A design strategy for daylight control for the project “Vertical City”, in Rotterdam

Marina Stavrakantonaki 4118057

First Mentor: Tillmann Klein
Second Mentor: Michela Turrin
Third Mentor: Truus Hordijk
BACKGROUND INFORMATION

THE FRAME

PARTIES INVOLVED

1. Broekbakema Architectural firm
2. DGMR
3. ABT

project:
“Vertical City”

Rotterdam, Conradstraat

source: Broekbakema
THE NEW BUILDING WILL NOT LEAVE THE SURROUNDINGS IN SHADOW: NORTH-SOUTH ORIENTATION

- The maximum height that a high-rise could possibly assume in this plot is 200m, at the eastern corner.
CLIMATE HAS A CENTRAL ROLE IN THE DESIGN CONCEPT

RESEARCH QUESTIONS

a. How can we assure maximum use of daylight for different functions?
b. How do changes in the geometry affect the daylight levels of the space?
c. Which systems could be used for the control of daylight?

OBJECTIVE

The purpose of the project is to propose through research, simulations, calculations and design a number of possibilities for efficient daylight design of a façade unit for the high-rise.
DAYLIGHT DESIGN

DAYLIGHT: the light flux jointly delivered by direct and diffuse solar radiation

VS

SUNLIGHT: direct solar radiation

BASIC IDEA: The daylight entering a space must provide satisfactory light levels for the visual tasks performed behind the façade.

EN 12665 (light and lighting)
EN 12464-1
EN 15251 (indoor environmental input parameters for design and assessment of energy performance of buildings)
WHY ARE THE LUX LEVELS USED IN THE NORMS: 1. can be easily measured 2. provide a rule of thumb

WHY we are NOT working with LUX levels: because we are interested in validating

satisfactory

office spaces: 500 LUX on working plane

WHY ARE THE LUX LEVELS USED IN THE NORMS: 1. can be easily measured 2. provide a rule of thumb

WHY we are NOT working with LUX levels: because we are interested in validating

satisfactory

office spaces: 500 LUX on working plane
GLARE

DUE TO

LUMINANCE IN THE VISUAL FIELD WHICH IS CONSIDERABLY GREATER THAN THE LUMINANCE TO WHICH THE EYES ARE ADAPTED

COMFORT

perception related

age of the user

visual tasks

expectations

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FACTORS associated with designing any daylighting system

Factors we CANNOT CONTROL, although most are predictable.

• Project’s location, specifically latitude. Latitude determines mainly solar altitude
• Time of the year. The sun is at its lowest in the winter months and at it’s highest during the summer.
• Sky conditions such as cloud cover and pollution.
• Time of the day. The sun rises in the east and sets in the west.

FACTORS we CAN CONTROL:

• Orientation of the building.
• Location and size of windows
  • Geometry of the space
  • Materials
STUDY ON SUN-CONTROL SYSTEMS

PHASE 1
ANALYSIS

PHASE 2
STUDY ON THE EFFECT OF GEOMETRY

PHASE 3
STUDY ON SUN-CONTROL SYSTEMS

PHASE 4
TESTS ON SYSTEMS

PHASE 5
PROPOSAL

A. TESTS ON GEOMETRY

1. changing the length of the overhang
2. arranging floors inside the unit
3. opening gaps in the overhang

OPTIMAL CONFIGURATION
THE UNIT: Typical repetitive space 13x13x22m

**FLOORPLAN**

- Overhang 7-9m (corridor)
- 20-22m in-between space
- Overhang

**CROSS-SECTION**

- Outside (corridor)
- Inside (floors)
- 13m

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### DIMENSIONS OF THE UNIT

#### PARAMETER 1: DEPTH TO HEIGHT RATIO (2:1)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Height of glazing</td>
<td>13 m (100%)</td>
</tr>
<tr>
<td>B. Depth of space</td>
<td>20-22 m</td>
</tr>
<tr>
<td>C. Length of the overhangs</td>
<td>7-9 m</td>
</tr>
</tbody>
</table>

#### SCHEME

![Scheme of the unit](source: Broekbakema)

1. How does the geometry of the unit affect the light levels in the interior?
2. Which is the optimal number of floors and the optimal position of the floors inside the unit?
3. How does a gap at the overhang affect the levels of light at the various floors?
4. Which is the minimum dimension of a gap in the overhang so that it can have a significant effect on the levels of light that we calculate in the interior?
A. TESTS ON GEOMETRY

**GOAL: TO SPECIFY**
- Changes in the illuminance levels for different lengths of the overhang
- Possible number of floors and their positions
- The minimum possible depth of a gap in the overhang in order to achieve considerable changes in the illuminance levels

<table>
<thead>
<tr>
<th>Height of glazing</th>
<th>Depth</th>
<th>Overhangs</th>
</tr>
</thead>
<tbody>
<tr>
<td>13m</td>
<td>22m</td>
<td>8m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8.6m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9m</td>
</tr>
</tbody>
</table>

**overcast, 21/3, 11:00 a.m**

rho of the walls = 50%
rho of the floors = 20%
rho of the ceilings = 70%
rho of the glass = 6%, transparency = 70%
OVERHANG= 9M (WORST CASE SCENARIO)

INVERSE LAW OF RADIATION

Levels of illuminance inside the unit, overhang=9m, no interior floors.

overcast sky, 21/3/2012, 11:00 a.m.

<table>
<thead>
<tr>
<th>LENGTH</th>
<th>ILLUMINANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.916 m</td>
<td>3308 lux</td>
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<tr>
<td>2.748 m</td>
<td>2479 lux</td>
</tr>
<tr>
<td>7.328 m</td>
<td>1506 lux</td>
</tr>
<tr>
<td>12.869 m</td>
<td>1234 lux</td>
</tr>
</tbody>
</table>
POSSIBLE NUMBER OF FLOORS AND POSITIONS

Calculation plane: h=4.05m (floor 1= 3.3 m)

Calculation plane: h=7.75m (floor 2= 7.0 m)

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GAPS IN THE OVERHANG

2 GAPS

3 GAPS

4 GAPS

THE GAPS TOWARDS THE EDGE OF THE OVERHANG DO NOT HAVE A SIGNIFICANT EFFECT

Initial situation

<table>
<thead>
<tr>
<th>floor3</th>
<th>Initial situation</th>
<th>D7.1</th>
<th>D7.1.1</th>
<th>D7.1.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>overcast sky, 21/6, 11:00 a.m</td>
<td>164 165 172</td>
<td>208 210 215</td>
<td>212 214 220</td>
<td>216 219 225</td>
</tr>
<tr>
<td>clear sky, 21/6, 11:00 a.m</td>
<td>775 781 770</td>
<td>1105 1100 1053</td>
<td>1169 1163 1113</td>
<td>1190 1185 1134</td>
</tr>
</tbody>
</table>

VALUES TAKEN IN THE MIDDLE OF THE FLOORPLAN
MINIMUM POSSIBLE DEPTH OF A GAP = 2.5M

(position of the gap)

gap = 1.0m, Height = 7.75

(position of the gap)

gap = 2.0m, Height = 7.75

(position of the gap)

gap = 2.5m, Height = 7.75

(clear sky, 21/3/2012, 11:00 a.m.)
RESULTING GEOMETRY

CONCLUSIONS

- THE DEVICE OF THE OPENINGS ALONG THE OVERHANG WILL ONLY IMPROVE THE LIGHT CONDITIONS IN THE UPPER FLOOR.

- THE GAPS SHOULD BE AT LEAST 2,5M WIDE.

- DEVICES THAT WILL BRING LIGHT DEEPER INTO THE SPACE ARE NECESSARY.

- in-between floors: d=0,75m
- in-between floors: d=0,75m
- mega-floors: d=1,5m

- d=4.5m
- d=3.7m
- d=3.3m
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- **SYSTEMS**
  - Daylight enhancement
  - Solar shading
  
  **Reflectors**
  
  **Light shelves**
  
  **Anidolic collectors**
  
  **Light ducts**
  
  **Light tubes**


Light duct, Friedrich Linhart, Stephen K. Wittkopf, and Jean-Louis Scartezzini

Anidolic Daylighting Systems (ADS) by the Solar Energy and Building Physics Laboratory of EPFL.

Light tubes

Light shelves, BrightShelf®

SYSTEMS  
solar shading

TYPOLOGIES

LOUVERS

VENETIAN BLINDS

CURTAINS

SLIDING SHUTTERS

OPENING SHUTTERS

ROTATION

SLIDING ALONG THE HORIZONTAL AXIS

HORIZONTAL AXIS/ VERTICAL AXIS

OPEN/ CLOSE

louvers

venetian blinds

sliding/folding shutters

opening shutters

rotating panels

brise soleil

canopies

awnings

curtains

Light reflecting
6. TENSIONED FABRIC SYSTEMS

7. STRETCHABLE TEXTILES

8. AWNINGS

9. ROTATING PANELS (HORIZONTAL/VERTICAL/TILTED)

- Rolling textiles
- Stretchable textiles
- Tensioned fabric systems
- Awnings
- Curtains
- Rolling textiles
- Stretchable textiles
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2 PERFORMANCES TO ACHIEVE:

- enhancement of the levels of light in the interior
- glare-control

HOW

- by means of light reflection
- by means of shading

zones to be tested for comfort

maximize the light levels: reflecting panels, no light blocking or filtering

control of glare: light blocking or filtering

maximize the light levels: reflecting panels, no light blocking or filtering

control of glare: light blocking or filtering

position 1

position 2
Enhancement of the levels of light in the interior

by means of: light reflection

21 March

Sun-rise: 6:26 a.m

Midday: 12:00 am

Sun-set: 18:23 am

Angle of incidence, θ: 0.6°–29.6°

Angle of incidence, θ: 29.6°–37.6°

Angle of incidence, θ: 37.6°–34.1°

Angle of incidence, θ: 34.1°–3.6°

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REFLECTION OF LIGHT DEEPER IN THE SPACE: determining the positions of reflectors

March 21st, 12:00 am, θ=37.6°
RESULTS

rotation angles and positions of the reflectors for the summer and the winter (direct light)

**Summary:** position and rotation angle of the panels for the redirection of light.

<table>
<thead>
<tr>
<th>March 21st</th>
<th>10:00 am</th>
<th>11:00 am</th>
<th>12:00 am</th>
<th>13:00 am</th>
<th>14:00 am</th>
</tr>
</thead>
<tbody>
<tr>
<td>θ=29.6°</td>
<td>θ=34.9°</td>
<td>θ=37.6°</td>
<td>θ=37.3°</td>
<td>θ=34.1°</td>
<td></td>
</tr>
<tr>
<td>pos1</td>
<td>position2</td>
<td>pos1</td>
<td>position2</td>
<td>pos1</td>
<td>position2</td>
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<tr>
<td>pl1</td>
<td>pl2</td>
<td>pl3</td>
<td>pl1</td>
<td>pl2</td>
<td>pl3</td>
</tr>
<tr>
<td>height of reflector (m)</td>
<td>4.5</td>
<td>7.2</td>
<td>2.5</td>
<td>5.65</td>
<td>0.73</td>
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<tr>
<td>rotation angle of reflector</td>
<td>0°</td>
<td>7°</td>
<td>0°</td>
<td>7°</td>
<td>7°</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>June 21st</th>
<th>09:00 am</th>
<th>10:00 am</th>
<th>11:00 am</th>
<th>12:00 am</th>
<th>14:00 am</th>
</tr>
</thead>
<tbody>
<tr>
<td>θ=42.7°</td>
<td>θ=51.1°</td>
<td>θ=57.7°</td>
<td>θ=61.3°</td>
<td>θ=55.6°</td>
<td></td>
</tr>
<tr>
<td>position1</td>
<td>position2</td>
<td>position1</td>
<td>position2</td>
<td>position1</td>
<td>position2</td>
</tr>
<tr>
<td>pl1</td>
<td>pl2</td>
<td>pl3</td>
<td>pl1</td>
<td>pl2</td>
<td>pl3</td>
</tr>
<tr>
<td>height of reflector (m)</td>
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<td>7.7</td>
<td>0.96</td>
<td>2.85</td>
<td>7.7</td>
</tr>
<tr>
<td>rotation angle of reflector</td>
<td>16°</td>
<td>16°</td>
<td>16°</td>
<td>16°</td>
<td>16°</td>
</tr>
</tbody>
</table>

θ= angle of incidence
METHOD:
SETUP OF TESTS FOR A MODULAR SPACE (UNIT)

PHASE 4
TESTS ON SYSTEMS

PHASE 5
PROPOSAL

B. TESTS ON LIGHT SHELVES
1. testing different cross-sections of reflectors.
2. testing different positions of reflectors with the optimal cross-section.
3. Tests on systems of reflectors with the optimal cross-section, placed in a unit with the optimal geometry.

C. TESTS ON GLARE
Tests on the optimal system of reflectors with the optimal cross-section, placed in a unit with the optimal geometry.

D. TESTS ON SHADING
B. TESTS ON LIGHT SHELVES

1. tests on cross-sections of the reflectors

- Lamellas 50mm aluminum semi-spectral
- "RETROflex" aluminum semi-spectral white RAL9010
- "RETROlux U" aluminum semi-spectral
- "RETROlux O" aluminum semi-spectral
LUMINANCE/ VIEW
ROTATION ANGLE 13°, JUNE 21, 11 A.M.

VEILING GLARE AND CONTRAST
CASE 3  CASE 4

LUMINANCE/ VIEW HORIZONTAL, JUNE 21, 11 A.M.

VEILING GLARE AND CONTRAST

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B. RESULTS LIGHT SHELVES:

![Graphs showing luminance (cd/m²) versus length (m) for different light sources including lamella 50cm, RETROAD, RETROflex, RETROluxU, and RETROluxO.](image-url)
B. TESTS ON LIGHT SHELVES

1. testing different cross-sections of reflectors.

2. testing different positions of reflectors

3. Tests on systems of reflectors with the optimal cross-section, placed in a unit with the optimal geometry.

C. TESTS ON GLARE
Tests on the optimal system of reflectors with the optimal cross-section, placed in a unit with the optimal geometry.

D. TESTS ON SHADING
1. TESTS ON POSITIONS AND SIZES OF THE REFLECTORS

- **Line 1**
- **Line 2**
- **Unit 1**
- **Unit 2**
- **Calculation plane (nodes)**

- **Small lamellas position 1, 24°**
- **Small lamellas position 1, 156°**
- **Small lamellas position 2, 24°**
- **Small lamellas position 1, 156°**
- **Big lamellas position 1, 11°**
- **Big lamellas position 2, 176°**
- **Big lamellas position 1, 11°**
- **Big lamellas position 2, 176°**

*L = 0.66*
configuration 1

Lamellas, position 1:
galvanized steel
rotation angle 24°
distance between lamellas 0.28m
length of cross-section: radialL=0.66
calculation plane: height=1.5m

configuration 2

Lamellas, position 2:
galvanized steel
rotation angle 24°
distance between lamellas 0.28m
length of cross-section: radialL=0.66
calculation plane: height=1.5m
configuration 3

Lamellas, position 1:
galvanized steel
rotation angle 156°
distance between lamellas 0.28m
length of cross-section: radial L=0.66
calculation plane: height=1.5m

calculation plane third floor

configuration 4

Lamellas, position 1 and position 2:
galvanized steel
rotation angle 156° and 24°
distance between lamellas 0.28m
length of cross-section: radial L=0.66
calculation plane: height=1.5m

calculation plane third floor
configuration 5

2 Lamellas at position 1
galvanized steel
rotation angle $11^\circ$
distance between lamellas 1.25m
radialL=2m
alignedL=1.24m

calculation plane: height=1.5m
Luminance: distance

configuration 6

2 Lamellas at position 2
galvanized steel
rotation angle $176^\circ$
distance between lamellas 1.25m
length of cross section: radialL=2m
alignedL=1.24m
position of the system: height=9.90m

calculation plane: height=1.5m
Luminance: distance

configuration 7

2 Lamellas at position 1 + 1 lamella at position 2
galvanized steel
rotation angle $11^\circ$ + $176^\circ$
distance between lamellas 1.25m
position of the system: height
A=9.90m
B= 8.85m

Luminance: distance
EVALUATION OF THE OPTIMAL CONFIGURATION

INDEX OF RESULTS

<table>
<thead>
<tr>
<th>test 1</th>
<th>test 2</th>
<th>test 3</th>
<th>test 4</th>
</tr>
</thead>
<tbody>
<tr>
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<td>luminance (cd/m²)</td>
<td>luminance (cd/m²)</td>
</tr>
<tr>
<td>609</td>
<td>111</td>
<td>2133</td>
<td>1449</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>test 5</th>
<th>test 6</th>
<th>test 7</th>
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<td>luminance (cd/m²)</td>
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<td>2428</td>
<td>2436</td>
</tr>
<tr>
<td>176</td>
<td>150</td>
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<td>15</td>
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<tr>
<td>14</td>
<td>13</td>
<td></td>
</tr>
</tbody>
</table>

configuration 5 vs 6 vs 7: optimal: 7
RESULTING CONFIGURATION

2 reflectors at position 1
Specifications of reflectors:
galvanized steel, rotation angle 11°
distance between lamellas 1.25m

1 reflector at position 2
Specifications of reflector:
galvanized steel, rotation angle 176°
distance between lamellas 1.25m
EVALUATION OF COMFORT

- Adequacy of the levels of light inside a typical office space at the third floor.
- Specification of potential glare sources.

PARAMETERS

Luminance
  a) distribution of luminance
  b) contrast between adjacent spaces
  c) contrast between ceiling and working plane
  d) contrast between window and working plane
  e) anticipated illuminance levels on the working plane.

Daylight Glare Probability (DGP)
B. TESTS ON LIGHT SHELVES

1. testing different cross-sections of reflectors.
2. testing different positions of reflectors

3. Tests on systems of reflectors with the optimal cross-section, placed in a unit with the optimal geometry.

C. TESTS ON GLARE
Tests on the optimal system of reflectors with the optimal cross-section, placed in a unit with the optimal geometry.

D. TESTS ON SHADING
COMFORT OF THE USER

DIVISION IN ZONES

Highly daylit area: zone1: $2xEWH = \frac{2x\alpha b\tau}{c}$

- $\alpha$: width of window above 0.9m
- $b$: height of window above 0.9m
- $c$: width of window
- $\tau$: transmission of window plane.

Intermediately daylit area: zone2: $1.5x EWH + 2x EWH$
(source: Osterhaus, W.K.E)

For the third floor: total height of window= 3.9m, total width of window= 13.5m.

Consequently:

$$EWH = \frac{13.1 \times 3}{13.5} \times 0.75 = 2.18333m$$
RESULTS (March 21st, 11:00, clear sky)

centre of zone 3, $d=9.7\text{m}$

values in the room: 903-892-68-62-53-51-49-48-48 (cd/m$^2$)
values on the ceiling: 568-496-427-345 (cd/m$^2$)
values on the window: 2000-1783 (cd/m$^2$)

centre of zone 2, $d=7.5\text{m}$

values in the room: 1482-892-68-62-53-52-49-48-48 (cd/m$^2$)
values on the ceiling: 564-503-425-345 (cd/m$^2$)
values on the window: 2000-1783 (cd/m$^2$)
VIEW FROM THE WORKING TABLE

Working table no3, zone2, d=9.7m
March 21st, 11:00, clear sky

values on the window: 1990-1720 (cd/m²)
**values on the desk: 105 (cd/m²)**
values on the laptop: 82 (cd/m²)
values on the ceiling: 554

south façade

Working table no3, zone2, d=9.7m
March 21st, 11:00, **overcast sky**

values on the window: 1990-1720 (cd/m²)
**values on the desk: 18 (cd/m²)**
values on the laptop: 27 (cd/m²)
values on the ceiling: 106

south façade
End of Zone 2: worst case scenario

09:00, 21st June, clear sky

DGP
- camera=1.3m,
- distance from window=7.8m
- angle of camera=60°
- DGP=26%

veiling glare/contrast

desk 1  90 cd/m²
desk 2:  57 cd/m²
desk 3:  52 cd/m²

1171 cd/m²
55   cd/m²
47   cd/m²
South: zone1

South: beginning zone2

South: end zone2

North: zone1

POSITION OF THE CAMERA: height=2m, position in zone 1
angle:60°

POSITION OF THE CAMERA: height=1.3m, distance from window=7.8m (end zone2),
age of camera=60°

POSITION OF THE CAMERA: height=2m, position beginning zone 2
angle:30°

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B. TESTS ON LIGHT SHELVES

1. testing different cross-sections of reflectors.
2. testing different positions of reflectors

3. Tests on systems of reflectors with the optimal cross-section, placed in a unit with the optimal geometry.

C. TESTS ON GLARE
Tests on the optimal system of reflectors with the optimal cross-section, placed in a unit with the optimal geometry.

D. TESTS ON SHADING
1. tests on shading devices

CRITERIA
a) the effectiveness of the system in glare control
b) the distribution of light in the interior
the program assumes glare for a height $> 90\text{cm}$

$$DGP = 24\%$$

$$\text{lines: } x = 8 \quad y = 8$$
$$\text{lines: } x = 8 \quad y = 12$$
$$\text{lines: } x = 8 \quad y = 16$$
opaque vs translucent shading

21st January 16:00

**NO SHADING**

![No Shading Image]

DGP = 25%

**OPAQUE SHADING**

![Opaque Shading Image]

DGP = 25%

**TRANSLUCENT SHADING**

![Translucent Shading Image]

DGP = 24%
type of gradient

lines: \(x = 8\)
\(y = 8\)

lines: \(x = 8\)
\(y = 12\)

lines: \(x = 8\)
\(y = 16\)

dots: \(x = 12\)
\(y = 8\)

dots: \(x = 16\)
\(y = 8\)
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A design strategy for daylight control for the project “Vertical City”, in Rotterdam
CONCLUSIONS

- **Geometry is important**

For a 9m overhang the illuminance levels drop by 4.5% along the first 2m, This drop decreases to 4.3% for the next 4.5m and to 0.49 for the next 5.5m.

-the gap should have a width of at least 2.5m

- the maximum number of floors is 2 (floor1=3.3m, floor2= 7.00m)

- **Reflectors are effective for a clear sky**

-We should optimally use the “RETROflex” cross-section

-The most effective combination of reflectors occurs when they assume radial dimension= 1.25m

-Two reflectors at position 1 and two reflectors at position 2 with rotation angles= 11° and 176° respectively, in combination with a highly reflective ceiling inside the room (reflectance=90%) provided optimal results. The material that was used for the calculations was galvanized steel.
The results on comfort proved:
- the resulting levels of light are adequate for zone 1 throughout the year
- the levels of light are not adequate for the end of zone 2 during an overcast sky. Yet zone 2 in total can be adequately lit throughout the year during a clear sky.
- zone 2 can be underlit during a winter overcast sky, seen that the reflectors have a smaller effect when the perform with diffuse light.
- glare occurs during the evening hours, especially in winter period. The occupants of zone 1 may also experience glare during a summer, clear sky.

The results on shading are the following:
- shading is necessary for a zone>90cm, for the western sun.
- the use of a translucent shader is more optimal than the use of an opaque shader.
- the system should preferably be linear and not dotted.
- the distribution of lines in a translucent shader does not significantly affect the results.
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THANK YOU!

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