Daylight

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Introduction

On one side, daylight is constantly changing so it is difficult to make a good lighting with it.

On the other side this changes can provide buildings with living quality unachievable with any other design.

Introduction

Daylighting is:

art & science

design element & environmental system

Daylight properties

Daylight has its **advantages** (high levels, high illuminances of indoor environment, daily rhythm favorable technical parameters, energy savings ...)

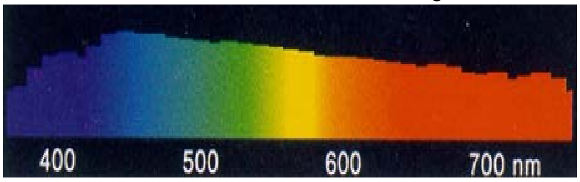
as well as **weaknesses** (rapid changes, strong shadows, limited duration, the need for heating and air-conditioning, glare ...)

Daylight properties

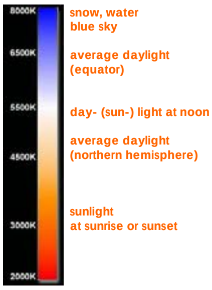
The spectrum: **full range**

Spectrum is dominated by blue and purple hues, but the differences are not pronounced. The spectrum can vary with time of day (and year) and weather ...

Color rendering index: **100.**



Daylight properties



Color temperature: **changes during the day.**

The average is about 6500 K (at the equator) and slightly less in Europe (5000 K).

Daylight properties

Available power (energy) :
on a sunny summer day:
1000 W/m²
100.000 lx
on a dark moonless cloudy night:
0,0001 W/m²
0,01 lx
in both cases outside in the open air.

Daylight properties

Lifespan :
unlimited
but the availability is very much limited to about 12 hours per day in average.

That is why daylight is today an alternative source of light in interiors as electric lamp was an alternative to daylight 100 years ago.

Why daylighting

+ Quality of the light

Daylight is what our eyes were made for: most closely matches human visual response, large quantity, full spectrum, good color rendering, good visual environment ...

Why daylighting

+ Importance of daylight as a design element

Daylight can be used as a central design determinant in the design (Wright, Le Corbusier, Aalto …). Daylight also adds aesthetic quality to space.

Why daylighting

+ View (daylight apertures provide visual communication channels)

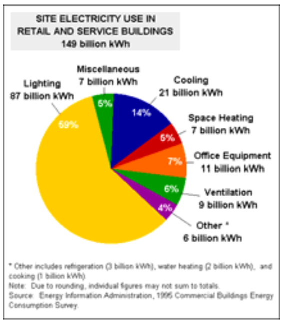
Humans have a strong desire for a view . What makes a good view and whether a good view is necessary is not yet clear.

Why daylighting

+ Use of daylight apertures as fire exits

The fire may require more victims in buildings, where occupants can not open windows to vent smoke, escape or allow firemen to enter.

Why daylighting



+ Energy conservation

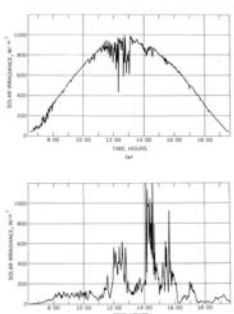
Daylight can significantly reduce energy consumption for lighting as well as costs as in modern buildings 30 % to 50 % of energy is used for lighting.

Why daylighting

+ Psychological and physiological benefits not obtainable with electric lighting

Students in windowless schools are more aggressive. Patients in windowless hospitals need more time to recover ...

Why daylighting

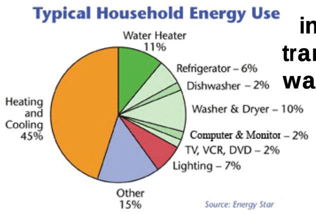


- Not a stable light source

Daylight parameters can change very fast (also illuminance) which may cause problems at work.

Why daylighting

- Energy consumption for heating and cooling



Big glazed openings in a building envelope transfer heat better than walls: in the winter more heating is needed and in the summer cooling is on.

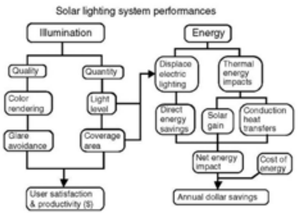
Why daylighting

- Glare and similar issues

Daylight van cause sever problems with glare and veiling reflections. Especially with the windows on east and west sides of the building.

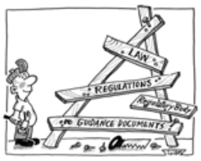
Why daylighting

- A loot of knowledge is needed



Some of the key information needed to design and analyze daylight systems is not common knowledge and is hard (impossible) to get.

Daylight legislation



Different countries = different views:

- No legislation at some.
- Minimum window area (according to room area).
- Minimum duration of direct sunlight.
- Minimum illuminance in a part of the room for minimum time.
- Different combinations.
- Sometimes for homes and sometimes for working places.

EU standard still in preparation.

Principles of daylight design

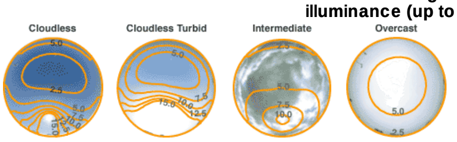
Facts:

- source of daylight is outside the room,
- daylight is extremely variable (with time and location – geographical latitude),
- daylight is not available whole (working) day so we need to decide the percentage of (working) hours for which adequate lighting is to be provided.

Principles of daylight design

Sky conditions vary so the nature and quantity of the light entering the building:

- overcast sky: uniform distribution of luminance which is higher at the zenith (3x);
- intermediate sky: 30 % - 80 % of sky obscured by clouds gives very varying conditions;
- clear sky: is less bright as the overcast sky and brighter at horizon as at zenith. Direct sunshine gives very high illuminance (up to 100.000 lx);



ASRC -CIE Luminance distribution for the four basic models (kcd/m^2)

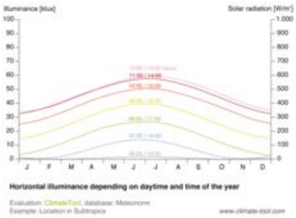
Principles of daylight design

Tolerable minimum conditions:

- minimum conditions (illuminance levels) available all the time,
- usually only encountered at the beginning and end of (working) day,
- higher levels will be available in between,
- special circumstances (e.g. thunderstorm) may reduce this minimum levels.

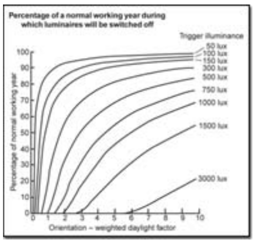
Principles of daylight design

In order to achieve this tolerable minimum conditions it is necessary to know:



- how much light is available outside the building,
- how much light is needed inside the building for the task.

Principles of daylight design

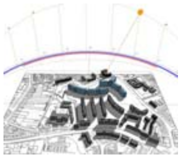


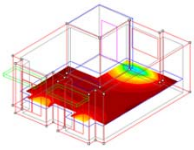
Tolerable minimum conditions includes:

- minimum illuminance levels,
- percentage of (working) hours between start and end of the (working) day (e.g. 8:00 to 16:00 or 9:00 to 17:00).

During this percentage of (working) hours at least the minimum illuminance should be achieved by daylighting.

Principles of daylight design

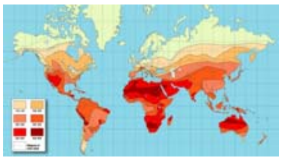




Based on that we can conclude that daylight design has two parts:

- site design (site planning) to assure adequate external illuminance during the (selected part of the) day,
- building and room design (design of daylight apertures) to bring enough daylight into the rooms.

Principles of daylight design

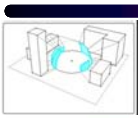


Site design includes:

- geographical position (latitude),
- average weather conditions,

these two defines the amount of daylight (horizontal illuminance) available on a horizontal plane exposed to the whole of a completely unobstructed sky.

Principles of daylight design



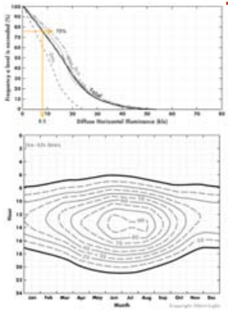
1 - Take a fish-eye view of the sky from the point of interest.

As every building is part of an urban area a places with unobstructed sky are very rare. So at site planning also following should be considered:

- adjacent buildings,
- adjacent vegetation,
- other obstructions (hills ...).

Rule of thumb: at least 5 % of unobstructed sky should be available at the spot.

Available daylight

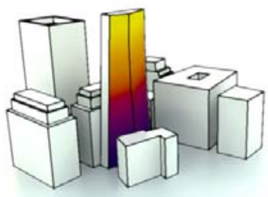


The available daylight (exterior illuminance) depends on:

- location,
- date and time,
- whether,
- atmospheric turbidity,
- micro location (surroundings objects)
- ...

Available daylight

To design daylighting systems and to analyze them as well as to calculate the possible energy savings (gains) we need to know:



- exterior illuminance (horizontal, vertical in different directions) – connected to lighting,
- exterior irradiance – connected to energy problems.

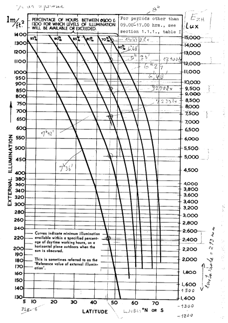
Available daylight

There are many approaches to determine both exterior illuminance and irradiance:

- observations,
- measurements,
- modeling,
- use of data provided by satellites.

Currently we know much more about exterior irradiance as about exterior illuminance.

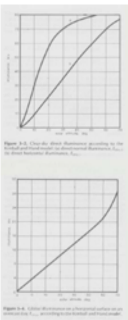
Available daylight-data



General tables and figures:

- based on geographic latitude and average weather,
- giving minimum external illuminance at the selected latitude for the selected portion of the day,
- available in CIE No. 16.

Available daylight-data



Locale specific exterior illuminance models:

- based on measurements of exterior illuminance or sky luminance,
- given in a form of equation for total global horizontal illuminance (for clear or overcast sky).
- to be considered: variables (solar altitude, asimuth) and constants (derived from measurements).

Available daylight-data

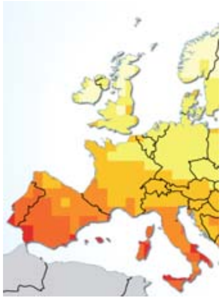
CIE Sky type	Gradation group	Indicatrix group	Description of luminance distribution	Parameters			
				B	C	D	E
1	I	1	CIE Standard Overcast Sky, Steep luminance gradation towards zenith, azimuthal uniformity	54.63	1.00	0	0
2	I	2	Overcast, with steep luminance gradation and slight brightening towards the sun	12.35	3.68	0.59	50.47
3	II	1	Overcast, moderately graded with azimuthal uniformity	48.3	1.00	0	0
4	II	2	Overcast, moderately graded and slight brightening towards the sun	12.23	3.57	0.57	44.27
5	III	1	Sky of uniform luminance	42.59	1.00	0	0
6	III	2	Partly cloudy sky, no gradation towards zenith, slight brightening towards the sun	11.84	3.53	0.55	38.78
7	III	3	Partly cloudy sky, no gradation towards zenith, brighter circum solar region	21.72	4.52	0.64	34.56
8	III	4	Partly cloudy sky, no gradation towards zenith, distinct solar corona	29.35	4.94	0.70	30.41
9	IV	2	Partly cloudy, with the obscured sun	10.34	3.45	0.50	27.47
10	IV	3	Partly cloudy, with brighter circumsolar region	18.41	4.27	0.63	24.04
11	IV	4	White-blue sky with distinct solar corona	24.41	4.60	0.72	20.76
12	V	4	CIE Standard Clear Sky, low illuminance turbidity	23.00	4.43	0.74	18.52
13	V	5	CIE Standard Clear Sky, polluted atmosphere	27.45	4.61	0.76	16.59
14	VI	5	Cloudless turbid sky with broad solar corona	25.54	4.40	0.79	14.56
15	VI	6	White-blue turbid sky with broad solar corona	28.08	4.13	0.79	13.00

CIE standardized sky models:

- theoretical representation of 15 different sky types (clear, intermediate, overcast),
- model defines ration between luminance of arbitrary sky element and zenith luminance,
- to be considered: indicatrix function (luminance as function of angular distance from sun), gradation function (luminance as function of zenith angle).

Available daylight-data

Exterior illuminance prediction models:



- no illuminance measurement results needed,
- instead more easily available weather data are used (global radiation on a horizontal surface, ratio of diffuse to total horizontal radiation ...),
- different models were developed.

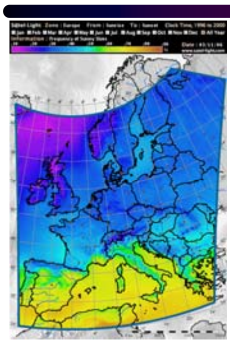
Available daylight-data

Sunlight probability data:

- duration and frequency of sunshine over the year,
- measured practically at every weather station,

- limit: 200 W/m^2,
- data available as percent sun (measured minutes of sunshine per hour).

Available daylight-data



Satellite data:

- meteorological satellites are regularly taking pictures of earth in different spectral channels,
- this data can be used for calculation of relative sunshine duration, horizontal irradiance and illuminance ...
- collection of data freely available on internet,
- available at www.satel-light.com.

Available daylight-data

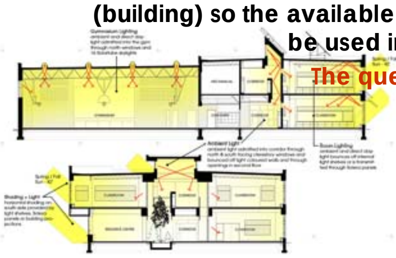
IDMP data base:

- network of IDMP measurement stations (measuring daylight),
- limited amount of data (location, duration, data),
- limited to members, which need to send some data to get access to data on server,
- available on idmp.entpe.fr.

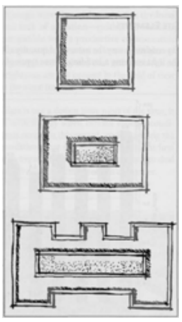
Design strategies

Once external illuminance over the day is known, we need to design the room (building) so the available daylight can be used in a best way.

The question is how?



Design strategies



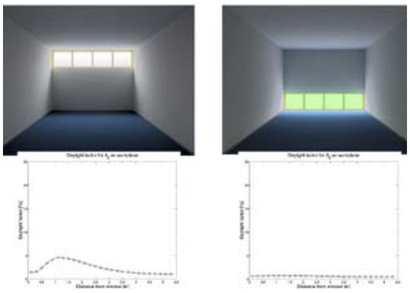
Increase perimeter daylight zones:

extending the perimeter form of a building may improve the building's performance by increasing the total daylight area.

Design strategies

Allow daylight penetration high in a space:

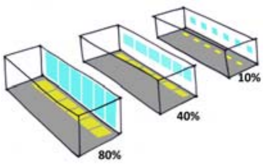
with the location of aperture high in a wall, deeper penetration will result.



Design strategies

Use “effective aperture” for initial estimates of the glazing area:

If “effective aperture”>0,18, daylighting saturation will be achieved.



effective aperture= window/wall x transmittance

Design strategies

Or use “rules of thumb” :

General rule:

- minimum window area >5% of floor area for room where people stay permanently;

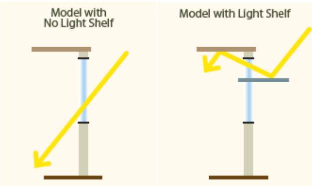
For dwellings:

- window area min 10% of floor area;
- better: 20% to 30% but then overheating in summere may occure.

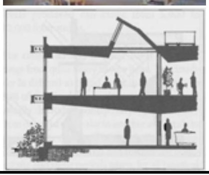
Design strategies

Reflect daylight within space to increase luminance:

surfaces and objects inside space reflect and scatter daylight so spreading and evening out brightness patterns will increase luminance in a room.



Design strategies



Slope ceilings to direct more light into space:

sloping away from fenestration are will increase luminance of the ceiling farther into a space.

Design strategies

Direct sunlight – wanted or not

For living spaces: preferably yes:

- larger contrasts between light and dark;
- light is more dynamic and so more interesting;
- but possible overheating;
- consider culture (location).

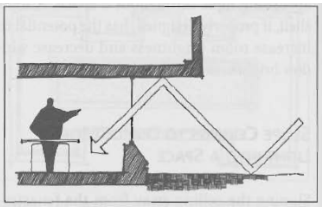
For work spaces: preferably no:

- larger luminance contrast – risk of glare;
- not comfortable for directly sunlit person.

Design strategies

Avoid direct-beam daylight on critical visual tasks:

direct-beams result in glare so poor visibility and discomfort may be the result. Use of fenestration controls may help.



Design strategies

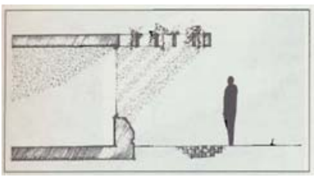
Use direct sun cautiously in areas where noncritical tasks occur:

patterns of light and shadow may contribute to well being and sense of time and orientation but can also cause difficulties.

Design strategies

Filter daylight:

when direct sunlight might be a problem, filtering by vegetation, curtains or louvers might be a solution.

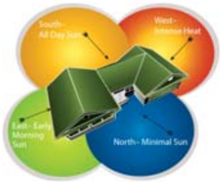


Design strategies

Orientation of the apertures:

Orientation makes the difference:

- daily and seasonal patterns are orientation dependent;
- aperture to the north: cool and diffuse light;
- aperture to the south: warm and direct (sun) light,
- aperture to the east: sunrise can be experienced;
- aperture to the west: sunset can be experienced.

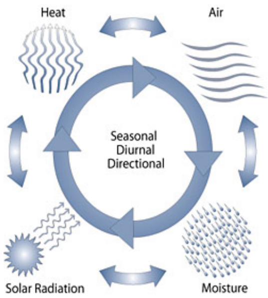


Design strategies

Location and shape of the apertures:

- determines how the space is perceived;
- determines the view to the outside;
- can be used to direct daylight within a space.

Design strategies

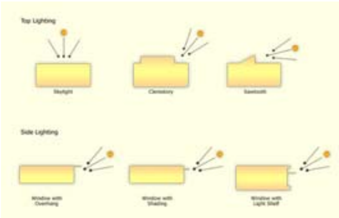


Consider other environmental control systems:

fenestration systems will allow light, heat, air, sound into space. So ventilation, acoustic, electric lighting, heating, ventilation, air-conditioning systems ... need to be considered.

Design concepts

We know what (amount of) daylight is available and what we would like to achieve in our interior.

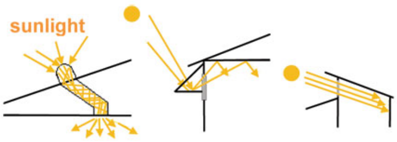


The question is what daylight system we can use for that?

Design concepts

The purpose of daylighting system is:

- to provide reasonable amount of light where it is needed in a building,
- ensuring good visual performance,
- providing sufficient lighting contrast for visual comfort.

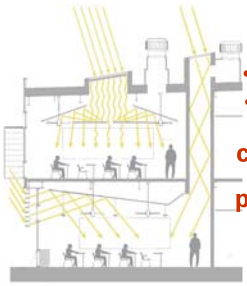


Design concepts

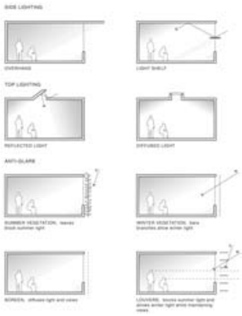
A daylighting system includes:

- daylight aperture,
- glazing media,
- shading and sun control,
- electric lighting controls.

Daylighting concept is combination of daylighting apertures necessary to provide desired distribution of daylight.



Design concepts



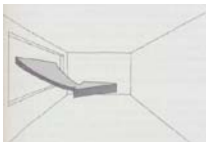
Daylighting concepts can be grouped into following categories:

- sidelighting,
- roof and top lighting (horizontal),
- angled lighting,
- beam lighting,
- indirect lighting,
- atria, light courts.

Design concepts

The actual design of the building's daylighting areas is based upon the geometric relationships between the room being daylit and the size, shapes and locations of the daylight apertures that provide room's natural illumination.

Sidelighting concepts



Sidelighting concepts use wall of the building as the location of daylight aperture:

- windows,
- clerestory aperture

They provide light that sweeps across horizontal work planes.

Sidelighting concepts

+ directionality of the light,
+ good lighting quality and quantity on horizontal surfaces,
+ good lighting quality and quantity on vertical surfaces with clerestories,
+ visual connection with the surrounding,
- not so good lighting quality and quantity on vertical surfaces,
- glare and high contrast in a room,
- visual connection with the surrounding.

Sidelighting concepts

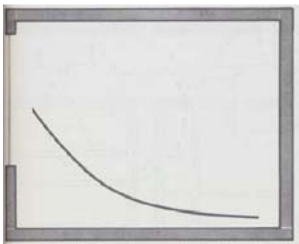


Figure 4-4. Section through a room showing the change in illuminance penetration along the workplane.

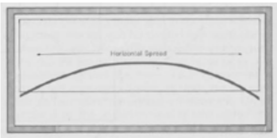
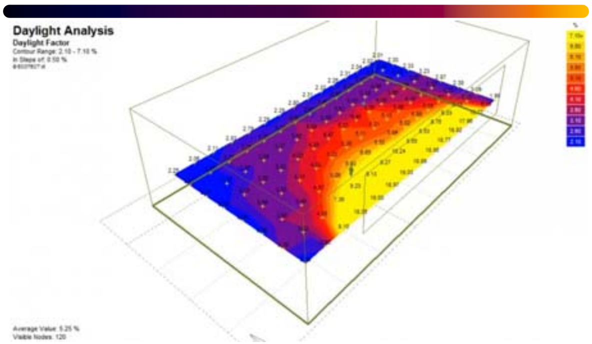
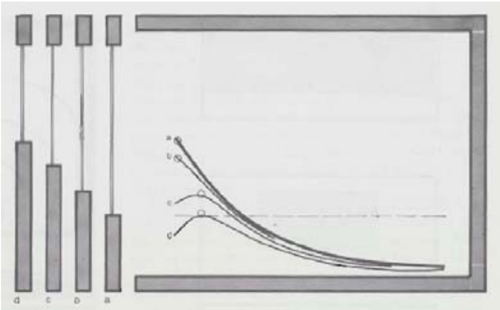


Figure 4-7. Latitudinal section of a room with a vertical aperture.

Sidelighting concepts



Sidelighting concepts



Sidelighting concepts

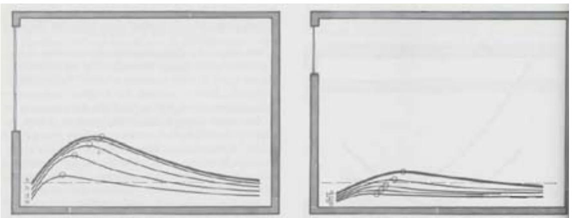


Figure 4–43. Impact on illuminance in a room with clerestory aperture when $\hat{H}$ = 1.7:1, $\hat{V}$ = 1:1, and $\hat{M}$ is varied as follows: (a) $\hat{M}$ = ∞:1; (b) $\hat{M}$ = 4:1; (c) $\hat{M}$ = 2:1; (d) $\hat{M}$ = 1:1; (e) $\hat{M}$ = 0.5:1.

Figure 4–44. Impact on illuminance in a room with cle story aperture when $\hat{H}$ = 3.3:1, $\hat{V}$ = 1:1, and $\hat{M}$ is vari as follows: (a) $\hat{M}$ = ∞:1; (b) $\hat{M}$ = 4:1; (c) $\hat{M}$ = 2:1; (d) $\hat{M}$ 1:1; (e) $\hat{M}$ = 0.5:1.

Sidelighting concepts

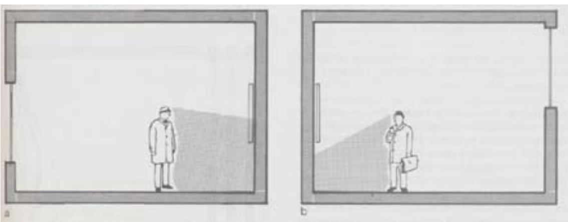
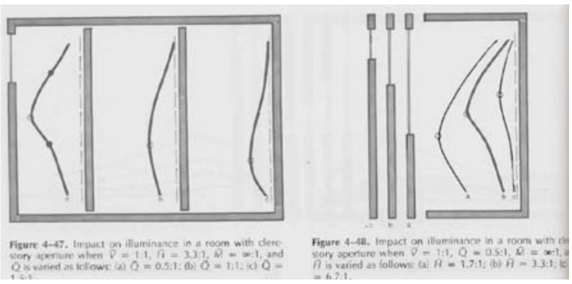
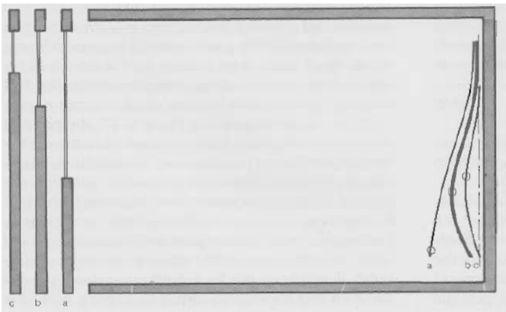


Figure 4–46. Problem of shadowing walls (a) using windows for lighting, and (b) using clerestories for lighting.

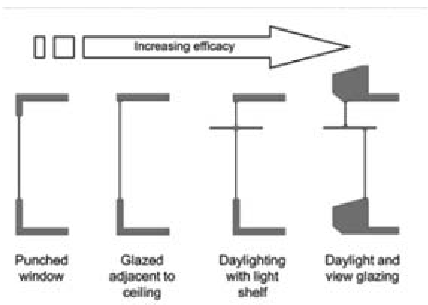
Sidelighting concepts



Sidelighting concepts



Sidelighting concepts



Toplighting concepts

In toplighting concepts daylight penetrates space from apertures located above the ceiling line (constitute part of the roof):

- horizontal lights and lightwells,
- angled roof lights,
- sawtooth lights,
- monitor lights,
- direct and indirect beam lighting.

Toplighting concepts

\+ relatively uniform level of illuminance through the space,

\+ allow use of sunlight and skylight,

\+ very good for general lighting,

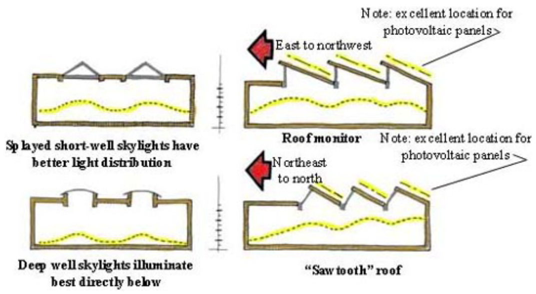
\+ less problems with glare,

\- can not be used in multistory buildings,

\- use of sunlight may cause reflected glare,

\- no visual connection with the surrounding.

Toplighting concepts



Toplighting concepts

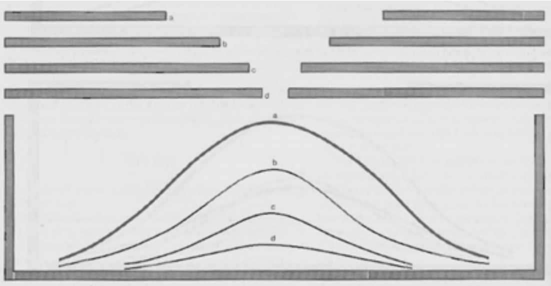


Figure 5–7. Impact on illuminance in a room with horizontal aperture when $\bar{O} = 16:1$, $\bar{M} = \infty:1$, and $\bar{N}$ is varied as follows: (a) $\bar{N} = 2:1$; (b) $\bar{N} = 1:1$; (c) $\bar{N} = 0.5:1$; (d) $\bar{N} = 0.25:1$.

Toplighting concepts

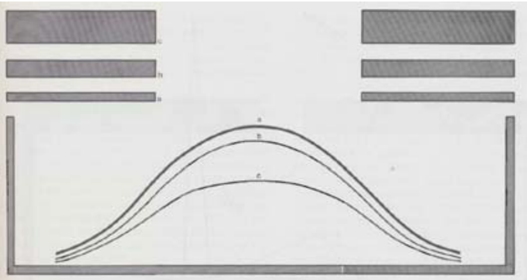


Figure 5–8. Impact on illuminance in a room with horizontal aperture when $\bar{N} = 2:1$, $\bar{M} = \infty:1$, and $\bar{O}$ is varied as follows: (a) $\bar{O} = 16:1$; (b) $\bar{O} = 8:1$; (c) $\bar{O} = 4:1$.

Toplighting concepts

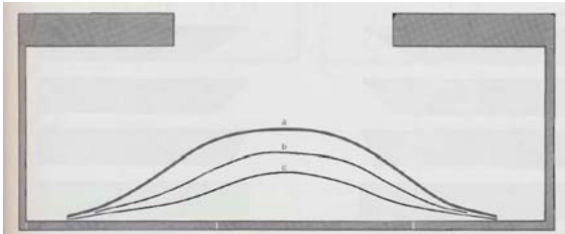


Figure 5–9. Impact on illuminance in a room with horizontal aperture when $\bar{N} = 2:1$, $\bar{M} = \infty:1$, $\bar{O} = 4:1$, and the lightwell reflectivity is varied as follows: (a) 80 percent reflective well; (b) 60 percent reflective well; (c) 40 percent reflective well.

Toplighting concepts

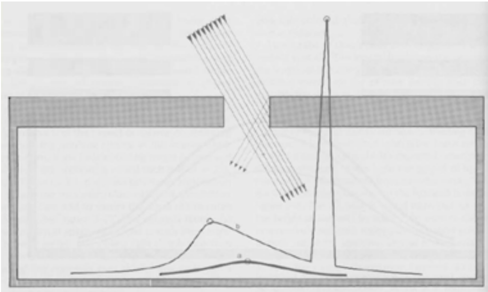
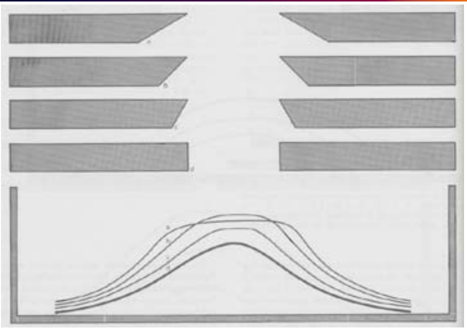


Figure 5–10. Direct sunlight's impact on space: (a) sky light only; (b) sky light, sunlight, and reflected sunlight.

Toplighting concepts



Toplighting concepts

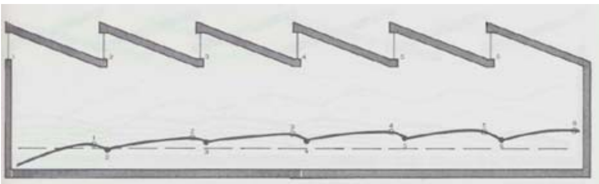
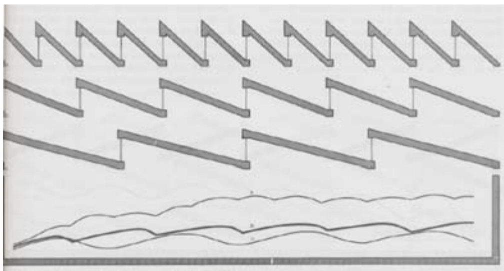


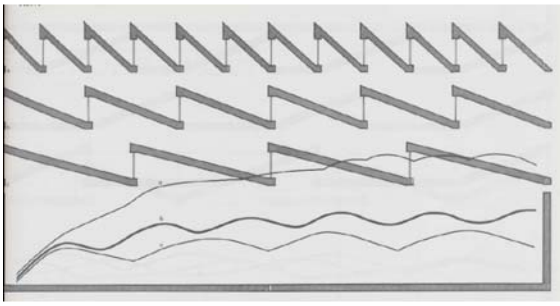
Figure 5–21. Location of points of maximum (○) and minimum (●) illuminance for the base case sawtooth aperture under an overcast sky.

Toplighting concepts



igure 5–24. Impact on illuminance in a room with sawtooth pertures under an overcast sky when $\bar{H}$ = 3.5:1, $\bar{M}$ = ∞:1, nd $\bar{S}$ is varied as follows: (a) $\bar{S}$ = 0.5:1; (b) $\bar{S}$ = 1:1; (c) = 1.5:1.

Toplighting concepts



Toplighting concepts

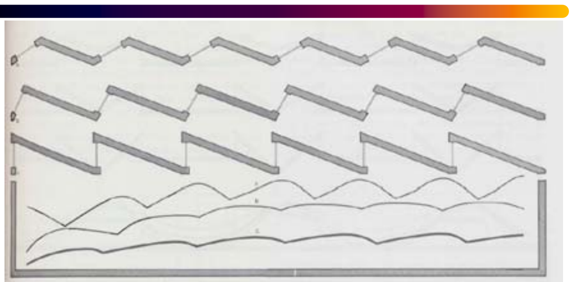


Figure 5–28. Impact on illuminance in a room with sawtooth apertures when $\bar{H}$ = 3.5:1, $\bar{S}$ = 1:1, $\bar{M}$ = ∞:1, and the slope of the apertures is varied as follows: (a) 30° slope; (b) 60° slope; (c) 90° slope.

Toplighting concepts

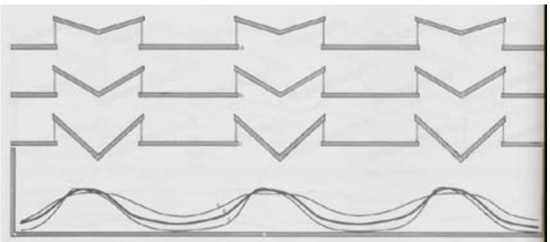


Figure 5-30. Impact on illuminance in a room with butterfly apertures under an overcast sky when $\bar{H}$ = 3.5:1, $\bar{V}$ = 1:1, $\bar{M}$ = ∞:1, and $\bar{T}$ is varied as follows: (a) $\bar{T}$ = 0.5:1; (b) $\bar{T}$ = 1:1; (c) $\bar{T}$ = 1.5:1.

Toplighting concepts

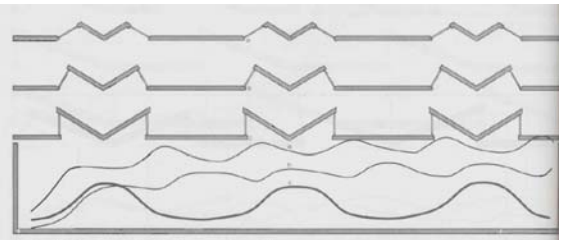


Figure 5-31. Impact on illumination in a room with sawtooth apertures when $\bar{H}$ = 3.5:1, $\bar{S}$ = 1:1, $\bar{M}$ = ∞:1, and the slope of the apertures is varied as follows: (a) 30° slope; (b) 60° slope; (c) 90° slope.

Toplighting concepts

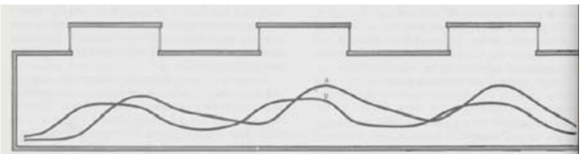


Figure 5-34. Impact on illuminance in a room with series of monitor apertures when $\bar{H}_1$ = $\bar{H}_2$ = 3.5:1, $\bar{S}$ = 1:1, $\bar{W}$ = 1:1, $\bar{M}_1$ = $\bar{M}_2$ = 4:1, and sky conditions are as follows: (a) clear sky, apertures facing and opposite sun; (b) overcast sky.

Toplighting concepts

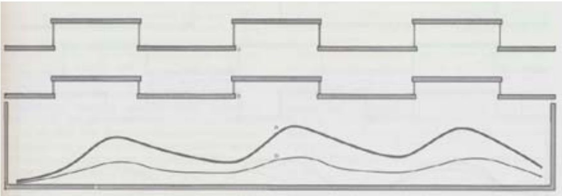


Figure 5–37. Impact on illuminance in a room with series of monitor apertures under an overcast sky when $\bar{S}$ = 1:1, $\bar{M}_t = \bar{M}_l$ = 4:1, and $\bar{R}_t$, where $\bar{R}_t = \bar{R}_l$, is varied as follows: (a) $\bar{R}_t = \bar{R}_l$ = 3.5:1; (b) $\bar{R}_t = \bar{R}_l$ = 6:1.

Toplighting concepts

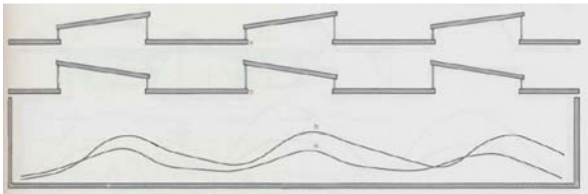


Figure 5–38. Impact on illuminance in a room with series of monitor apertures under an overcast sky when $\bar{S}$ = 1:1, $\bar{M}_t = \bar{M}_l$ = 4:1, and $\bar{R}_t$, where $\bar{R}_t \neq \bar{R}_l$, is varied as follows: (a) $\bar{R}_t$ = 6:1, $\bar{R}_l$ = 3.5:1; (b) $\bar{R}_t$ = 3.5:1, $\bar{R}_l$ = 6:1.

Toplighting concepts

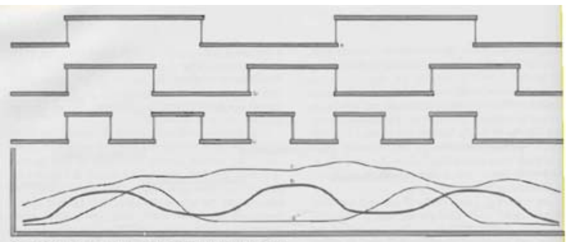


Figure 5–39. Impact on illuminance in a room with series of monitor apertures under an overcast sky when $\bar{R}_t = \bar{R}_l$ = 3.5:1, $\bar{M}_t = \bar{M}_l$ = ∞:1, and $\bar{S}$ is varied as follows: (a) $\bar{S}$ = 1.5:1; (b) $\bar{S}$ = 1:1; (c) $\bar{S}$ = 0.5:1.

Toplighting concepts

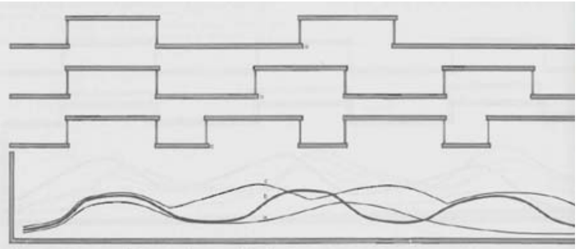


Figure 5–40. Impact on illuminance in a room with series of monitor apertures under an overcast sky when $\bar{H}_1 = \bar{H}_2 =$ 3.5:1, $M_1 = M_2 = \infty$:1, $\bar{S} =$ 1:1, and $\bar{W}$ is varied as follows: (a) $\bar{W} =$ 1.5:1; (b) $\bar{W} =$ 1:1; (c) $\bar{W} =$ 0.5:1.

Toplighting concepts

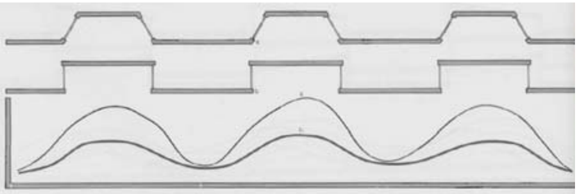
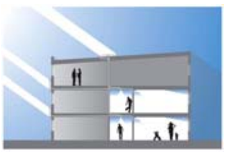


Figure 5–41. Impact on illuminance in a room with series of monitor apertures under an overcast sky when $\bar{H}_1 = \bar{H}_2 =$ 3.5:1, $\bar{M}_1 = \bar{M}_2 = \infty$:1, $\bar{S} =$ 1:1, and the slope of the aperture is varied as follows: (a) slope = 60°; (b) slope = 90°.

Daylight guidance systems

Spaces that do not have "direct wall" to the outside can be daylit with help of daylight guidance systems.



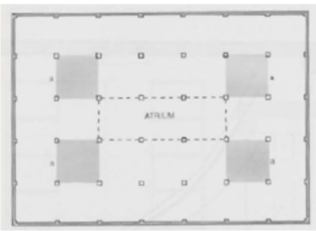
Atria, light courts, reentrants

These are more ways to manipulate the form of a building's perimeter to optimize the amount the space that can be illuminated with daylight.

They are usually used with the sidelighting concepts.

Atria, light courts, reentrants

Sidelighting concepts are designed to illuminate parts of the building that are closed to the daylight apertures.



This works well for the perimeter but not for the core.

With atria, light courts and reentrants the daylight perimeter is increased and the core area is reduced.

Atria, light courts, reentrants

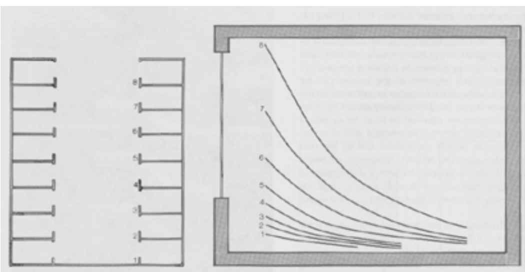


Figure 6–4. Average light penetration on first through eighth floors in a building with light court when $\bar{A}$ = 2:1, $\bar{H}$ = 1:1, $\bar{V}$ = 1:1, and $\bar{M}$ = 8:1.

Atria, light courts, reentrants

Figure 6–8. Classical reentrant forms: (a) C or U forms; (b) E forms.

Figure 6–9. Double and multiple reentrant forms: (a) double C or U forms; (b) double E forms.

Atria, light courts, reentrants

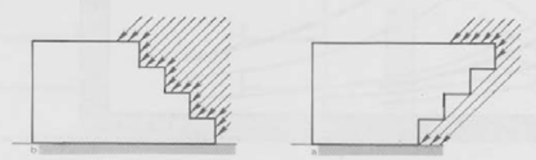
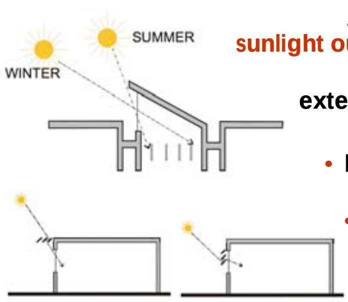


Figure 6–10. Vertical/stepped reentrant forms: (a) self-shading forms; (b) self-sunning forms.

Sun control and shading devices



Vertical and Horizontal Louvers to Re-direct Sunlight

Are used to keep sunlight out of the building:

- overhangs and extended overhangs,
- light shelves,
- horizontal louvers and blinds,
- vertical louvers, fins and blinds.

Sun control and shading devices

Some of them (like horizontal louvers or blinds) can be placed on either exterior or interior of the building.

Exterior sun control devices are usually better when combination of daylighting and cooling is important.

Sun control and shading devices

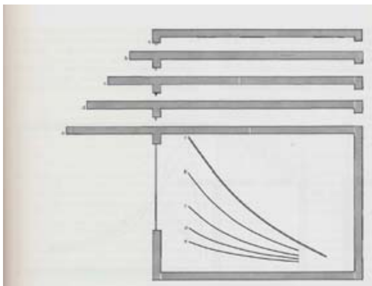


Figure 6-13. Impact on daylight penetration and spread in a room with overhang when $\bar{H}$ = 1.3:1, $\bar{V}$ = 1:1, $\bar{M}$ = ∞:1, and $\bar{D}$ is varied as follows: (a) no overhang; (b) $\bar{D}$ = 0.25:1; (c) $\bar{D}$ = 0.5:1; (d) $\bar{D}$ = 0.75:1; (e) $\bar{D}$ = 1:1.

Sun control and shading devices

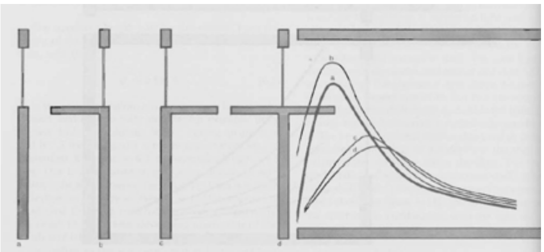


Figure 6-15. Impact on daylight penetration in a sunless room with various light shelves when $\bar{H}$ = 1.5:1, $\bar{V}$ = 1:1, $\bar{M}$ = ∞:1, solar altitude is 30°, solar azimuth is 0°, and $\bar{D}$ is varied as follows: (a) no light shelf; (b) + $\bar{D}$ = 1:1; (c) − $\bar{D}$ = 1:1; (d) $\bar{D}$ = 2:1.

Sun control and shading devices

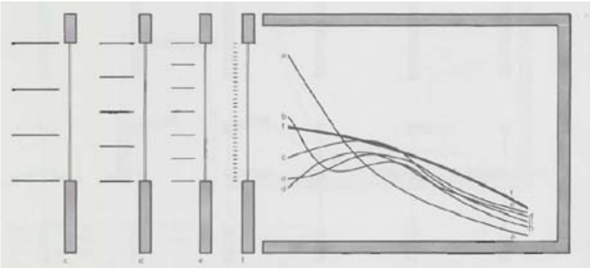
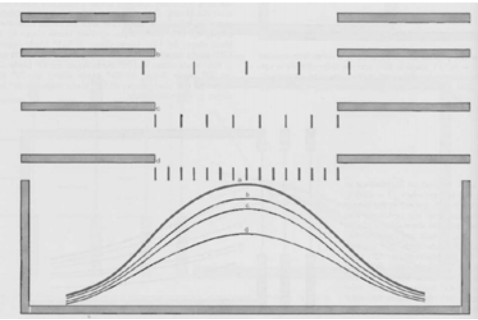


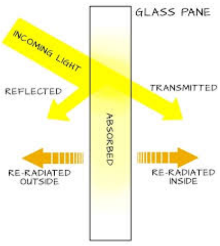
Figure 6–19. Horizontal louver and blind performance at different $\bar{D}$ ratios: (a) $\bar{D}$ = 1:1 extended overhang (not ill… (b) $\bar{D}$ = 0.5:1 (not illustrated); (c) $\bar{D}$ = 0.25:1; (d) $\bar{D}$ = 0.20:1; (e) $\bar{D}$ = 0.17:1; (f) $\bar{D}$ = 0.03:1 (blinds).

Sun control and shading devices



Glazing

Very few daylight apertures are just "holes in wall". They are usually closed with glazing.



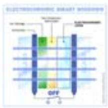
Glass properties:

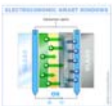
- absorption,
- reflection,
- transmission.

Glazing

Glass properties can be changed in various ways:

- coating or coloring,
- different material (plastics),
- gas filling and vacuuming,
- directionally selective materials,
- electrochromic materials,
- inovative glazing types (phase change materials).





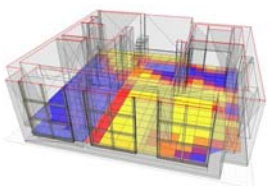
Glazing

GLASS TYPE (PRODUCT)	GLASS THICKNESS (INCH)	VISIBLE TRANSMITTANCE (% DAYLIGHT)	U-VALUE (WINTER)	SHADING COEFFICIENT	SOLAR HEAT GAIN COEFFICIENT	EFFICACY FACTOR (T_{vi}/SC)
Single-pane glass (*Standard-clear*)	0.25	89	1.09	0.94	0.81	0.95
Single white laminated w/heat-rejecting coating (*Southwall California Series*)	0.25	73	1.06	0.54	0.46	1.35
Double-pane insulated glass (*Standard-clear*)	0.25	79	0.48	0.82	0.70	0.96
Double bronze reflective glass (*LOF Eclipse*)	0.25	21	0.48	0.41	0.35	0.51
Triple-pane insulated glass (*Standard-clear*)	0.125	74	0.36	0.78	0.67	0.95
Pyrolytic low-e double glass (*LOF clear low-e*)	0.125	75	0.33	0.82	0.71	0.91
Soft-coat low-e double glass w/argon (*PPG Sungate 100 clear*)	0.25	73	0.26	0.66	0.57	1.11
High-efficiency low-e (*Solarscreen 2000 VE1-2M*)	0.25	70	0.29	0.43	0.37	1.63
Suspended coated film (*Heat Mirror 66 clear*)	0.125	55	0.25	0.41	0.35	1.34
Suspended coated film w/argon (*Azurlite Heat Mirror SC75*)	0.125	53	0.19	0.32	0.27	1.66
Double suspended coated films w/krypton (*Heat Mirror 77 Superglass*)	0.125	53	0.10	0.40	0.34	1.33

Daylight analysis

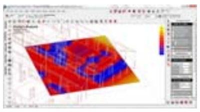
Daylight design should be checked if it fulfills needed criteria:

- lighting performance,
- lighting energy use,
- trade off (lighting, heating, cooling),
- costs,
- human comfort.



Daylight analysis

Lighting performance analysis can be done in different ways:



- mathematical modeling,
- computer simulations,
- scale modeling and measurements,
- mockup modeling and measurements.

Daylight analysis

Mathematical modeling

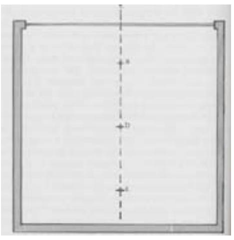
is used to calculate absolute or relative (according to exterior illuminance) illuminance levels in a room. It is:

- fast and so useful for gauge the sensitivity of a design to changes in daylight apertures,
- can be used with computers,
- can include also artificial lighting sources,
- can be used to calculate level for the extended period of time.

Daylight analysis

Mathematical modeling

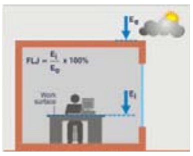
Lumen input method

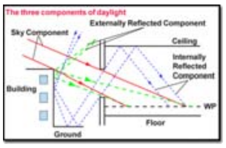


Absolute method for small rooms which gives illuminance in three points based on luminous flux entering through the daylight apertures (calculated from illuminance at the aperture and its area). Data from tables (originally from measurements) need to be used.

Daylight analysis

Mathematical modeling
Daylight factor (DF) method





Relative method. DF is defined as ratio of internal illuminance in a given point and external illuminance. Knowing DF for each point in a room illuminance in this points can be calculated from chosen external illuminance.

Daylight analysis

Mathematical modeling
Daylight factor (DF) method

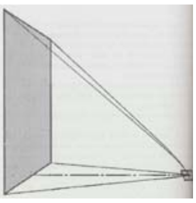
How large DF should be?

Daylight factor	< 1% Very low	1%-2% Low	2%-4% Moderate	4%-7% Acceptable	7%-12% High	>12% Very high
Perception of illuminance	Dark to gloomy		Gloomy to light		Light to very light	
Remarks	Fits for secondary spaces (corridors, storage,...		Fits for work spaces		Glare risk	
Atmosphere	Space has no relation with outside			Space has a relation with outside		

Daylight analysis

Mathematical modeling
Flux transfer method

Absolute method. Illuminance in a point is calculated from luminous flux coming to this point (small area) from different sources like sunlight, sky, internal and external surfaces ...It is basis for some methods used in simulation programs.



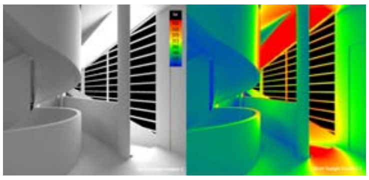
Daylight analysis

Computer simulation

is also mathematical modeling but no basic knowledge about calculations is needed. Different simulation programs can be used with provided or self-made models of daylight apertures. Advantages:

- fast and reliable,
- analysis can include both daylighting and artificial lighting,
- room furniture … can be included,

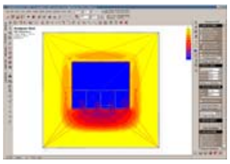
different sky models can be used for simulations (clear, overcast, CIE standard skies …).

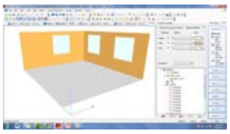


Daylight analysis

Computer simulation

use of daylight aperture models provided by simulation program



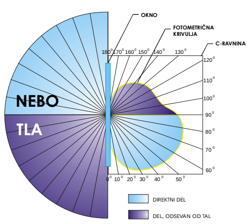


Most today's simulation programs include daylight simulations with different "window" models. Limitations: limited number of sky types, limited number of "window" models (e.g. just vertical or horizontal) limited data about typical weather conditions …

Daylight analysis

Computer simulation

use of self made daylight aperture models



Daylight aperture can be modeled and included into simulation program in a same way as an electrical luminaire. Advantages: different sky models can be used, real weather data can be taken into account, different "window" models can be made (different slopes …).

Daylight analysis

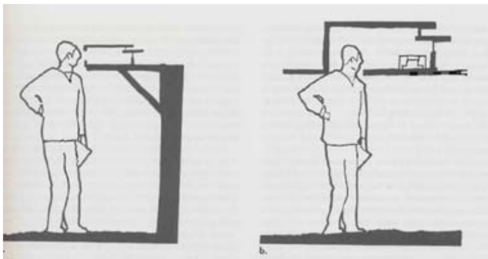
Scale modeling and measurements

A scale model of a room with daylight apertures is made and measurements are done under real or artificial sky. Properties:

+ no mathematical knowledge needed,
+ results are very close to reality, less room for mistakes,
+ real photographs can be made,
- accurate model need to be made (reflectance, dimensions ...),
- propriate measurement instruments are needed,
- could be time and money consuming.

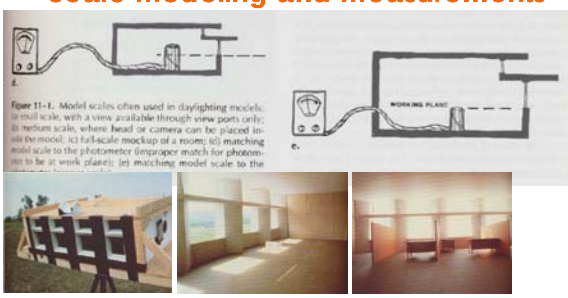
Daylight analysis

Scale modeling and measurements



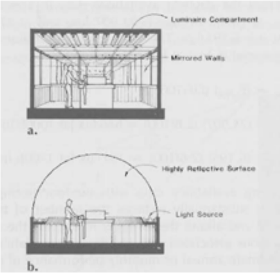
Daylight analysis

Scale modeling and measurements



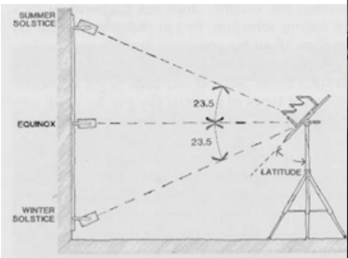
Daylight analysis

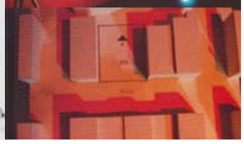
Scale modeling and measurements



Daylight analysis

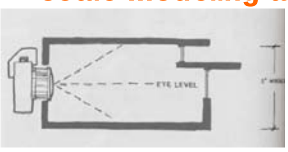
Scale modeling and measurements

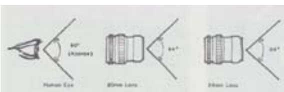


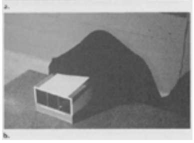


Daylight analysis

Scale modeling and measurements





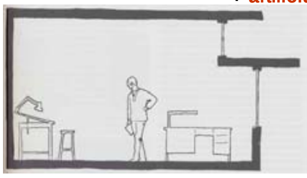


Daylight analysis

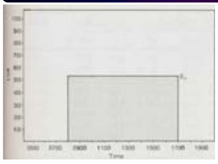
Mockup modeling and measurements

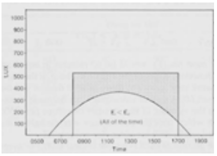
A mockup model (1:1) of a room with daylight apertures is made and measurements are done under real or artificial sky. Properties:

+ very accurate results,
+ model can include furniture ... and is so very realistic,
+ artificial lighting can be included,
+ model can be shown to customers,
- adequate space for modeling is needed,
- measurement instruments are needed,
- could be very time and money consuming.



Daylight/Electric lighting integration





It is practically impossible to provide adequate illuminance (according to standards) through the year in an interior only by daylighting.

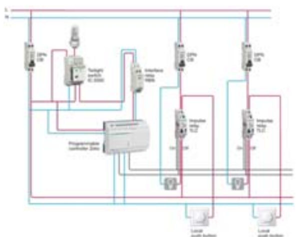
That is why artificial daylighting needs to be combined with artificial lighting.

Daylight/Electric lighting integration

If there is not enough daylight artificial lighting needs to be switch on.

This is usually done manually but can also be automated:

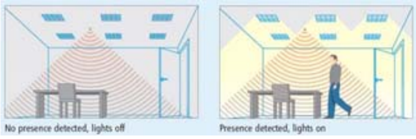
- automated on/off switching,
- automated step switching,
- automated linear continuous dimming.



Daylight/Electric lighting integration

Automated switching of artificial lighting have many advantages:

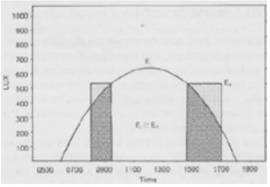
- always provides needed illuminance on the task area,
- saves electrical energy for lighting,
- can be upgraded with occupancy control for additional energy savings.



Daylight/Electric lighting integration

In the part of the day, when daylight provides needed illuminance, artificial lighting can be switched off.

During other parts of the day at least part of the artificial lighting needs to be switched on.



Saved electrical energy depends on switching strategy.

Daylight/Electric lighting integration

On/off switching strategy:

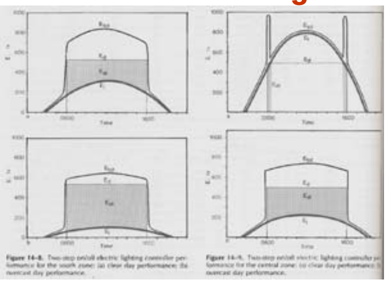
all luminaires in room are switched on or off together;

interior illuminance will be larger than needed most of the time daylight is present;

simplest control and smallest energy savings.

Daylight/Electric lighting integration

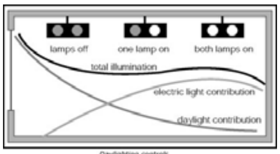
On/off switching strategy:



Daylight/Electric lighting integration

Stepped switching strategy:

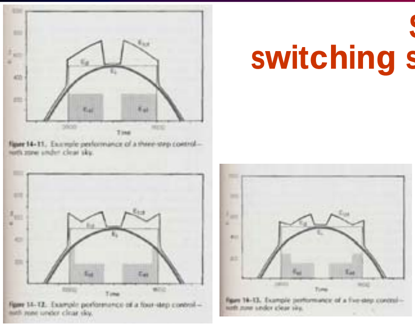
- individual luminaires or groups of luminaires can be switched on and off,
- luminaires in one group are in line parallel to daylight aperture,
- control switches on groups (luminaires) according to available daylight,
- illuminance is higher than needed,
- medium savings can be achieved.



Daylighting controls

Daylight/Electric lighting integration

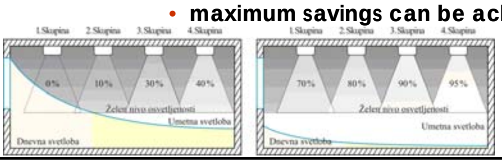
Stepped switching strategy:



Daylight/Electric lighting integration

Continuous dimming strategy:

- luminous flux of individual luminaires or groups of luminaires can be controlled (0-100 %),
- control dimes luminaires (groups) according to available daylight,
- illuminance is as needed,
- maximum savings can be achieved.



Daylight/Electric lighting integration

Continuous dimming strategy:

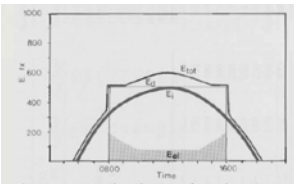


Figure 14-15. Example performance of a simple continuous dimming control—north zone under clear sky.

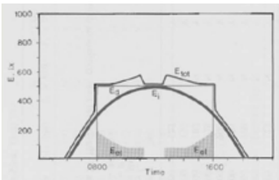
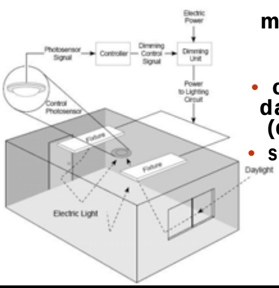


Figure 14-16. Example performance of a continuous dimming plus off control—north zone under clear sky.

Daylight/Electric lighting integration

Needed equipment:



- for automatic control a measuring device is needed to provide data about available daylight;
- controller get the data from daylight sensor and switches (dimes) luminaires (groups);
- special ballasts are needed for dimming;
- daylight sensor can be combined with presence sensor.

Daylight/Electric lighting integration

Integration with EMS:

controlled artificial lighting can be integrated into EMS (Energy Management System) of the building to achieve additional energy savings (due to connection with heating and AC systems ...)

At the end ...

Daylighting has many benefits and is much more than just a lighting.

During planning of daylighting a lot of data needs to be considered.

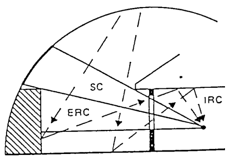
As daylighting is never enough it should carefully be integrated with artificial lighting.

... and now:

Questions?

Daylight factor (DF) method

$$DF = \frac{E_i}{E_e} \cdot 100\%$$



$$DF = (SC + ERC + IRC) \cdot \tau \cdot k_1 \cdot k_2$$

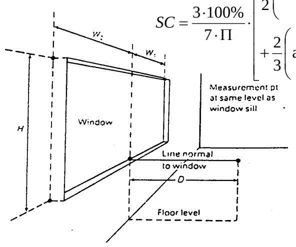
SC .. sky component
ERC .. externally reflected component
IRC .. internally reflected component
τ.. transmittance of glazing material (0,85)
k_1 .. frame factor
k_2 .. “dust” factor (0,9)

$$k_1 = 1 - \frac{A_{frame}}{A_{aperture}}$$

Daylight factor (DF) method

Sky component in a given point

$$SC = \frac{3 \cdot 100\%}{7 \cdot \Pi} \cdot \left[\frac{1}{2}\left(\arctan q - \frac{1}{\sqrt{p^2+1}} \cdot \arctan \frac{q}{\sqrt{p^2+1}} \right) + \frac{2}{3}\left(\arctan \frac{p \cdot q}{\sqrt{p^2+q^2+1}} - \frac{p \cdot q}{\sqrt{p^2+q^2+1}} \cdot \frac{1}{p^2+1} \right) \right]$$



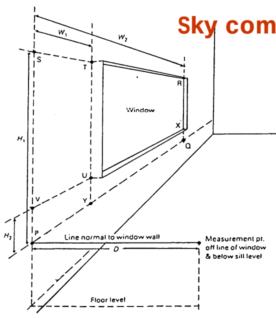
$$p = \frac{H}{D}$$

$$q = \frac{W_1}{D}$$

SC1: H/D & W_1/D
SC2: H/D & W_2/D
SC=SC1+SC2
It should be calculated just for the part of the aperture where sky is visible

Daylight factor (DF) method

Sky component in a given point



WINDOW

SC1 -SRQP : H1/D, W2/D
SC2 -STYP : H1/D, W1/D
SC3 -VXQP : H2/D, W2/D
SC4 -VUYP : H2/D, W1/D

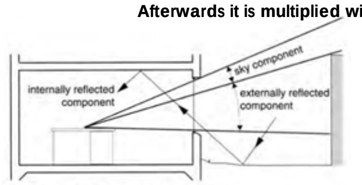
SC = SC1 - SC2 - SC3 + SC4

Daylight factor (DF) method

Externally reflected component in a given point

ERC is calculated in a same way as SC but just for the part of aperture where outside obstacle is seen.

Afterwards it is multiplied with the reflection factor of obstacle (usually 0,2).



Daylight factor (DF) method

Internally reflected component (average)

$$IRC = \frac{A_g}{A_r} \cdot \frac{1}{1-R_r} \cdot \left[C_1 \cdot R_l + C_2 \cdot R_u\right] \cdot 100\%$$

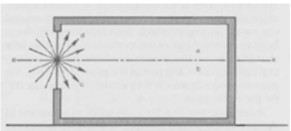


Figure 9–5. Example room for *IRC* calculations: (a) upper zone, receiving light from ground; (b) lower zone, receiving light from sky; (c) light from all parts of the sky; (d) light reflected off the ground plane; (e) midheight of the aperture.

A_g .. area of the glazing
A_r .. area of the room
R_r .. average reflectivity of the room
R_l .. average reflectivity of the lower part of the room
R_u .. average reflectivity of the upper part of the room

$$R_r = \frac{A_1 \cdot \rho_1 + A_2 \cdot \rho_2 + A_3 \cdot \rho_3 + ... + A_n \cdot \rho_n}{A_1 + A_2 + A_3 + ... + A_n}$$

Daylight factor (DF) method

Internally reflected component (average)

Angle of Obstruction* (deg)	C_1
no obstruction	39
10	35
20	31
30	25
40	20
50	14
60	10
70	7
80	5

Average Ground Reflectivity (%)	C_2
10	5
20	10
30	15
40	20
50	25
60	30
70	35
80	40