Introduction – What is solar shading?

Passive cooling
- Adequate climate
- Large openings, some in higher part
- Good thermal insulation
- Avoid heat sources
- Thermal mass
- **Efficient solar shading devices**
- Ventilation strategies
Introduction – Why is solar shading actual?

Elemental deconstruction of traditional load-bearing wall

<table>
<thead>
<tr>
<th>Bearing wall</th>
<th>Light frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rain barrier</td>
<td>Rain barrier</td>
</tr>
<tr>
<td>Thermal barrier</td>
<td>Thermal barrier</td>
</tr>
<tr>
<td>Solar protection</td>
<td>Solar protection</td>
</tr>
</tbody>
</table>

U = 5.8 W/m²K

U = 0.5 W/m²K


Introduction

Thus, an elemental deconstruction of the traditional load-bearing wall had occurred, with frame, skin and brise-soleil as the main layers, each specialised to fulfill specific functions.

K. Steemers (1989)


Introduction

Bang & Olufsen, Jutland, Denmark, 1998

Source: Photo Steen Traberg-Borup, Danish Building Research Institute.
Introduction

It is trendy to build glazed buildings!

Source: Photo Arnaud Bontemps, project SSHRC environmental adaptability, GRAP.

Introduction

Caisse de dépôt et placement, Montreal

Source: Photo Arnaud Bontemps, project SSHRC environmental adaptability, GRAP.
Introduction
Modification of work position

Source: Lam, 1992. Perception and lighting as formgivers of architecture

Introduction
Modification of work position

Source: Marie-Claude Dubois

Introduction
Modification of work position

Introduction
Modification of work position

Undesirable reflections in computer screens

Introduction
Undesirable reflections in computer screens
Introduction

Summary
3 elements contribute to increase problems related to solar exposure of buildings

1. Thinner building envelope
2. Increased glass area
3. Work on computers = horizontal gaze

Solar protection

Traditional design approach
Solar protective glazing + BIG mechanical room
Solar protection

Solar protective glazing

Limitations of solar protective glazing

- Reduction of solar gains in the winter
- Reduction of daylight all year and under all conditions (including overcast)
- Modification of quantity and quality (spectral) of natural light
- Does not allow adequate glare protection
- Yields exclusive, non-adaptive building
Modern design approach = Adaptive buildings = Solar protection

Source: York University Computer Science Facility, de Bupty & Associates, 1998 (source: www.busby.ca)

Solar protection

Impact of solar shading devices on energy use:

Summer
Reduction of unwanted solar gains

Winter
Possibility to use solar gains for passive solar heating (with movable shading device)
Possibility to use daylight
Reduction of (night time) heat losses through window due to additional layer (optimum if airtight)


Solar protection

Effect on total energy use
Europe

Heating=> reduction of 12 MTeq/year
Cooling=> reduction of 31 MTeq/year

(455 MTeq/year for the EU-25 building sector)

Source: ES-SO (European Solar Shading Organization, 2006).
Solar protection

**Effect on peak cooling load**

Peak cooling demand (W) - 12 pers.

- **Hour**
  - 1
  - 2
  - 3
  - 4
  - 5
  - 6
  - 7
  - 8
  - 9
  - 10
  - 11
  - 12
  - 13
  - 14
  - 15
  - 16
  - 17
  - 18
  - 19
  - 20
  - 21
  - 22
  - 23

**Source:** Bülow-Hübe & Dubois (2000). Butterickshörnet.

---

**Solar protection**

**Effect on thermal comfort**

Operative temperature, 15 March (ext. temp. 6.8°C)

- **Direct insolation**
- **No direct insolation**

**Source:** Ericksen & Horgen (2001).

---

**Solar protection**

**Effect on thermal comfort, productivity and costs**

**Additional annual cost, reduction of productivity of one employee (500 NOK/hr)**

<table>
<thead>
<tr>
<th>Solution</th>
<th>Direct cost</th>
<th>No direct cost</th>
<th>Annual cost (NOK)</th>
<th>Number of hours</th>
<th>Annual cost (NOK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No protection</td>
<td>39</td>
<td>10,500</td>
<td>98</td>
<td>98</td>
<td>49,000</td>
</tr>
<tr>
<td>Existing protection</td>
<td>7</td>
<td>3,500</td>
<td>25</td>
<td>25</td>
<td>12,500</td>
</tr>
</tbody>
</table>

**Investment cost, maintenance and energy (by office)**

<table>
<thead>
<tr>
<th>Investment cost</th>
<th>No protection</th>
<th>Existing protection</th>
<th>Exterior protection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing power</td>
<td>250W</td>
<td>200W</td>
<td>100W</td>
</tr>
<tr>
<td>Cost of solar protection</td>
<td>3,000</td>
<td>3,000</td>
<td>3,000</td>
</tr>
<tr>
<td>Convecter (25NOK/W)</td>
<td>2,000</td>
<td>1,800</td>
<td>3,000</td>
</tr>
<tr>
<td>Cooling device (2,5NOK/W)</td>
<td>625</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>Automatic system</td>
<td>200</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>Other</td>
<td>5,000</td>
<td>5,000</td>
<td>5,000</td>
</tr>
<tr>
<td>Total investment</td>
<td>7,825</td>
<td>7,500</td>
<td>7,500</td>
</tr>
<tr>
<td>Cost maintenance + energy / year</td>
<td>185</td>
<td>185</td>
<td>47</td>
</tr>
</tbody>
</table>

**Source:** Ericksen & Horgen (2001).
Solar protection

Temperature and productivity

![Chart showing the relationship between temperature and productivity for men and women.](chart.png)


Summary

Solar protection devices allow:

1. Reduction of unwanted solar gains and cooling during the summer
2. Improvement of thermal comfort and productivity of employees
3. Utilization of passive solar gains in the winter
4. Better daylighting year-round
5. Slight reduction of heating at night due to additional layer in the window assembly


Solar protection

Thermal and optical properties

![Image of a building with solar protection devices.](image.png)

Solar protection

Thermal and optical properties

- g-value (Solar Heat Gain Coefficient SHGC)
- Shading coefficient (SC)
- Visual transmittance (Tvis)
- U-value or air permeability


Solar protection

G-value (Solar Heat Gain Coefficient SHGC)

'G-value' is the coefficient commonly used in Europe and 'solar heat gain coefficient (SHGC)' is used in the United States

Sum of the primary solar transmittance (T-value) and the secondary transmittance.

Primary transmittance is the fraction of solar radiation that directly enters a building through a window compared to the total solar insolation, the amount of radiation that the window receives.

The secondary transmittance is the fraction of inwardly flowing solar energy absorbed in the window (or shading device) again compared to the total solar insolation.


Solar protection

G-value (Solar Heat Gain Coefficient SHGC)

The total solar energy transmitted g is the sum of the directly transmitted radiation T, and that part of the absorbed radiation A which finally ends up in the room.

Solar protection

G-value (Solar Heat Gain Coefficient SHGC)


Efficient solar shading devices: on the exterior side of windows!


Importance of the position of shading device

Solar protection

Solar protection between panes

Source: Unicel architectural, ref. Louis Dubost.

Solar protection

G-value (Solar Heat Gain Coefficient SHGC)
Varies as a function of fabric colour


Solar protection

G-value (Solar Heat Gain Coefficient SHGC)

<table>
<thead>
<tr>
<th>Product</th>
<th>$E_{S	ext{un}}$</th>
<th>$E_{S	ext{an}}$</th>
<th>$E_{S	ext{sc}}$</th>
<th>Measuring months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Woven textiles</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dark blue (NCS 7000-R70B),</td>
<td>0.18</td>
<td>0.32</td>
<td>0.12</td>
<td>June</td>
</tr>
<tr>
<td>fully extended</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dark blue (NCS 7000-R70B),</td>
<td>0.30</td>
<td>0.40</td>
<td>0.18</td>
<td>June</td>
</tr>
<tr>
<td>partially extended</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light beige (DCS 0902-Y),</td>
<td>0.45</td>
<td>0.52</td>
<td>0.20</td>
<td>June</td>
</tr>
<tr>
<td>fully extended</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light beige (DCS 0902-Y),</td>
<td>0.40</td>
<td>0.58</td>
<td>0.23</td>
<td>June</td>
</tr>
<tr>
<td>partially extended</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Synthetic textiles</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dark blue (NCS 7000-R70B),</td>
<td>0.13</td>
<td>0.26</td>
<td>0.07</td>
<td>September</td>
</tr>
<tr>
<td>fully extended</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dark blue (NCS 7000-R70B),</td>
<td>0.70</td>
<td>0.83</td>
<td>0.43</td>
<td>September</td>
</tr>
<tr>
<td>partially extended</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light beige (DCS 0902-Y),</td>
<td>0.50</td>
<td>0.67</td>
<td>0.37</td>
<td>September</td>
</tr>
<tr>
<td>fully extended</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light beige (DCS 0902-Y),</td>
<td>0.75</td>
<td>0.89</td>
<td>0.43</td>
<td>September</td>
</tr>
<tr>
<td>partially extended</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External venetian blinds</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25% shade, 40°</td>
<td>0.28</td>
<td>0.60</td>
<td>0.17</td>
<td>July</td>
</tr>
<tr>
<td>60% shade, 40°</td>
<td>0.35</td>
<td>0.63</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td>95% shade, 40°</td>
<td>0.42</td>
<td>0.65</td>
<td>0.08</td>
<td></td>
</tr>
</tbody>
</table>
Solar protection

G-value (Solar Heat Gain Coefficient SHGC) as a function of lamellas' width

\[ G = \frac{Q_{\text{cool}}}{Q_{\text{sun}} + 10^\circ C} \]

The ideal g-value varies constantly in the course of one day.

Shading coefficient (SC)

Ratio of solar gain (due to direct sunlight) passing through a glass unit to the solar energy which passes through a reference glass (most often a 3mm Clear Float Glass, \( \tau_s = 0.86, \rho_s = 0.08, \) and \( \alpha_s = 0.06 \)) for the same angle of incidence and spectral distribution.

\[ SC = \frac{g(\theta)_{\text{test}}}{g(\theta)_{\text{ref}}} \]

Solar protection

Shading coefficient (SC)


Solar protection

Visual versus solar performance
Reflectance measured within the visual spectrum


Solar protection

Visual versus solar performance
Reflectance measured within the visual spectrum

Solar protection

U-value (thermal conductance)

The conduction of heat (defined by the U-value, \( U = 1/R \)) is reduced when the shading device is airtight and sealed to the window.

Recommendations:

- Seal the sides of the shading device to the window.
- Use airtight material.
- Use low-emissivity material (e.g. aluminum)

Source: Dubois (1997)

Solar protection

<table>
<thead>
<tr>
<th>Device</th>
<th>U-value reduction w/r single gl.</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum screens</td>
<td>45-58%</td>
<td>Lund (1957)</td>
</tr>
<tr>
<td>Venetian blinds</td>
<td>25%</td>
<td>ASHRAE (1972)</td>
</tr>
<tr>
<td>Rolling screens</td>
<td>25%</td>
<td>ASHRAE (1972)</td>
</tr>
<tr>
<td>Curtains</td>
<td>25-30%</td>
<td>Grasso (1990)</td>
</tr>
</tbody>
</table>

Source: Dubois (1997)

Solar protection

Solar protection

Canadian company, Volets Josuma (shutters)

Source: Jocelyn Perron, architect, Volets Josuma.

Solar protection

Josuma shutters

Source: Jocelyn Perron, architect, Les Volets Josuma.

Solar protection

Summary

Performance of shading devices can be characterized by thermal and optical properties:

1. Lower g-value indicates higher efficiency for reducing solar gains.
2. Exterior shading devices have a lower g-value.
3. SC (shading coefficient) abandoned
4. Tvis or Tdaylight should be as high as possible
5. Lower U-value indicates higher efficiency in reducing nighttime thermal losses
**Solar protection and orientation**

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Potential natural light</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOUTH</td>
<td>Optimal</td>
<td>Solar control is easy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Variable daylight</td>
</tr>
<tr>
<td>NORTH</td>
<td>Excellent</td>
<td>Solar control not required</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Most constant daylight</td>
</tr>
<tr>
<td>EAST</td>
<td>To avoid</td>
<td>Solar control difficult</td>
</tr>
<tr>
<td>WEST</td>
<td></td>
<td>Great variation in daylight</td>
</tr>
</tbody>
</table>

Source: Claude-Alain Roulet (2004) Santé et qualité de l’environnement intérieur...
Solar protection

Solar protection and orientation
SOUTH

To manage snow loads

Source: C-A Roulet (2004) Santé et qualité de l'environnement intérieur dans les...

Solar protection

Solar protection and orientation
SOUTH

Solar protection

**ANGULAR EFFECTS  EFFECT OF INCIDENCE ANGLE**

\[ I_0 = I_{DN} \cos \theta \]

Solar protection

**ANGULAR EFFECTS  OPTICAL PROPERTIES OF GLASS**
Solar protection

**ANGULAR EFFECTS**

- G-value 90-100%
- G-value 80-90%

**Solar protection**

**COMBINED ANGULAR EFFECTS**

21 OCT. 13h
700W/m²
- g-value 0.90
= 630 W/m²

21 SEPT. 13h
800W/m²
- g-value 0.80
= 640 W/m²

21 June 13h
800W/m²
- g-value 0.1
= 80 W/m²

21 June 17h
700W/m²
- g-value 0.9
= 630 W/m²

**Solar protection**

**COMBINED ANGULAR EFFECTS**

[Image: Diagram showing solar protection effects with g-values and power calculations.]

**Source:** Dubois, 2000

**Source:** Dubois, 2001
Solar protection

**Solar protection and orientation EAST + WEST**

![Graph showing solar radiation and normalized flux for EAST and WEST orientations.]

Source: Dubois (2001).

---

**Solar protection**

**WEST orientation**

![Image of a building with west orientation.]

Source: Claude-Alain Roulet (2007).

---

**Solar protection**

**WEST orientation**

Partial reduction of solar gains for EAST and WEST orientations

Source: Claude-Alain Roulet (2007).
Solar protection

Combined angular effects

Solar gains (W/m²)

EAST  SOUTH  WEST  NORTH

Solar protection

Strategies to reduce solar gains on WEST facade

Source: York University Computer Science Facility, de Busby & associates, 1998 (source: www.busby.ca)
student project Petits Édifices Publics (2004).

Solar protection

ENERGY BASE, VIENNA
URSULA SCHNEIDER (2008)

Source: www.eurosolar.at, 2009
Solar protection

**EAST WEST orientations = Flat vertical protection**

Rotating devices

Movable devices

Source 1: GS1 Headquarters, Berlin
Source 2: Wean Wendt Architects, Épiscure et appartements, Munich

---

Solar protection

**CALIFORNIA ACADEMY OF SCIENCES, SAN-FRANCISCO**

RENZO PIANO BUILDING WORKSHOP (2008)

---

Solar protection

**Solar protection and orientation**

**SOUTH, EAST, WEST**

-----

Source: Course notes, Bülow-Hübe, H (2006)
Solar protection

Mobile systems allow more daylighting

Source: Course notes, Bülow-Hübe, W (2006)

Solar protection

Mobile systems: types of protections

Source: C-A Roulet (2004) Santé et qualité de l’environnement intérieur ...
Solar protection
Mobile systems: types of protections

Solar protection
In the future we will shade AND produce electricity!

Solar protection
In the future we will shade AND produce electricity!

PV shade
### Solar protection

**Summary**

Solar protection and orientation:

1. **SOUTH** orientation is the easiest to shade due to solar position (sun is high in the sky and in front of window);
2. **NORTH** orientation does not require solar protection but may require visual protection;
3. **EAST** and **WEST** orientations are to avoid as much as possible. They require a flat shading device parallel to the window glass;
4. **WEST** is the worst orientation due to the accumulation of solar gains in the building at the end of day.

### Sizing solar protection

**Methods**

1. Graphical method (very early design phase)
2. Computer simulations (optimization phase)

---


---

**Step 1:**

Determine at which time the solar protection is needed.

---

Sizing solar protection

**Graphic method**

Shading calendar (St-Louis, 38°, 45°)


Sizing solar protection

**Graphic method**

Shading calendar (Minneapolis, MN, 45°N)


Sizing solar protection

**Effect of Earth thermal inertia**

Sizing solar protection

Step 2:
Determiner corresponding solar angles

---

Sizing solar protection

Computer method

[Image of computer program interface]

Source: http://home.hefi.ch/compag/solangles/solangles.htm

---

Sizing solar protection

Computer method

[Image of computer program interface]

Source: www.parasol.se
Visual protection
Ferring, Ørestad, Denmark
Henning Larsen 2001

Source: Photo, Marie-Claude Dubois, 2001.

Visual protection

Source: Photo, Bang og Olufsen, Denmark, photo by Steen Traberg-Brosup.

Visual protection

Problems caused by daylight through windows:
1. Glare (direct, indirect, disability, discomfort)
2. Reflections in computer screens or on paper

Source: Fonteynord, Want.
### Visual protection

#### Disability glare
**Loss of visual information**

#### Discomfort glare
- **Caused by sharp contrasts**
- **No loss of visual information**
- **Long term effects (fatigue)**

Source: Newsham, via Christoffersen, 2006, Light, health and well-being

---

### Visual protection

**Recommendation:**
- Avoid placing computer screens directly in front of windows;
- Orientate the screen perpendicular to the window.

![Good VDT/task placement](image)


---

### Visual protection

**Recommendation:**
- Select a device which allows blocking the brightest part of the view out (sky, snow)

Source: Sten Traberg Borup (2000). Danish Building Research Institute
Visual protection

Maximum tolerated luminance 1000 cd/m²

<table>
<thead>
<tr>
<th>Object seen from the window</th>
<th>Luminance of object</th>
<th>Necessary light transmission factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>White cumulus reflecting the sun</td>
<td>10 000 cd/m²</td>
<td>T = 10 %</td>
</tr>
<tr>
<td>Hazy summer sky</td>
<td>10 000 cd/m²</td>
<td>T = 10 %</td>
</tr>
<tr>
<td>Intermediate hazy sky</td>
<td>5 000 cd/m²</td>
<td>T = 20 %</td>
</tr>
<tr>
<td>Concrete façade lighted by the sun</td>
<td>8 000 cd/m²</td>
<td>T = 12 %</td>
</tr>
<tr>
<td>Sun at the end of the day</td>
<td>50 000 cd/m²</td>
<td>T = 2 %</td>
</tr>
<tr>
<td>Reflection of the sun on a glass facade</td>
<td>100 000 cd/m²</td>
<td>T = 1 %</td>
</tr>
<tr>
<td>Full sun</td>
<td>1 million cd/m²</td>
<td>T = 0.1 %</td>
</tr>
</tbody>
</table>


Visual protection

Recommendation:
For any situation where direct view of sky is critical, select a device with a visual transmittance (Tvis) of 2-10%.


Visual protection

Direct sunlight patches on lateral walls are often a source of discomfort glare.

Visual protection

Recommendation:
Avoid white, translucent fabric, which may exacerbate the glare problem.


---

Visual protection

Problem with diffusing glass

Source: Photo MCDubois, Laboratoire du COPL, Universite Laval

---

Visual protection

Problem with white diffusing fabric

Source: Photo MCDubois, AF Hagaporten, Stockholm.
Visual protection

Problem with white diffusing fabric
Source: Phot by MC Dubois, MF Hagaporten, Stockholm.

Visual protection

Recommendation:
Avoid white, translucent fabric, which may exacerbate the glare problem.


Visual protection

**Visual protection**

**Recommendation:**
Venetian blinds (with horizontal lamellas) are high performance devices because they allow a fine tuning of light level (like a dimmer) and reflect light upwards, towards the ceiling and back of the room.

---

**Visual protection**

**Recommendations:**
Venetian blinds (horizontal lamellas)

---

**Visual protection**

**Recommendation:**
Venetian blinds (horizontal lamellas), 2 slat angles.

---
Visual protection

Diffusing glass in upper window section

Source: Steve Selkovitz, Green Build 2008

Visual protection

Recommendation:
Light shelves

Source: Steve Selkovitz, Green Build 2008

Visual protection

Visual protection

Visual protection

Summary

1. Work position perpendicular to window if possible.
2. Select device which blocks the brightest part of window view (sky, snow, etc.).
4. Discomfort glare may be caused by direct sunlight patch on lateral wall.
5. White, translucent fabrics or diffusing glass increase the glare problem.
6. Venetian blinds allow adjusting light level and reflect light in the back of the room.
View out


---

View out

**Most positive attribute of a window**

<table>
<thead>
<tr>
<th>Option</th>
<th>Average, all buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can see out</td>
<td>70%</td>
</tr>
<tr>
<td>Can see weather</td>
<td>60%</td>
</tr>
<tr>
<td>Can ventilate</td>
<td>50%</td>
</tr>
<tr>
<td>Natural light in room</td>
<td>40%</td>
</tr>
<tr>
<td>Natural light to work</td>
<td>30%</td>
</tr>
<tr>
<td>Sunlight</td>
<td>20%</td>
</tr>
<tr>
<td>Time of the day</td>
<td>10%</td>
</tr>
<tr>
<td>Light for plants</td>
<td>5%</td>
</tr>
<tr>
<td>Other</td>
<td>5%</td>
</tr>
</tbody>
</table>


---

View out

**Notice:**

Bright-colour, translucent fabric block the view out.

Source: Christoffersen, Jens, SBI.
Bi-directional materials (dark inside, reflective outside)

Recommendation:
Quality of view out strongly depends on optical properties of shading material (can be different from one side to the other)

« Koolshade »
View out

« KoolShade »

Recommendation:
Dark-coloured fabric

Source:

View out

Recommendation:
Dark-coloured fabric

Source:
**Conclusions**

**Exterior solar protection**

**Interior visual protection**

Visual protection:
- high $g$ value
- manual control

Exterior solar protection:
- low $g$ value

*Source: Dubois MC (2003), PhD thesis presentation.*
Conclusions

Shading device needs to be planned at early design phase.


To remember:
1. Include shading concept at early design phase.
2. Solar shading and visual protection = two different problems and two different solutions.
3. Solar shading ⇒ efficient outside (geometrical problem)
4. Visual protection ⇒ efficient inside (redirection of light and optical properties are key factors)

Source: Photo étudiant maîtrise, Caisse de Dépôt et Placement, Montréal.