Daylighting buildings

Course plan

1. Short historic overview
2. Benefits of using daylight
3. Risks with daylight
4. Design strategies for daylight harvesting
5. DAYSIM and its daylight metrics

Daylighting buildings

Definition

Daylighting is the practice of placing windows or other openings and reflective surfaces so that during the day natural light provides effective internal lighting.

Historic overview

The history of architecture is the history of the struggle for light.
(Le Corbusier)
Daylighting buildings

Historic overview

[source: Exterior and interior view of the mashrabiya at the Ansahiyar House in Cairo, Egypt, in Baker & Steemers, 2002, Daylight Design of Buildings]

Daylighting buildings

Historic overview


Daylighting buildings

Historic overview

[source: Column at the Baths of Caracalla in Rome, in Mildet, 1996, Light revealing architecture]

Daylighting buildings

Historic overview

[source: Pantheon, Rome, artist Giovanni Battista Piranesi]
Daylighting buildings
Historic overview

(source: King's College Chapel, Cambridge, Baker & Steemers, 2002, Daylight Design of Buildings)

(source: Palladio, Palazzo Chiericati, Vicenza, 1556-1567, and Villa Foscari, ‘La Malcontenta’, 1558 ca, sur le Brenta, photo Georges Teyssot)

(source: St Peter’s Church, architect Bernini, Rome, and The Trasparente, Toledo, Spain, in Baker & Steemers, 2002, Daylight Design of Buildings)
Daylighting buildings

Historic overview

(source: Covent Garden, London, in Millet, 1996, Light revealing architecture)

Daylighting buildings

Historic overview


Daylighting buildings

Historic overview

(source: Rookery building by John Root & D Burnham, 1885-88, Chicago, in Millet, 1996, Light revealing architecture)
Daylighting buildings

Historic overview

- Candles, oil lamps
- Gas
- Coal
- Kerosene
- Incandescent lamps
- Fluorescent lamps

Time =>

- 1700
- 1710
- 1720
- 1730
- 1740
- 1750
- 1760
- 1770
- 1780
- 1790
- 1800
- 1810
- 1820
- 1830
- 1840
- 1850
- 1860
- 1870
- 1880
- 1890
- 1900
- 1910
- 1920
- 1930
- 1940
- 1950
- 1960
- 1970
- 1980
- 1990
- 2000
- 2010

[Source: Lechner, 2001, Heating, Cooling, Lighting]

Daylighting buildings

Historic overview

Daylighting buildings
Benefits of daylight

1. Performance of the visual system
2. Stimulation of circadian cycle (night day)
3. Synthesis of vitamin D (skin)
4. Reduction of stress
5. Variation = positive biological response

6. Luminous efficacy (lm/W) = energy efficiency
7. Increased rental value
8. Positive effect on sales
9. Increased productivity

Why daylight...? [source: Jens Christoffersen, SBI, Denmark, 2009]

- People prefer daylight as light source
- Daylight is ‘free’ and efficient
- Daylight is available during working hours
- Large energy savings potential
- Health and well-being

Quality parameters: View, light, air and variation

Daylighting buildings
Benefits of daylight

Daylight has a high luminous efficacy (lm/W)!

(source: Lechner, 2001, Heating, Cooling, Lighting)
Daylighting buildings

Benefits of daylight

Daylight has a high luminous efficacy (lm/W)!


Daylighting buildings

Benefits of daylight

Energy savings with daylight utilization

Commercial buildings:

Artificial lighting = 30-40% energy use

Energy savings with daylight utilization

Commercial buildings:

Artificial lighting = 30-40% energy use

Using daylight allows:

- Reduction of installed power density (W/m²) up to 25% (Canada)
- Reduction of electricity consumption for lighting up to 50%
Daylighting buildings


<table>
<thead>
<tr>
<th>Annual budget, typical office building</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 $/m²</td>
</tr>
<tr>
<td>200 $/m²</td>
</tr>
<tr>
<td>2000 $/m²</td>
</tr>
</tbody>
</table>

An increase in productivity of employees of 1% can save $$$ corresponding to the annual energy budget.

Daylighting buildings

Risks associated with daylight (source: Newsham, via Christoffersen, 2006, Light, health and well-being)

Disability glare
Loss of visual information

Discomfort glare
Caused by large contrasts
No loss of visual information
Long term effects (fatigue)

Most negative aspects of windows (source: Christoffersen et al., 1999, Vinduer og daglys – en helunder-aarglæs i kontor bygninger)
Daylighting buildings
Risks associated with daylight

Reflections in computer screen

Daylighting buildings
Risks associated with daylight

Glare and reflections in computer screens

Daylighting buildings
Risks associated with daylight

Overheating and direct glare

(source: Fontyvment, 1999, Daylight performance of buildings.)
Daylighting buildings

Daylight Harvesting
Term used in sustainable architecture and the building controls and active daylighting industries for a control system that reduces the use of artificial lighting with electric lamps in building interiors when natural daylight is available, in order to reduce energy consumption.

- Passive daylighting
- Active daylighting

(source: Wikipedia.org)

Daylighting buildings

Design strategies

Passive daylighting
System of both collecting sunlight using static, non-moving, and non-tracking systems such as windows, sliding glass doors, most skylights, light tubes, and light louvers; and reflecting the collected daylight deeper inside with elements such as light shelves. Passive daylighting systems are different from active daylighting systems in that active systems track and/or follow the sun, and rely on mechanical mechanisms to do so.

(source: Wikipedia.org)
Daylighting buildings
Design strategies

Active daylighting
system of collecting sunlight using a mechanical device to increase the efficiency of light collection for a given lighting purpose. Active daylighting systems are different from passive daylighting systems in that passive systems are stationary and do not actively follow or track the sun.

[source: Wikipedia.org]
Daylighting buildings
Design strategies

Passive daylighting
1. Site and orientation
2. Plan depth
3. Windows
4. Light distribution/reflection
5. Control
6. Other things to know…

Daylighting buildings
Design strategies

Good daylight design is not a restriction on architectural expression – on the contrary; it is more likely to act as an inspiration and foundation for good architecture.

(Baker & Steemers, 2002, Daylight Design of Buildings)

[source: MIT Chapel, by Eero Saarinen]

Daylighting buildings
Design strategies

1. Site and orientation

The no-sky line is a divider between the part of the working plane from which a part of the sky can be seen directly and the part from which it can’t. The scene appears brighter if the no-sky line penetrates larger part of the room. A room may be considered gloomy if more than 50% of the working plane area is beyond the no-sky line.
Daylighting buildings
Design strategies

1. Site and orientation

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Potential for daylighting</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOUTH</td>
<td>optimal</td>
<td>Solar control = easy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Favourable daylighting</td>
</tr>
<tr>
<td>NORTH</td>
<td>excellent</td>
<td>No solar control necessary</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Most constant daylight</td>
</tr>
<tr>
<td>EAST</td>
<td>avoid</td>
<td>Solar control = difficult</td>
</tr>
<tr>
<td>WEST</td>
<td></td>
<td>Great variation in daylight</td>
</tr>
</tbody>
</table>


North orientation may be the best for high internal loads buildings

(source: Bang og Olufsen, Denmark, photo by Steen Traberg-Børup)
Daylighting buildings
Design strategies

2. Plan depth

Common building plans before XXth century, allowing natural ventilation and daylighting

Examples of Building Footprints With High Daylight Access


Daylight in buildings
Design strategies

2. Plan depth

Daylight Depth as a Function of Window Height

Light Distribution with Light Shelves

Interior and Exterior Light Shelves

Daylighting buildings
Design strategies

2. Plan depth

ARUP - Solihul

- Self reported increase in productivity of 17%
- Reduction of energy use by 33%
- Extra cost of £3 million


Daylighting buildings
Design strategies

2. Plan depth

(photo: Claude Demers, GRAP, Université Laval, Québec Canada)

Daylighting buildings
Design strategies

2. Plan depth skylights

(photo: Jens Christoffersen, SBI, Denmark, 2009)
Daylighting buildings
Design strategies

2. Plan depth – solar tubes

[Image: Solar tubes, retrieved from Wikipedia, 2010, on daylighting]

Daylight in buildings
Design strategies

3. Windows

It is too simplistic to try to increase energy savings by increasing the size of windows. Daylight over-illumination may cause glare for occupants, causing them to deploy blinds or other window shading devices, and compromising the daylight harvesting system. Even partially-deployed venetian blinds can cut energy savings in half. [11]


Daylight in buildings
Design strategies

3. Windows

Daylight over-illumination may cause glare for occupants, causing them to deploy blinds or other window shading devices, and compromising the daylight harvesting system.
3. Windows

Relationship between the degree of satisfaction with indoor climate and glazed portion in offices

(source: Christoffersen et al., 1999, Vinduer og dagslys – en feltunder-søgelse i kontor-bygninger)

Daylight in buildings

Design strategies

3. Windows

Relationship between performance and illuminance (lux)

(source: Lechner, 2001, Heating, Cooling, Lighting)

Daylight in buildings

Design strategies

3. Windows

Photos of Hewlett & Packard offices, Stockholm, and Ny Credit, Copenhagen.

(source: photos by Steen Træbøll Borup)
Comparable results of minimum and preferred window size as a percentage of window wall area:

- IES: 20-40 %
- CIBSE: 20-35 %
- Ne’eman et al: 25-32 %
- Ludlow: 50-80 % (scale models)
- Keighly: 60-75 % (scale models)
- Boyce (1981): 25-30 % (view), 55-60 % (daylight)
- SBI (1999): 25-30 % (glazed area)

Glazed portion with respect to total building envelope in offices

- Never < 20%
- > 40% = risk for overheating + glare
- Optimal = 30%
Daylight in buildings
Design strategies

3. Windows

![Chart showing the most positive aspects of windows with categories like view out, daylight in room, light for working, etc., with responses in percentages.]

- Most positive aspects of windows:
  - View out
  - Daylight in room
  - Light for working
  - Gives sunshine
  - Other

- Responses (%)

- Place window where the view is desirable and above task area.

- Window is too high from sitting position!
Daylight in buildings
Design strategies

3. Windows

Place window where the view is desirable

(source: CTBG, Laval University, Quebec City)

Daylight in buildings
Design strategies

3. Windows

Place window where the view is desirable

(source: E. Pihl & Søn AS, Lyngby, Denmark, KHR architects)

Daylight in buildings
Design strategies

3. Windows

Place window where the view is desirable
Daylight in buildings
Design strategies

3. Windows
If the view is not important, place windows high up

(source: CTBD, Laval University, Quebec City)

Daylight in buildings
Design strategies

3. Windows
If the view is not important, place windows high up

(source: Dutch window and Music lesson by Vermeer, in Millet, 1996, Light revealing architecture)

Daylight in buildings
Design strategies

3. Windows
If the view is not important, place windows high up

3. Windows

A satisfying view should embrace both skyline and foreground

[Source: Jens Christoffersen]

Shape windows according to the elements to be seen outside

[Source: Enebolig Lund, Oslo, Norway, architects Lund og Slaatto]
Daylight in buildings
Design strategies

3. Windows
Use window reveals to allow soft light transitions

(source: Mt. Angel Abbey Library by Alvar Aalto in Millet, 1996, Light revealing architecture)

(source: Wikipedia.org, 2010)
### Daylight in buildings

#### Design strategies

3. **Windows**

**Use frame details that allow soft light transitions**

[source: Helena Bülow-Hübe]

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#### Daylight in buildings

**Design strategies**

3. **Windows**

**Choose appropriate glazing**

Spectrally selective glazing reject heat, not light


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#### Daylight in buildings

**Design strategies**

3. **Windows**

**Choose appropriate glazing**

<table>
<thead>
<tr>
<th>Glazing type</th>
<th>Tvis</th>
<th>SHGC</th>
<th>LSG</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bad choice</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Double glazing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clear</td>
<td>0.82</td>
<td>0.75</td>
<td>1.20</td>
</tr>
<tr>
<td>Bronze</td>
<td>0.62</td>
<td>0.60</td>
<td>1.03</td>
</tr>
<tr>
<td>Reflective</td>
<td>0.20</td>
<td>0.16</td>
<td>1.25</td>
</tr>
<tr>
<td><strong>Good choice</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spectrally selective</td>
<td>0.70</td>
<td>0.46</td>
<td>1.52</td>
</tr>
</tbody>
</table>
Daylight in buildings

Design strategies

4. Light distribution/reflection
Admit light by more than one opening (better daylight distribution in space)

(source: Lechner, 2001, Heating, Cooling, Lighting)

+ More daylight deep in space
+ Less contrast between sky and surrounding surfaces

4. Light distribution/reflection

Reflect light with well located, light-coloured interior surfaces


[Source: Kimbell Art Museum, Louis Kahn]
Daylight in buildings
Design strategies

4. Light distribution/reflection
Reflect light with well located, light-coloured interior and exterior surfaces

Source: Section at Office Wing, NREL Solar Energy Research Facility, in Brown Dekay, 2001, Sun Wind Light
Daylight in buildings
Design strategies

4. Light distribution/reflection
Reflect light with well located, light-coloured interior and exterior surfaces


Daylight in buildings
Design strategies

4. Light distribution/reflection
Reflect light with well located, light-coloured interior and exterior surfaces

(source: Lockheed building, Sunnyvale, California, Leo Daly in Brown Dekay, 2001, Sun, Wind, Light)

Daylight in buildings
Design strategies

4. Light distribution/reflection
Study reflection strategy in plan and in section

(source: CTBO, Claude Demers, consultant, Laval University, Quebec City)
Daylight in buildings
Design strategies

4. Light distribution/reflection

Use intermediate glazed partitions

[source: CTBO, Claude Dennis, consultant, Laval University, Quebec City]

Daylight in buildings
Design strategies

4. Light distribution/reflection

Daylight in buildings
Design strategies

4. Light distribution/reflection

[source: Mt. Angel Abbey Library by Alvar Aalto, in Millet, 1996; Light revealing architecture]
Daylight in buildings
Design strategies

4. Light distribution/reflection
Choose interior finishes with light colour

Choose interior finishes with light colour

Daylight Factor, standard office room:
White walls/ceiling = 5.2% = 520 lux for 10 000 lux
Black walls/ceiling = 2.2% = 220 lux for 10 000 lux

Daylight in buildings
Design strategies

4. Light distribution/reflection
Choose interior finishes with light colour

Daylight in buildings
Design strategies

4. Light distribution/reflection
Choose interior finishes with light colour

Daylight in buildings
Design strategies

4. Light distribution/reflection
Choose interior finishes with light colour

Daylight in buildings
Design strategies

4. Light distribution/reflection
Choose interior finishes with light colour

Daylight Factor, standard office room:
White walls/ceiling = 5.2% = 520 lux for 10 000 lux
Black walls/ceiling = 2.2% = 220 lux for 10 000 lux

Average Daylight Factor = $\frac{V_r - A_{offer} \cdot \theta}{A_i \cdot (1 - R^2)}$
Daylight in buildings
Design strategies

5. Controls
Artificial lighting system should be planned according to daylighting

Types of controls
1. On-off (occupation: infra-red, ultra-sounds, programmed)
2. Staged (100%, 50%, etc)
3. Dimming (automatic or manual)

Daylight in buildings
Design strategies

5. Controls
Any space with a DF of 5% during some hours of the day should have artificial lighting controls

Daylight in buildings
Design strategies
Daylight in buildings
Design strategies

5. Controls

Daylight in buildings
Design strategies

6. Other things to know
Use daylight for orientation (where do I go?)

Daylight in buildings
Design strategies

6. Other things to know
Use daylight for orientation (where do I go?)

Daylight in buildings
Design strategies

6. Other things to know
Use daylight for orientation (where do I go?)
Daylight in buildings
Design strategies

6. Other things to know
Use daylight for orientation (where do I go?)

[source: CTIO, Claude Demers, Laval University, Quebec City]

Daylight in buildings
Design strategies

6. Other things to know
Use daylight to highlight the building structure

[source: Määrskirch church, Finland, architect Juha Leiviskä]

Daylight in buildings
Design strategies

6. Other things to know
Use daylight to highlight the building structure

[source: Vuosenniska church, Imatra, Finland, Alvar Aalto, from Millet, 1996, Light Revealing Architecture]
Daylight in buildings
Design strategies

6. Other things to know

Use daylight to bring attention to important activity

[source: MIT Chapel, Eero Saarinen]
6. Other things to know

Use daylight to bring attention to beauty (relaxation, interest)

(source: Bonaventure Hotel, Montreal, architects Affleck Desbarats Dimakopoulos & Sise, in Lam, 1992, Perception and lighting as formgivers of architecture.)

Use daylight to circumscribe personal territory

(source: Mt. Angel Abbey Library, Oregon, Alvar Aalto, from Millet, 1996, Light Revealing Architecture)
6. Other things to know
A little sunlight spot is needed (psychologically)

Be careful:
- of the amount
- in work environment

How to daylight buildings
‘It’s all about finding the right balance’
'and not leave us in search of the good light...'

Daylighting buildings

Daylight metrics

Light
Part of the electromagnetic spectrum for which our eye is sensitive.

Source: Moore F. 1985

Course: Solar Energy in Architecture
Lund, Sweden, 19 November 2010
The color of light depends on the wavelength

Daylighting buildings

Daylight metrics

Luminous flux
Rate of emission of luminous energy in time (lumen, lm).

source: Mo....
Daylighting buildings
Daylight metrics

Illuminance
Density of luminous flux on a surface (lux, lx).

Luminous intensity
Quantity of luminous flux emitted in a given direction (candela, cd). 1 cd = 1 lm/sr.

[Image of illuminance explanation]

[Image of luminous intensity explanation]
**Daylighting buildings**

**Daylight metrics**

**Steradian (sr)**

Solid angle subtended at the center of a sphere of radius \( r \) by a portion of the surface of the sphere whose area, \( A \), equals \( r^2 \).

\[
\text{sr} = \frac{A}{r^2}
\]

![Diagram showing the definition of steradian](source: Wikipedia)

**Luminous intensity**

2000 lumens  
7400 candelas

2000 lumens  
1100 candelas

![Diagram showing luminous intensity](source: Moore F, 1985)

**Luminous intensity**

In a beam candle, a 1 cd source emits 111 lumens at the brightest point in the beam. In most spherical candlepower, a 1 cd source emits 32.644 lumens over 4π sr averaging 1 lum in every direction. From spherical candlepower and beam candela are units for a source that emits equally in all directions (isotropic), source.

![Diagram showing luminous intensity](source: Moore F, 1985, Fig. 2.2, p. 18)
Daylighting buildings

Daylight metrics

Luminance
Density of luminous intensity (cd/m²).

Daylight factor (DF)
- Ratio of inside illuminance to exterior illuminance, expressed in per cent.
- The higher the DF the more natural light is available in the room.
- The DF is often expressed for a fixed point on a desk.

New daylight metrics:
1. Daylight autonomy, DA (%)
2. Daylight autonomy continuous, DAcon (%)
3. Daylight autonomy max, DAmax (%)
4. Useful Daylight Illuminance, UDI (%)
   - UDI < 100 lx
   - UDI 100-2000 lx
   - UDI > 2000 lx
Daylight autonomy, DA (%)  
Percentage of the occupied times of the year when the minimum illuminance requirement (e.g. 500 lx) at the sensor is met by daylight alone.

Daylight autonomy continuous, DAcon (%)  
Partial credit is attributed to time steps when the daylight illuminance lies below the minimum illuminance level.

For example, in the case where 500 lx are required and 400 lx are provided by daylight at a given time step, a partial credit of 400lx/500lx=0.8 is given for that time step.

Daylight autonomy maximum, DAmax (%)  
DA_{max} compiles the percentage of times during a year when the illuminance at a sensor is at least ten times the recommended illuminance.

In such a situation, there is a high chance that this will correspond to a situation with direct sunlight patch at the sensor and hence glare.

### Daylighting buildings

#### Daylight metrics

**Useful Daylight Illuminance, UDI (%)**

Annual occurrence of illuminances across the work plane that are within a range considered ‘useful’ by occupants:

- UDI within the useful range (i.e. 100 lx to 2000 lx).
- UDI fall short of the useful range (i.e. less than 100 lx).
- UDI exceed the useful range (i.e. greater than 2000 lx).
21 June, 12:00, Soltis screen
Daylighting buildings

DAYSIM

- DAYSIM is a RADIANCE-based daylighting analysis tool
- Developed at the National Research Council of Canada and the Fraunhofer Institute for Solar Energy Systems in Germany.
- DAYSIM uses the daylight coefficient method to efficiently calculate illuminance distributions under all sky conditions in a year and the Perez sky model.