Sustainability in lighting and the role of daylight

Prof. Griet Verbeeck
Faculty of Architecture and Art, Hasselt University
Department of Civil Engineering, Catholic University Leuven
Summer school LiDe 2013, Athens
Energy consumption for lighting

Europe by night (Nasa)
Energy consumption for lighting

New York and Times Square in the 1930’s ↑
and in the 2000’s ↓
Energy consumption for lighting

Table 4. Electric versus fuel-based lighting: relative global energy use, emissions, costs, and services delivered.

<table>
<thead>
<tr>
<th></th>
<th>Population (billion)</th>
<th>Energy (Petajoules/yr.)</th>
<th>Greenhouse-Gas Emissions (MT CO2/yr.)</th>
<th>Energy Cost ($ billion/yr.)</th>
<th>Energy Services (Trillion lumen-hours/yr.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>4</td>
<td>67%</td>
<td>21103</td>
<td>85%</td>
<td>1775</td>
</tr>
<tr>
<td>Fuel</td>
<td>2</td>
<td>33%</td>
<td>3603</td>
<td>15%</td>
<td>244</td>
</tr>
<tr>
<td>Total</td>
<td>6</td>
<td></td>
<td>24706</td>
<td></td>
<td>2020</td>
</tr>
</tbody>
</table>

Source: Mills E., 2002

World Electricity Consumption for Lighting by Sector, 2005

- Residential: 31%
- Commercial: 43%
- Industrial: 18%
- Outdoor: 8%

Total: 3,418 Terawatt-hours

Source: EPI from IEA

1TWh = $10^9$ kWh
1PJ (Petajoule) = $10^9$ MJ
However!

Last century, lighting efficiency (lm/W) x 100, but energy consumption x 10,000! → efficiency as such does not induce decrease in energy consumption (Richard Friend)

Impact of (artificial) lighting on energy consumption cannot be ignored
Role of lighting

Society
Visual comfort
Wellbeing
Health
Indispensable for life

Economy
Energy cost
Jobs in lighting industry

Environment
Energy consumption
Material use
Pollution

Sustainable Development

Source: Rethink Group
Role of **daylighting**

**Improving**
- Visual comfort
- Wellbeing
- Health
- Indispensable for life

**Society**

**Economy**
- Energy cost
- Jobs in lighting industry

**Environment**
- Energy consumption
- Material use
- Pollution

*Source: Rethink Group*
Role of daylight in improving the ecological impact of lighting

TRIAS ECOLOGICA

1. Optimize lighting, while minimizing the need for energy for lighting
   → optimal use of daylight

2. Maximize the use of renewable energy sources
   → renewable electricity production

3. Minimize the remaining use of fossil fuels
   → efficiency of artificial lighting systems
Interaction of daylight and artificial light

- Illuminance to be realised
- Additional artificial lighting needed

Relative illuminance realised with daylight

- Beginning of work day
- End of work day

Source: TU Eindhoven
Evaluation of daylight

Daylight factor:

• metric since early 20th century
• allows a quick and easy evaluation of daylight penetration in a space
• assumes an completely overcast sky → mainly useful in climates with substantial periods of overcast skies, less useful in very sunny climates

Daylight autonomy:

• metric since ‘90s
• represents the percentage of annual daytime hours that the illuminance level due to daylight at a given point in a space is above a specified illuminance level.

Free software for daylight evaluation: Velux Daylight Visualizer, Dialux
http://viz.velux.com or www.dial.de
Example: design assignment 2Ba interior design.pdf
Daylight factor DF

DF = (E_{point} / E_{horizontal free field}) \times 100\%

Valid for a completely overcast sky!

E_{point} = illuminance at certain point, E_{horizontal free field} = external illuminance
Daylight factor

\[
DF = (d_s + d_{e,r})C_r + d_{i,r}
\]

- \(d_s\) = sky component
- \(d_{e,r}\) = external reflection component
- \(d_{i,r}\) = internal reflection component
- \(C_r\) = filthiness correction factor
Sky component \( d_s \)
External reflection component $d_{e,r}$

External reflection component depends on the characteristics of the obstruction.

1) What part of the sky is blocked by the obstruction?

2) What is the reflection factor of the obstruction? (10 à 20%, av. 15%)

3) If no obstruction $\rightarrow d_{e,r} = 0$
Internal reflection component $d_{i,r}$

Internal reflection component depends on the characteristics of the space:

1) Window to floor ratio
2) Dimensions of the space
3) Reflection factors of floor, walls, ceiling
External illuminance level depends on location and time of the day.

Reference values for illuminance levels in the free field for the Netherlands.

Percentage of time the indicated illuminance level is exceeded.

Figur 2.53. Verlichtingssterkte overschrijding in het vrije veld (Nederland) als percentage van de tijd.
# Daylight factor and perception of the space

<table>
<thead>
<tr>
<th>Daylight factor</th>
<th>&lt; 1% Very low</th>
<th>1%-2% Low</th>
<th>2%-4% Moderate</th>
<th>4%-7% Acceptable</th>
<th>7%-12% High</th>
<th>&gt;12% Very high</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perception of illuminance</td>
<td>Dark to gloomy</td>
<td>Gloomy to light</td>
<td>Light to very light</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remarks</td>
<td>Fits for secondary spaces (corridors, storage,…)</td>
<td>Fits for work spaces</td>
<td>Glare risk</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atmosphere</td>
<td>Space has no relation with outside</td>
<td>Space has a relation with outside</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Daylight factor website FAGO

- No obstructions outside
- Fixed reflection factors for space
- Desk height = 0.75 cm above floor level

http://sts.bwk.tue.nl/daylight/
How to influence the amount of daylight in a room?

Mainly through constructional elements

- Window area
- Orientation of the window
- Glazing type
- Location and shape of the window
- Window shadings
- Overhangs
- Reflections and obstructions outside

- Dimensions of the space
- Colour use and finishing of the space

affect the amount of daylight entering the space

affect the distribution of daylight within the space

Interaction between daylight and artificial light

- Use of daylight sensors
Window area

1. General rule: minimal window area > 5% of floor area for spaces where people stay permanently

2. Dwellings:
   • min 10% of floor area
   • rule of thumb: 20-30 % of floor area, but beware of summer overheating!
   • rule of thumb not valid for all locations

These rules of thumb don’t take into account the impact of shape and position of the window nor the shape of the space.

The effective amount of daylight entering the space, strongly depends on the illuminance outside
Orientation of the window

- For daylight evaluation → standard CIE sky:
  • Assumption of completely overcast sky
  • Luminance highest in zenith
  • Luminance at horizon = 1/3 of luminance zenith

  — Vertical façade orientation:
    Theoretically no impact on daylight
  — Window slope: large impact
    Horizontal window receives 3x more light than a vertical window
Artist’s studio: tries to create a very homogeneous illuminance both during day and night (B-architecten Bis)
Location of windows in the façade

Kimball Art Museum
Texas, Louis Kahn
From a light technical point of view: windows high in the façade -> more light
• Even better: horizontal windows
Location of daylight openings

Impact of the location of windows on the daylight factor and luminance + examples

Daylight Design Webpages (TU Eindhoven)

http://sts.bwk.tue.nl/daylight/varbook/index.htm
Glass type

- Glass properties: absorption $\alpha$, reflection $\rho$ and transmission $\tau$
- Clear float glass, single glass pane: least impact on daylight
- Choice of glazing:
  - Light technical requirements
  - Thermal/energy requirements: most dominant
    - Northern countries: high thermal resistance to avoid high thermal losses (low $U_g$ value W/m²K)
    - Southern countries: high solar control to avoid high solar gains
  - Acoustical requirements

- Coating or coloring glass $\rightarrow$ impact on $\rho$, $\tau$ en $\alpha$
  - Coating mostly due to thermal reasons (heat loss or solar control)
  - But also impact on spectrum of incoming daylight

- LT or light transmission $\leftrightarrow$ SF or solar factor
  - Single glass: LT = 0,78
  - Reflective glazing: high LR, low LT [Infosheet Stopsol.pdf](#)
  - Combined low SF and high LT (and low $U_g$) [Infosheet Stopray.pdf](#)
Glass type
Innovative glazing types

- Electrochromic glass:
  - also called smart glass or switchable glass
  - electrochromic material: absorption and reflection properties change, when a voltage is added
Electrochromic glass

For privacy control

For climate control
Innovative glazing types

• Glazing with Phase Change Materials (PCM):
  – phase (solid, liquid, gas) changes with temperature
  – For PCM’s, only solid-liquid phase change is used
  – transparent liquid at high temperatures ↔ translucent solid at low temperatures
  – through phase change: storage and release of heat
Advanced glazing

Southwest Working Women Together, Chicago. Wheeler Kearns Architects
Advanced glazing

AG4 Mediatecture, Keulen
Advanced glazing

Omaha Performing Arts Center, Nebraska. Polshek Partnership, NY
Window screens (inside)

Presence of daylight = comfortable, but too much daylight might hinder (especially in work environment)

→ window screens:
  • **solar screens:**
    • ≠ solar shading to avoid overheating
    • to avoid direct sunlight (on a workplace)
    • screens or horizontal/vertical blinds

  • **luminance screens:**
    • even without direct sunlight, the luminance of a window can be too high, compared to the luminance within the space → risk of glare
    • to control the luminance ratios
    • recommended: 1 (desk):3 (direct around the desk):10 (surroundings)
    • preferably adjustable luminance screens
Luminance

Luminance, cd/m²

Recommended
Window screens

≠ solar shading, but luminance screens to control the luminance level
Overhangs (outside)

Reasons to apply overhangs

**functional:**
- architectural element for solar control (↔ direct sunlight)
- architectural element for luminance control (↔ diffuse sunlight)
- ex. dwelling: for solar control in case of large glazing areas
- ex. shop-window: for luminance control to allow people in the street to see the products in the shop-window
  - reflection of sun/daylight → glare
  - often compensated with strong lamps in the shop-window

**esthetical:**
- architectural design element in the façade

- drawback: permanent element → also present at moments of low illuminance outside or overcast sky
Light shelves (inside or outside)

= special type of overhang:
- normal overhang = horizontal element at the top or above the window
- light shelf = horizontal element above eye level with glass below and above

- improves illuminance distribution and reduce glare
- most appropriate for south orientation in predominantly clear sky climate
- best matte white or diffusely specular finishing at top of shelf

Source: Tips for daylighting with windows
Reflections and obstructions (outside)
Google Office Center

Designing with (day)light
Designing with (day)light

Google Office Center
from functional use of daylighting to designing of/with daylighting
Overcast sky = dull, depressive atmosphere
- because of uniform, directionless quality of light → no shadows, no texture
- very cool white light (10.000K)
= what we try to avoid in interior design!
Designing with daylight

- trying to avoid the depressive, uniform effect of an overcast sky
- trying to capture the qualities of daylight
  - Wide range of intensity
  - Changing direction of light
  - Changing colours of light

Designer has enormous power to influence not only the visual perception, but also the emotional and physical experience of the built environment.

Pantheon, Rome
Orientation of the window

For daylight in reality: orientation makes a difference

- Daily pattern
- Seasonal pattern [location dependent](DaylightChart.exe)

- Windows to the north: cool light (only diffuse light)
- Windows to the south: warm light
- Through the orientation of spaces the atmosphere in a space can be improved
  - Space with east-oriented window → can experience sunrise
  - Space with west-oriented window → can experience sunset
Direct sunlight wanted or not?

For a **living space** preferably sunlight:
- larger contrasts between light and dark,
- light is more dynamic → more interesting
- but, beware of overheating
- beware of culture difference: association and appreciation might differ between cultures
  - northern cultures: warm light = cosy
  - southern cultures: cool light = coolness

For a **work space** preferably no sunlight:
- larger luminance contrasts → glare risk, fatiguing the eyes
- person directly sunlit: not comfortable during work, reduced productivity
Living space → vs workplace →
(dwelling B-architecten Bis)
Location and shape of windows

- Determines how a space is perceived
- Determines the view to the outside
- Can be used to deliberately direct daylight within a space
Daylight penetration + view to the outside
View to the outside

Church on the water Hokkaido Tadao Ando
View to the outside
Directing daylight

University Alicante, Alvaro Siza

University Porto, Alvaro Siza
Directing daylight

Koshino House, Tadao Ando
Directing daylight

TNW sports facility NL Architects Utrecht
Directing daylight

Townhouse Retail store
Means to alter daylight

- Redistribution of daylight
- Use of uncommon window shapes
- Creation of light patterns, dynamic effects
Redistribution of daylight

Smith Middle School, North-Carolina.

Fabric baffles help ensure uniform light distribution while eliminating potential glare from the roof monitors.
Sun tunnel Designer Lamp (by Ross Lovegrove)
Daylight guidance systems.

Bron: University of Liverpool
Daylight guidance systems
Daylight guidance systems

Lighting caves with daylight
Daylight guidance systems

Boutique JC Jitrois by Studio Christophe Pill
Use of coloured glazing

Le Corbusier, Chapelle du Haute, Ronchamp → colour and window shape used to create dynamic light effect
Use of coloured glazing
Use of daylight for art spaces

Lotus shaped artscience museum, Singapore
Use of daylight for art spaces

Emil Schumacher museum
Use of daylight for art spaces

Museum of Fine Arts, Houston

Museum for modern art
Use of daylight for art spaces

Herning museum of contemporary art by Steven Holl
Use of daylight for art spaces
Unusual window shape

Institut du Monde Arabe, Parijs. Jean Nouvel
Unusual window shape

New Oslo train station by Space Group
Unusual window shape

Church of light, Osaka, Tadao Ando
Unusual window shape

Dzn Stairs House by Y+M Design Office
Unusual window shape

Diagram 3: how to adapt to summer climate

Diagram 3: how to adapt to winter climate

Dzn Stairs House by Y+M Design Office
Unusual window shape
Creating light patterns

Science Tower, University of Copenhagen

Green House
Creating light patterns

Christ of Light Cathedral, Pulpit

Alessi Flagstore, New York
Creating light patterns

Hans Grohe event hall

Traditional mashrabiya
Creating light patterns

Accordia, Cambridge

Assyafaah Mosque, Singapore
by Tan Kok Hiang
Creating light patterns
Creating light patterns

Lille Metropole museum
Painting with daylight

D.E. Shaw office building (architect Steven Holl)
Painting with daylight

D.E. Shaw office building (architect Steven Holl)
Painting with daylight

Luis Barragan

Capella de madres Capuchinas, Mexico City
Use of coloured walls
Examples

1) Steven Holl Architects www.stevenholl.com

- Educational & campus works
  - Institute for Contemporary Art
  - Hunters Point
  - Glasgow School of Arts
  - Knut Hamsun Center
  - NYU Department of Philosophy
  - College of Architecture & Landscape
  - Simmons Hall, MIT
  - Chapel of St Ignatius

- Offices & mixed use
  - Sarphatistraat, offices
  - D.E. Shaw & Co offices

- Museums
  - T Space
  - Herning Museum
  - Nelson-Atkins Museum
  - Kiasma Museum
  - Danish Natural History Museum
Examples

1) Steven Holl Architects [www.stevenholl.com]

2) Peter Zumthor

   Thermen, Vals [http://www.youtube.com/watch?v=6uGcQAC0VUw]
   4:00-7:50 en 9:00-12:30

   Bruder Klaus kapel, Metternich
Ex.: Therms in Vals, arch. Peter Zumthor
Interesting literature

• Lighting for interior design (Malcolm Innes, Laurence King Publishing)

• Tips for daylighting with windows

• Daylighting Pattern Guide  http://patternguide.advancedbuildings.net/home
Designing with daylight
= controlling the incoming levels of daylight
= using the qualities of daylight

Library Seinajoki, Sweden. Alvar Aalto
Role of daylighting

Improving
- Visual comfort
- Wellbeing
- Health
- Indispensable for life

Society

Economy
- Energy cost
- Jobs in lighting industry

Sustainable Development

Environment
- Reducing
- Energy consumption
- Material use
- Pollution

Source: Rethink Group