry
- Design Parameters Controllers

Daylighting Performance Simulation
- DIVA-Daysim-Radiance
- Climate- Based Simulation

Results and Fitness
- Results (Output)
  - Daylight Availability
- Daylit Area Percentage Calculations
- Fitness

Optimization
- Galapagos (GA optimization)
  - Maximizing Fitness Values
- Best performance for 20 continuous generation?

Generate New Generation

Yes
Optimal Solution
No
Case 1: Light shelf and Solar screen Combination

Various combinations of light shelves and solar screens were tested. total number of possible combinations was **2,304 cases** for six different variables.

**Solar Screen Variables**
- Vertical shading angle
- Perforation ratio
- Aspect ratio

**Light Shelf Variables**
- External light shelf depth
- Internal light shelf depth
- External light shelf rotation angle
Case 1: Light shelf and Solar screen Combination

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Case 1: Light shelf and Solar screen Combination

Various combinations of light shelves and solar screens were tested. The total number of possible combinations was 2,304 cases for six different variables. To avoid simulating and analyzing all the cases, Galapagos, a genetic-algorithm evolutionary solver was used.

**Solar Screen Variables**
- Vertical shading angle
- Perforation ratio
- Aspect ratio

**Light Shelf Variables**
- External light shelf depth
- Internal light shelf depth
- External light shelf rotation angle

<table>
<thead>
<tr>
<th>Daylit Area</th>
<th>Overlit Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>64%</td>
<td>0%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Daylit Area</th>
<th>Overlit Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>62%</td>
<td>7%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Daylit Area</th>
<th>Overlit Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>62%</td>
<td>3%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Daylit Area</th>
<th>Overlit Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>61%</td>
<td>6%</td>
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</table>
Case 2: Form Finding
Free Form Gills Surface
Case 2: Form Finding

The façade was divided into upper part where a curved light shelf was modeled. In the lower part a free form configuration “Gills surface” divided into four curved panels. Total number of possible solutions exceeds 4 millions.

Variables for each curve
- Curve height
- Peak point position
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Case 2: Form Finding

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Variables for each curve
- Curve height
- Peak point position

56%  
Daylit Area  
53%  
Daylit Area

2%  
Overlit Area

3%  
Overlit Area

51%  
Daylit Area

3%  
Overlit Area
Future Work

The Future

Next Exit
Future Work

Research can extend to cover other environmental aspects to achieve an integrated high performance facades.
- Energy consumption/ Thermal comfort/ Natural ventilation/ Digital fabrication, paneling and structure aspects/ Life cycle cost

Investigating the use of dynamic and kinetic systems for more adaptive solutions and comparing the feasibility of dynamic systems and fixed systems may give a better guide for designing even more dynamic and higher performance facades.

-Finally, verification of the results of this study by real life measurements can strengthen the thesis recommendations.
THANK YOU!