ULRIKE BRANDI
CHRISTOPH GEISSMAR-BRANDI

LIGHTBOOK

THE PRACTICE OF LIGHTING DESIGN

Birkhäuser – Publishers for Architecture
Basel · Boston · Berlin

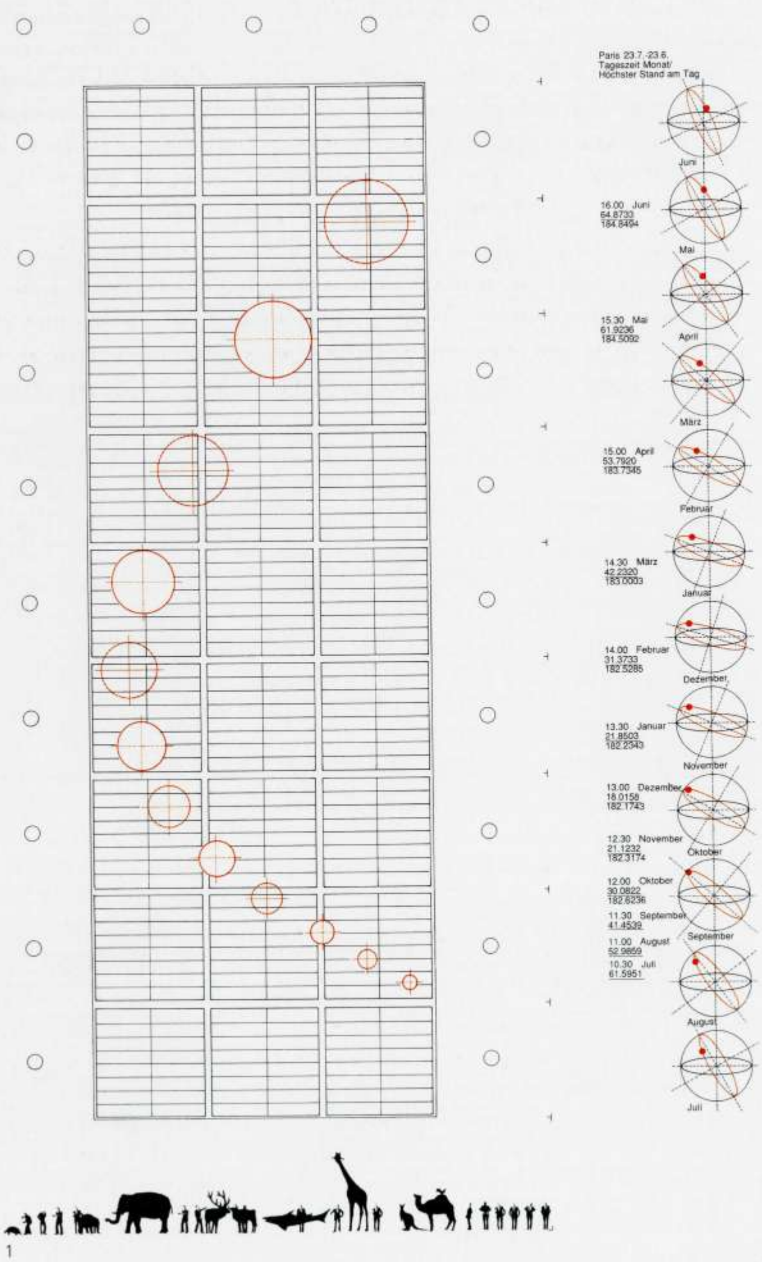
2 THE FUNDAMENTALS

DESIGNING WITH LIGHT

1 **Originally, the movement of the sun was supposed to be reproduced on the glass ceiling of the *Galerie de l'Evolution* in Paris through a round opening in the roof.**

Daylight

The common view reduces "lighting design" to "artificial lighting design". There are historical reasons for this. Up until the first half of the twentieth century, the architect as universalist was responsible for lighting. With his façades, roofs and floor plans, he planned the daylight conditions in his buildings, subsequently adding artificial lighting. At first, the means of artificial lighting employed were various types of incandescent bulbs. Already beginning around 1925, however, the nowadays ubiquitous fluorescent lamps made their first appearance.
With the progress in lamp technology and the wide selection of available lamp types, lighting design became the purview of specialized engineers, whose task it was to devise technically sophisticated and economical lighting solutions. Thus, the planning of artificial lighting fell to electrical engineers, while the daylight conditions continued to be determined by the architects. In twentieth century architecture, new materials such as concrete, steel and glass gave rise to new forms and uses of buildings. Natural light has always played an important role in the design of buildings. In the last hundred years, however, architecture has taken a real turn towards light as a determining element of designs. And it makes no difference in this regard whether architects chose "closed" structural designs or had buildings erected with the transparency of steel and glass.



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The buildings always display a reverence for natural light such that in the twentieth century one could also speak of a new architecture of light. In the meantime, daylight planning too has become a very specialized field. For about the last 20 years, the use of daylight has been gaining further prominence on the side of engineering. For the purpose of energy conservation, engineers are looking for ways of utilizing as much daylight as possible for illumination while reducing the negative effect of increased daylight incidence in buildings, that is, the accompanying heat irradiation. This new coupling of daylight planning with air-conditioning technology has a promising future in which, even architecturally speaking, many issues still need to be resolved.

Characteristics of Sunlight

In addition to the ecological and economic advantages of daylight in interior spaces, there are the artistic advantages and the positive effects on the physical and psychological well-being of people. There are no substitutes for the qualities of daylight. Hence, the question regarding the daylight conditions in a given space (indoors and outdoors) should be considered at the beginning of any artificial lighting design. An initial answer is derived from the orientation of the building, from its location (degrees of latitude and longitude) and from the environment of the building (a possible blocking of light through surrounding buildings). Needs vary according to the building's geographical location: In the north, where sun, light and heat are scarce, an extensive utilization of light is desirable. The nearer one draws to the equator the more light there is and the more closed off the buildings become.

As a simple first consideration, it is helpful to establish the extreme insolation at noontime and to take all seasons into account. The times of sunrise and sunset also need to be considered.

In addition to the positions of the sun, various weather situations must be taken into account: glaring sun, mucky weather, fog, the redness of the sky at sunset, brilliant fall weather, thunderstorms, rain and snow. It is desirable that daylight enters the building in such manifold ways that it continually affects the atmosphere inside the building.

Sometimes it will be necessary to block the rays of the sun, while in other cases daylight will have to be supplemented with artificial light. It is precisely this variation which affects the well-being of people in a room. For years, experts sought to determine and guarantee by means of standards the ergonomically "correct" light. Especially in office spaces, the result

Sunrise and Sunset in Central European Time

Date	January	February	March	April	May	June
1st	8:27 am/4:25 pm*	8:00 am/5:12 pm	7:07 am/6:12 pm	6:58 am/7:55 pm	5:55 am/8:45 pm	5:11 am/9:29 pm
15th	8:20 am/4:43 pm	7:36 am/5:38 pm	6:36 am/6:27 pm	6:27 am/8:18 pm	5:31 am/9:07 pm	5:05 am/9:40 pm

	July	August	September	October	November	December
1st	5:10 am/9:41 pm	5:46 am/9:09 pm	6:35 am/8:08 pm	7:22 am/7:00 pm	7:15 am/4:56 pm	8:04 am/4:17 pm
15th	5:23 am/9:32 pm	6:08 am/8:44 pm	6:57 am/7:37 pm	7:46 am/6:29 pm	7:39 am/4:33 pm	8:20 am/4:14 pm

*Sunrise/Sunset

2 Deep reveals painted in bright colors reflect light from outside into interior spaces.

3 On a much smaller scale this also occurs with window bars.

4 The dome of the Pantheon in Rome allows the various types of daylight to enter into the building.

5 The light appears as a narrow cone in the hazy air, models the ceiling panels ...

6 ... and migrates as a contoured circle across the walls.

7 Water surfaces create moving light reflections on the ceilings in neighboring houses.

8 The light shelf protects the area of the room near the window against excessive sunlight and directs this light against the ceiling in the inner recesses of the room.

9 Heliostats are reflectors which follow the sun while transmitting its light in a uniform direction, in this case an inner courtyard.

10 Light is filtered by thin straw mats. Direct sunlight creates sharp shadows.

11 In the interior of the Hongkong-Shanghai Bank, the movable mirrors direct sunlight onto the public square below the building.

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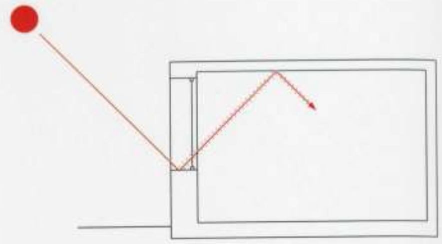

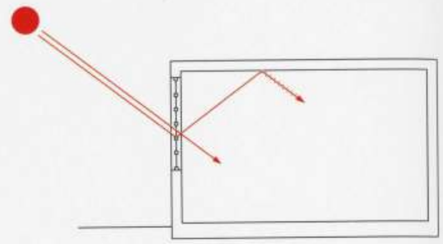

was a monotone uniformity of illuminance and a reduction of contrast and reflection. With a little exaggeration, one could say that this approach regarded every window as a nuisance rather than a positive quality. While the standards continue to exist, they are now no longer defined as the sole objective of lighting design. Rather, the aim is now to imitate qualities of daylight in artificial light. Even in terms of quantity, daylight is far superior to artificial light: outdoors, the prevailing illuminance on sunny days measures between 10,000 and 100,000 lux. By contrast, the German DIN standard prescribes 500 lux for office lighting. A further feature affecting the human organism is the spectral composition of light, which, as we know from admiring the steel blue sky during the day and the red sky at sunrise and sunset, can change dramatically. There are traditional, sometimes simple yet effective, means of controlling and directing daylight. Besides, there are the technical and often very sophisticated systems developed over the last 20 years.

Traditional and Simple Daylight Systems

The Pantheon in Rome is a famous example of a clever use of daylight through a simple opening positioned in the right place. Simple shutters which, with the appropriate slats, block just the right amount of light are effective means of directing light, as are wide eaves, pergolas and trees. Some of these devices are adjustable (shutters) and can be used

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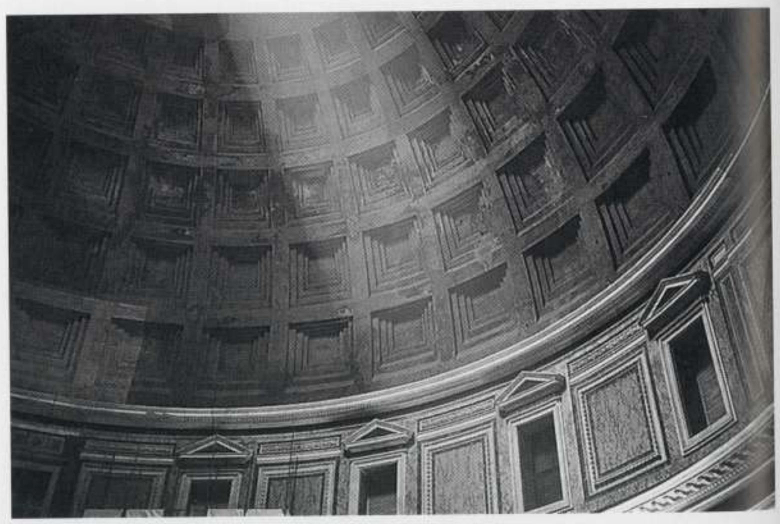

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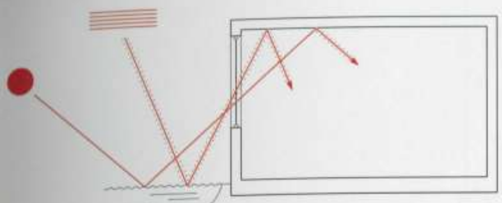

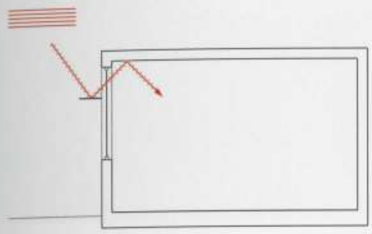

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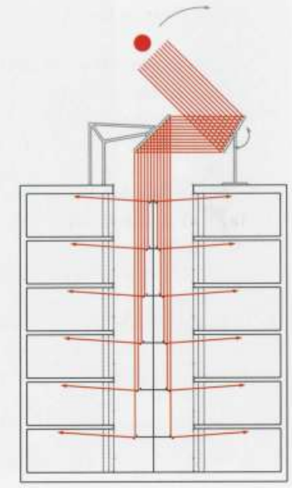
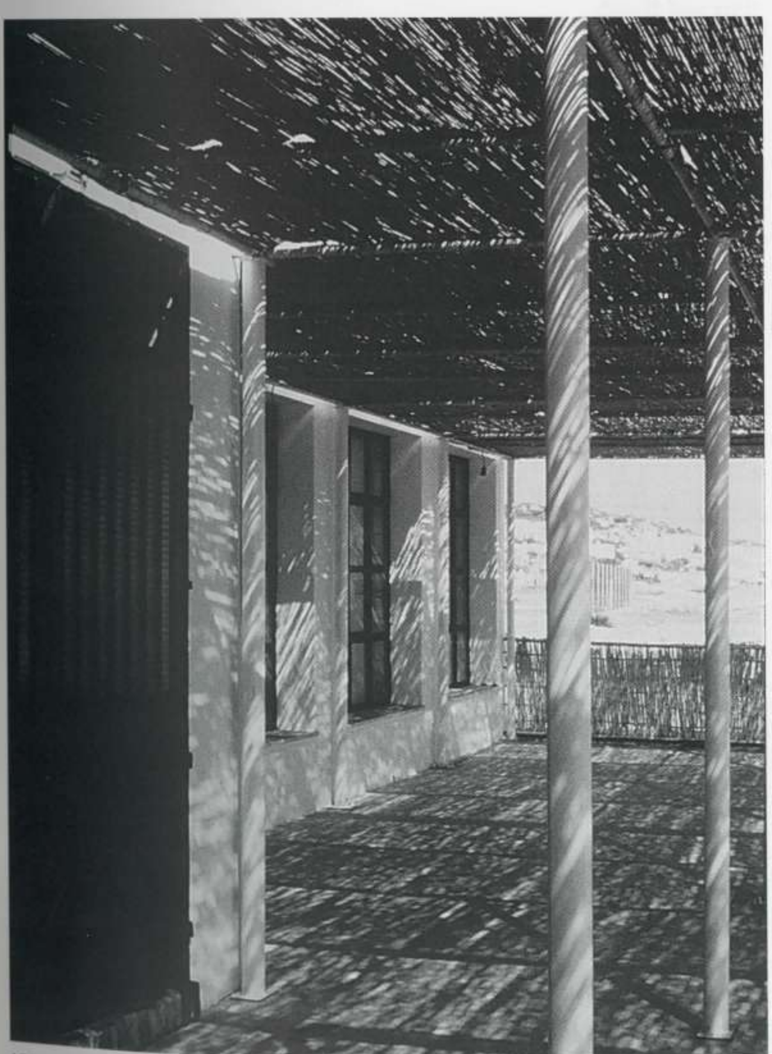


in accordance with the time of day, some change with the seasons (plant-covered pergolas), allowing only a small amount of light to pass through in the summer and a large amount in winter. Deep white-washed window reveals direct daylight far into the room. Even the bars on old windows direct some light against the ceiling of a room, making such windows, in spite of their comparatively smaller glass surface area, hardly inferior to windows with large glass surfaces, as far as the utilization of daylight is concerned. A body of water along-side a building is also an ingenious way of reflecting daylight into the interior.

The "lightshelf" too reflects daylight against the ceiling of a room. It is mounted onto the façade outside in the upper third portion of the window and simultaneously protects the area close to the window against exposure to direct sunlight.

Fundamentally, one can distinguish systems and principles of directing daylight according to whether they are used in the area of the façades/ windows or the roofs/skylights of buildings. While some systems use direct sunlight or the diffuse light of the sky, others shade and shield against glare.



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12 The heliostat with asymmetric optics directs sunlight into the inner recesses of rooms.

13 In contrast with other heliostats, this device only rotates around a fixed axis in the course of a day. Its incline depends on the time of year and the degree of latitude of the location.

14 Blinds for the direction of light block direct sunlight and redirect certain angles of elevation.

15 Various positions of a pivoted blind.

16 Variously shaped blinds in the space in between window panes and on the exterior.

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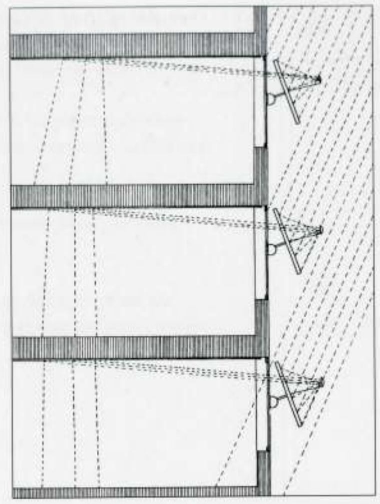

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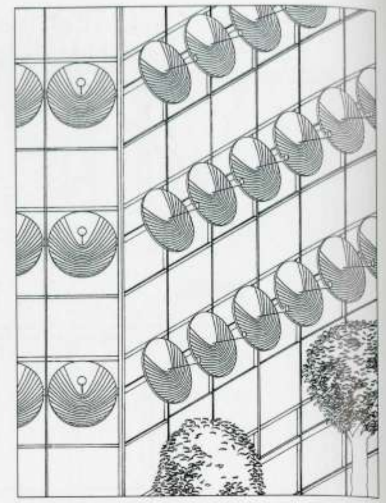


Movable and Fixed Systems

Protective Glass Against Solar Radiation

In the 1970s, coated glass began to be used for filtering out thermal radiation in the infrared part of the sunlight spectrum. Nowadays, there are many different varieties of protective glass:

- strongly shielding varieties of glass which appear like mirrors from the outside can have an unpleasant blinding effect on the surroundings; especially during bad weather, the interior is quite dark.
- less strongly shielding varieties which are more like clear glass but are also less effective. These types of glass are frequently used in skylights and glass-covered atriums.
- glass coated with durable stove-enamels. Partial covering of glass is possible. Fine grids on glass-covered atriums are hardly noticeable from below and scarcely reduce the translucence of the glass.

Heliostats

Heliostats are mirrors for "pursuing" the sun and channeling its rays in a uniform direction. Thus, the light of the sun can be transmitted, e.g. from the roof of a building through an inner courtyard into the lower stories. Conventional heliostats must be guided in two directions, since in travelling from east to west, the sun also rises and sets. The mechanism of heliostats requires maintenance and their effect depends on the size of the mirror capturing the light. The heliostat depicted is an asymmetric parabolic reflector that is partitioned into segments and embedded in a dual pane of glass. Over the course of a day, it must only turn about its own axis; thus, its mechanism is simpler than that of conventional heliostats.

Slats and Blinds

In principle, horizontal slats and blinds offer very precise control. Sunlight may be blocked completely or directed against the ceiling in order to utilize it in the inner reaches of the room. There are a variety of coatings avail-

17 The parabolic slanted lamellae of the heliostat focus the rays onto the small concave mirror.

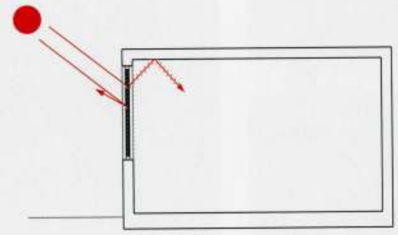
18 The effects of weather limit the use of exterior systems. Slats installed in the space in between dual window panes are protected against dirt.

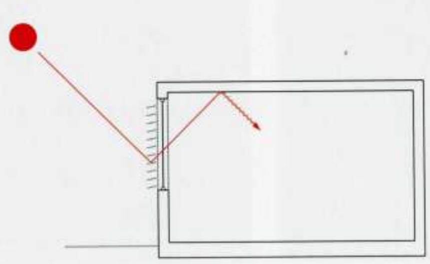
19 They can be directed and drawn up.

20 Light-directing glass cut horizontally: it utilizes the total reflection at the transition between media of various densities. Detail of light-directing glass cut vertically: it redirects direct sunlight but allows the diffuse sky radiation to pass through.

21 Light-directing glass at roof level also reacts effectively to the changing elevations of the sun.

22 In a sectional view, mirror profiles are spatial, their upper and lower ends reflecting light effectively towards each other.





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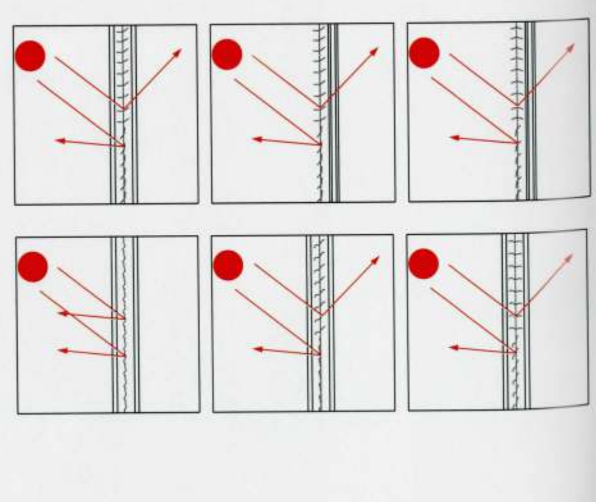

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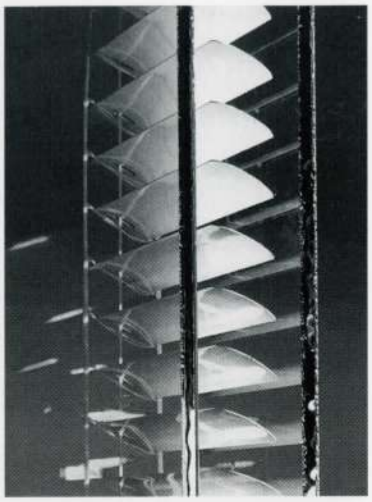


able. Exterior blinds, however, are susceptible to wind, while interior blinds do not protect well against thermal radiation. Blinds may be installed inside a dual pane window, where they do not get dirty. Slats on the façade – made of anodized aluminum or glass – may be of larger size with various profiles. The curvature of the reflective surface spreads out the light.

Light-Directing Glass

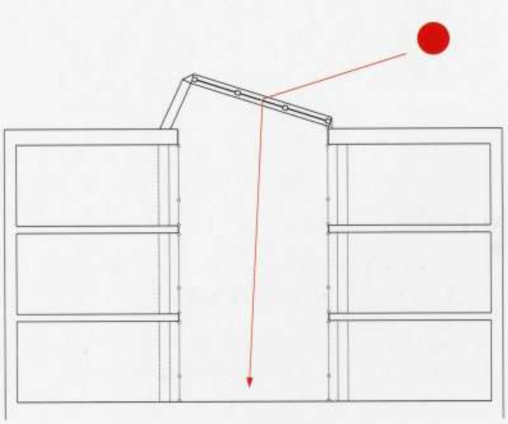
Several systems utilize the interstice of dual panes of glass in order to accommodate minimized optical objects and profiles. Light-directing glass is filled with acrylic profiles which throw light onto the ceiling of a room by means of a total reflection within the acrylic substance. An additional prismatic profiling of the inner window pane helps better distribute the light entering the room at an angle.

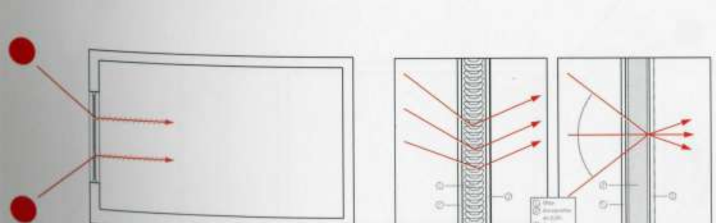
Mirror Profiles in Dual Panes of Glass

The mirror profiles of the "Köster sheets" are likewise contained within dual panes of glass. The variously shaped parabolic mirror surfaces are arranged in such a way that they allow the horizontal sunlight in winter to pass through, while blocking the steep radiation in the hot summer season. The profiles are rigid and are designed differently for the various directions and types of installation. They are used in the façade and roof areas.

Prism Sheets in Dual Panes of Glass

Prism sheets also make use of the total reflection in acrylic glass: while direct sunlight is reflected back to the outside or directed against the ceiling of the room, diffuse light of the sky can pass through the material. Prism sheets are used in windows (even hooked-out with mirror) and in skylights. Up to three layers with various prism geometries and partial mirror vaporization of the prism flanks may be combined, in order to ensure sun protection, glare protection and redirection for the various positions of the sun. Prism slats have a simpler construction. Like Venetian blinds, they are adjustable and are mounted either horizontally or vertically. In combination with light-conducting mirror blinds, prism





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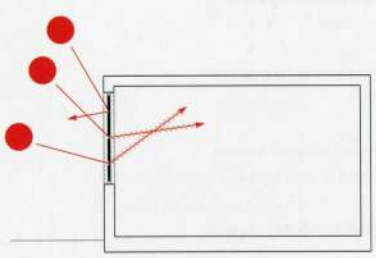

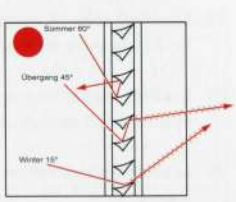

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23 Hooked-out prism panels collect a larger amount of zenith light than prism panels vertically integrated into the window.

24 Prism panels in combination with interior blinds.

25 Laser cut panels react differently to the sun in summer and in winter.

26 Minute spaces as slits in acrylic glass create horizontal reflective surfaces, which reflect light coming in vertically, while allowing light coming in horizontally angles to pass through.

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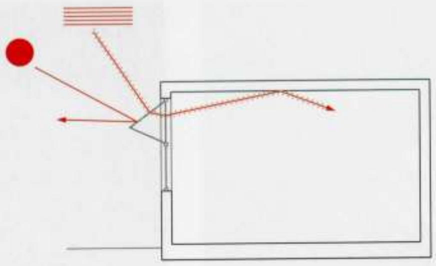

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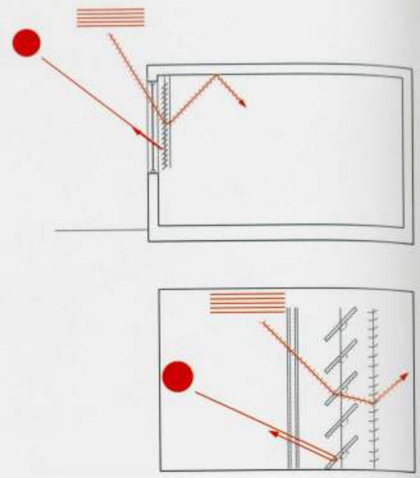


slats permit the utilization of daylight especially in the inner reaches of rooms.

Laser Cut Panels (LCP)

Laser Cut Panels are used as a fixed system within dual panes of glass in skylights or as swivel elements on the front of a façade. They redirect sunlight at the surface of small incisions created by means of lasers in a sheet of acrylic glass. Although they hardly obstruct the view, they must be installed above windows, since blinding effects can occur on their inside.

Holographic-Optical Elements (HOE)

Holographic-optical elements consist of holographic film inserted into multi-layer glass so as to redirect sunlight. The disagreeable separation into the spectral colors occurring in the refraction of light is largely concealed by the slightly scattering quality of the glass. HOE are only effective for limited angular ranges. Hence, a variety of different HOE exposed side-by-side or one above the other are used. Installed in the upper window area in the façade or in the skylight, the elements redirect direct sunlight. In façades facing north, they also direct diffuse light of the sky into rooms as hook-out elements. Their specially designed optics offer sun protection. HOE can bundle sunlight on photo-voltaic surfaces arranged behind them and thereby increase their efficiency by up to 50%.

Mirror Screens and Anidolic Systems

Flat mirror screens inserted into dual panes of glass serve to block direct sunlight in the utilization of the diffuse light of the sky. They open towards the north and reflect the sun entering from the east, south, and west. These screens are found in skylights. Anidolic or non-imaging systems work on a similar principle, although spatially they are constructed differently: they form a wide "chimney of light" which is oriented northwards. The desired light is concentrated, and as a consequence, the required size of the opening is reduced by a third as compared with traditional skylights.

Many of these new systems for the direction of light, sun protection and glare protection may be combined. The redirection of direct sunlight into rooms may lead to surprisingly brilliant effects; of course, only when the

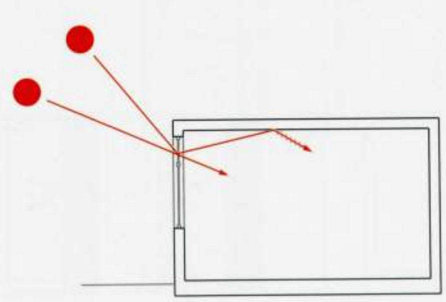
27 Holographic-optical elements redirect light in skylights ...

28 ... or in front of façades. Here they are combined with photo-voltaics.

29 Charming colorful images are visible from below, which hardly affect the transparency.

30 Spatially shaped mirror screens protect interior spaces against direct sunlight. They were used in museums.

31 Anidolic systems reflect light from the north into interior spaces.



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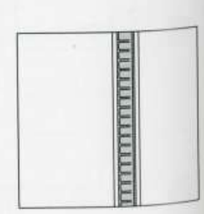

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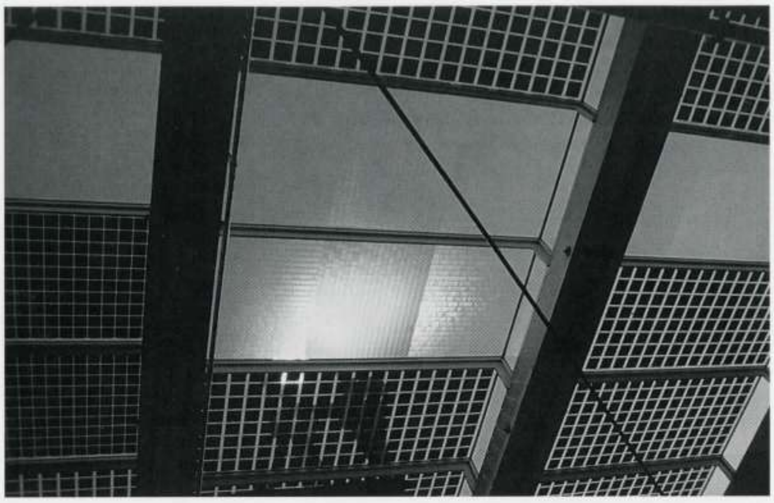
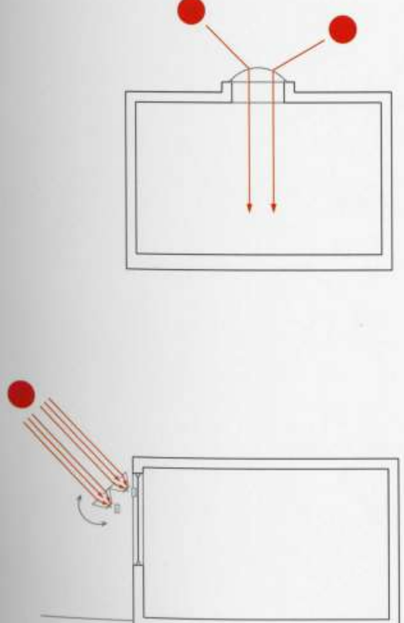


sun is shining. Thermal loads must always be considered in this context. The amount of daylight gained depends on the size and the orientation of the collecting surfaces (the zenith is two thirds brighter than the horizon). Many systems have unwanted side effects such as the separation of white sunlight into its spectral colors. Some redirecting systems impede the view to the outside. For this reason, today, mostly the overhead areas of façades are used for redirecting systems. Some systems form their own distinctive patterns: the streaks of prisms, the squares of individual sheets, the dovetails formed when such sheets are combined are details which do not suit all architectures. Vaulted metal ceiling elements which may be required can spoil the view in interior spaces.

The manufacture of prism sheets, LCP and HOE is technically very sophisticated and hence costly. In some cases, the manufacture of the systems consumes large amounts of energy. This expense must be set off against the energy conserved later, in order to evaluate the total costs of the system. It is difficult to compare the various systems directly, since for a certain task one system will be more practical and effective, while for another building another system will be more suitable. Lighting designers must rely on their experience and their feel for the material. Currently, comparative calculations with computers are possible, but only in a limited and improvised way, since current software has difficulty in dealing with the dynamic situations which must also be considered.

The daylight systems presented here follow promising approaches which require further development. Frequently, simple arrangements are sufficient to create a well thought-out system of daylight direction in interior spaces. A precondition for sound daylight planning is an early involvement of the lighting designer in the design process.



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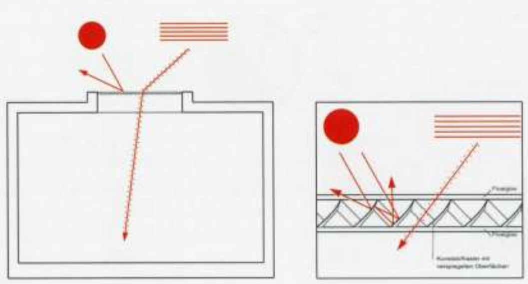

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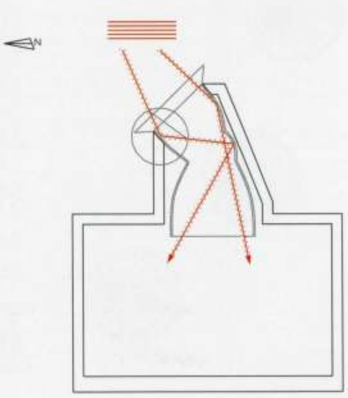

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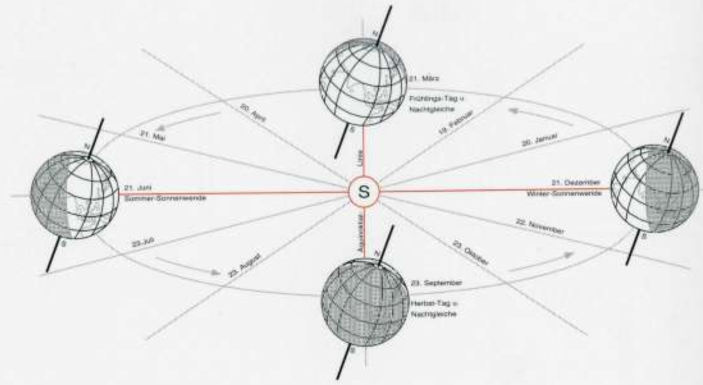
32 **The various seasons are brought about by the changing incline of the earth's axis with respect to its orbit.**

33 **The length of the days and the highest position of the sun varies in the course of the seasons. Designers pay special attention to the solstice in summer and in winter and to the equinox.**

34 **The incline of the earth's axis affects the length of the shadow of every object on earth.**



30 **Determining Daylight Conditions**

Direct Insolation and the Daylight Factor

Daylight in interior spaces changes with the time of day and with the season. Hence, the extreme values are particularly important for making general statements about lighting conditions. For planning purposes, the lighting designer needs to know the degree of latitude of the locale, which determines the angles and duration of solar radiation, the orientation of the building and information regarding adjacent structures which might cast shadows on the building. In addition there are tables listing the probabilities of sunshine in a region.

Direct insolation illustrates how the various positions of the sun arise during the different seasons. The reference point is the city of Hamburg. The earth's axis is tilted towards the plane of the earth's orbit around the sun by 23.5°. Hamburg is located at 53.5° north. The highest position which the sun ever achieves in this city (that is, at 12 noon on June 21) is

$90° + 23.5° - 53.5° = 60°$.

The lowest position at 12 noon on December 21 is

$90° - 23.5° - 53.5° = 13°$

and at the equinox in spring or in fall on March 21 and on September 23, the sun at 12 noon is

$90° - 53.5° = 36.5°$

above the horizon.

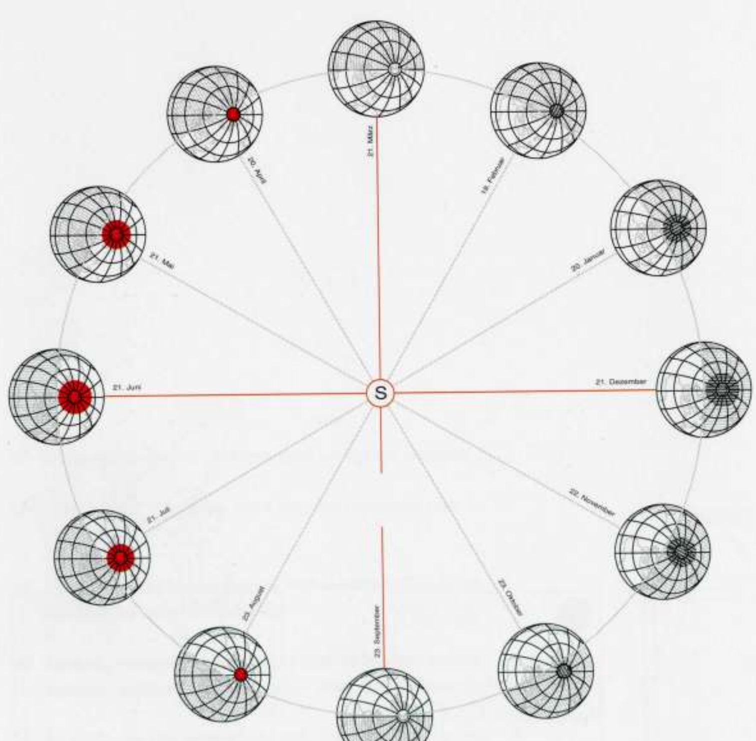
The various angles are explained when one looks at the illustration more closely and considers the earth's surface as the tangent of the sphere. The sun's rays enter the house in Hamburg parallel at an angle γ. This angle forms a right-angled triangle (the right angle is β) with the latitude of Hamburg (53.5°) and the incline of the earth's axis towards the earth's orbit around the sun (= direction of the sun's rays at an angle of 23.5° (α)). The following applies:

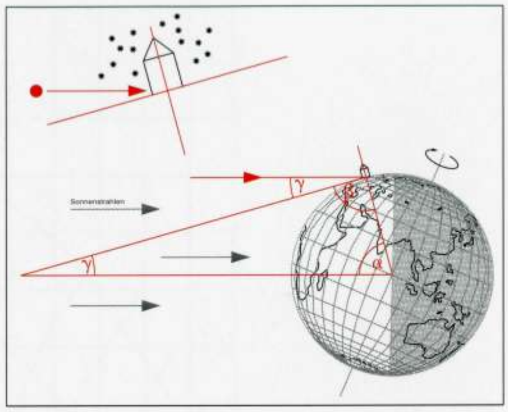
$\alpha + \beta + \gamma = 180°$ and:

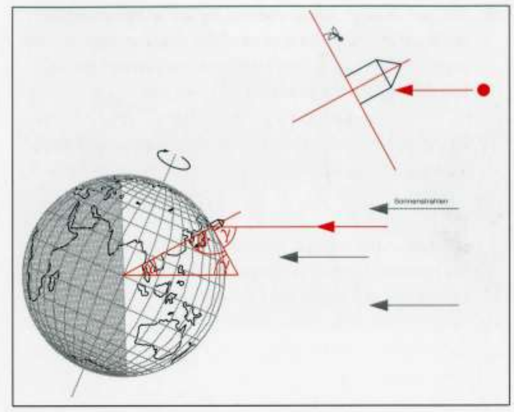
$\alpha = 53.5° + 23.5° = 77°$;

$\beta = 90°$;

$\gamma = 180° - 77° - 90° = 13°$.







This calculation yields the insolation of a building in the northern hemisphere in winter. The next illustration shows the situation in summer. The corresponding formula is:

$\alpha + \beta + \gamma = 180°$;
$\alpha = 53.5° - 23.5° = 30°$;
$\beta = 90°$;
$\gamma = 180° - 30° - 90° = 60°$

This value – the angle between the sun and the horizontal plane – is called the altitude of the sun. Every additional degree of latitude in the northerly direction equals a reduction of the altitude of the sun by one degree, while every degree of latitude in the southerly direction equals an additional degree in the altitude of the sun: the sun's position is higher in the south than in the north. With the help of sun position diagrams, which in each case refer to a certain degree of latitude, the insolation of a building can be drawn into the floor plan and the sectional view. The graph refers to a particular time of day and season. The elongated floor plan of the *Franckesche Stiftungen* in Halle allows for the simultaneous representation of the direct insolation at various times of day and during various seasons.

Daylight Simulations

Models

Models offer another way of gaining insight into the daylight conditions within a building. Required is a light source emitting parallel rays of light in order to simulate the sun. The parabolic mirrors which produce this type of radiation usually have a diameter between 60 and 100 cm. The model must not exceed this size, if it is to be completely insolated. Now the artificial sun can be adjusted in such a way that every desired location and every desired time can be simulated; even entire days can be run through in quick motion. The simulation rooms have an evenly illuminated ceiling so as to take the light of the sky into account. Some universities, luminaire manufacturers, and lighting designers operate daylight simulators.

Altitude of the Sun:

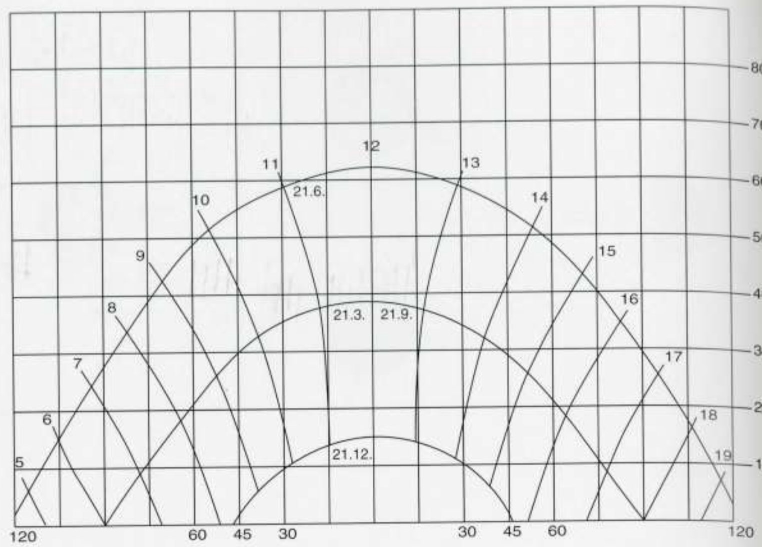
At 12 Noon	Degree of Latitude	21.6.	21.3./23.9.	21.12.
Murmansk				No Sun
Hamburg	53.5° N	60.0°	36.5°	13.0°
London	51.5	62.0	38.5	15.0
Paris	49.0	64.0	40.5	17
Munich	48.0° N	65.5°	42.0°	18.5°
Milan	45.5	68.0	44.5	21.0
New York City, Rome	41.5	72.0	48.5	25.0
Beijing	40.0	73.5	50.0	26.5
Tokyo	36.0	77.5	54.0	30.5
Los Angeles	33.5	80.0	56.5	33.0
The Tropic of Cancer	23.5° N	90.0°	66.5°	43.0°
Hongkong	22	93.5	68.0	44.5
Dakar	15	98.5	75.0	51.5
The Equator	0°	113.5°	90.0°	66.5°
Brisbane	27.5 S	86.0	62.5	39.0
Cape Town	33.5 S	80.0	56.5	33.0

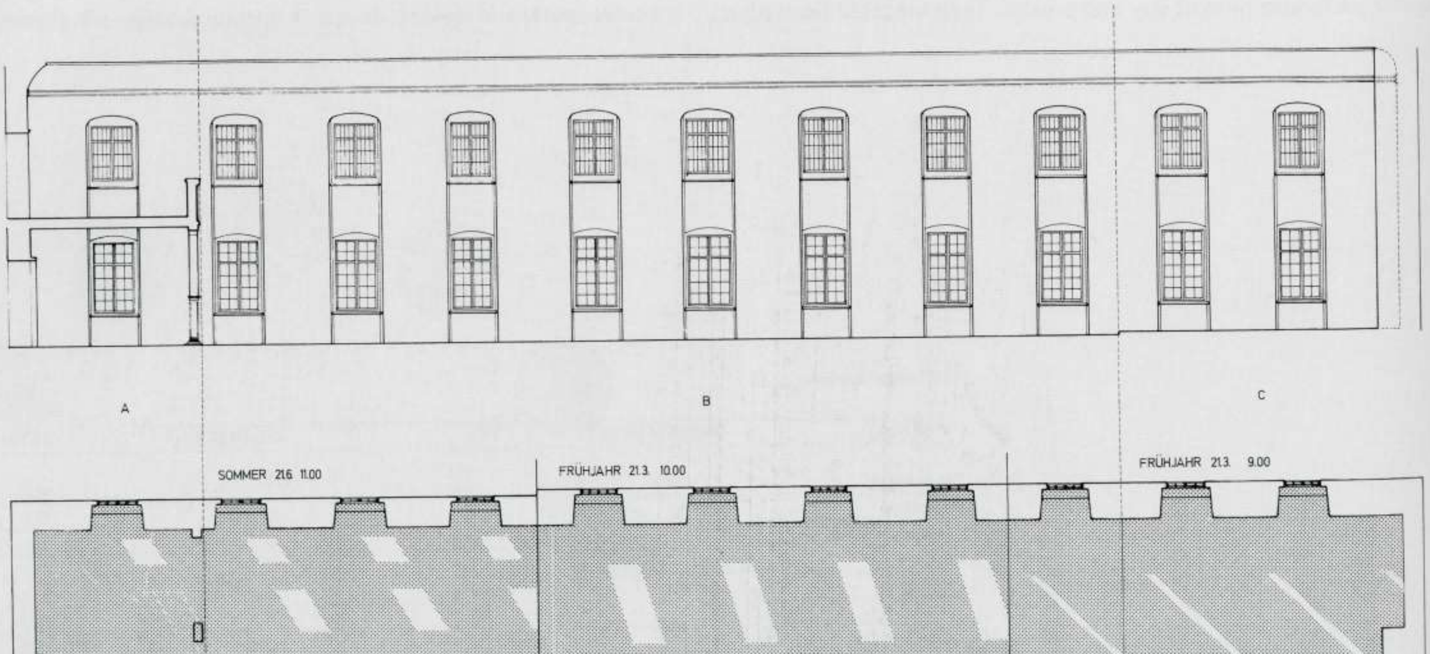
35 **The sun position graph depicts, for all locations at 51.5° northern latitude, the course of the sun from east to west together with its various elevations throughout the day and throughout the seasons.**

36 **The measured values are entered in a shadow construction with the help of the section and the floor plan of a building.**

37 **A model in the daylight simulator (ERCO) indicates the shadows formed in the space. The effect of the diffuse light of the sky can be seen as well.**

35





37

Computer Simulations

A number of programs allow daylight simulation in various degrees of quality. First, this involves the preparation of a three-dimensional model room with the respective window openings and skylights. Second, a location and sky values in accordance with the CIE standard sky (sunny, overcast, etc.) must be attributed to the model. Afterwards, the incidence of light is calculated. Unfortunately, the programs on the market today do not yet permit dynamic calculations. Further, they only provide a very limited simulation of systems for the direction of daylight, shadowing and glare protection. For this reason, the use of the computer programs remains limited.

The Basic Rules of Daylight Planning

Irrespective of how the building is simulated, the planning process is determined by the following rules:

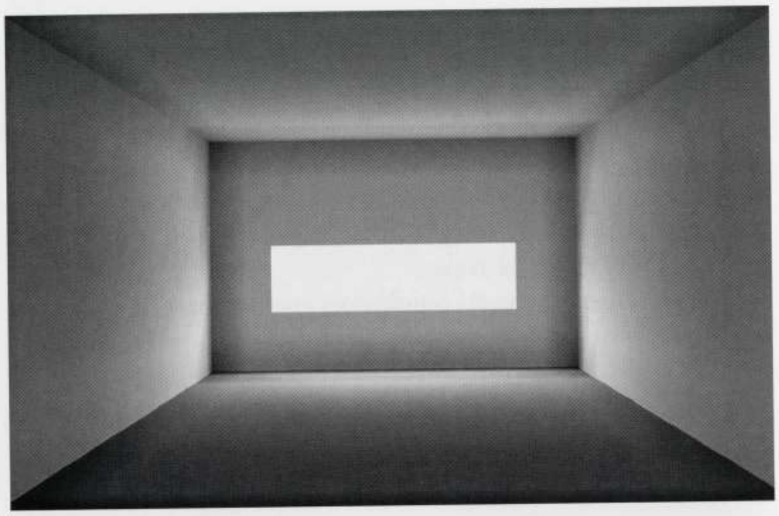
Checklist

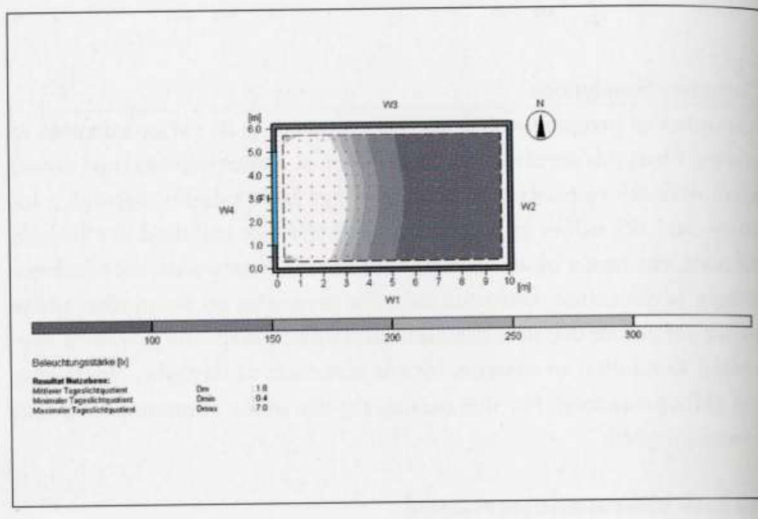
- The more horizontal a daylight opening is, the more effectively will it bring light into the room, since the zenith light of the sky is three times brighter than the light of the horizon.
- The more square a room is, the higher is its room utilization factor and the higher will be the mean daylight factor with the same daylight opening.
- As a rule, a number of smaller daylight openings are more favorable (especially with regard to uniformity) than one large opening.

The following exemplary calculations demonstrate the influence of various parameters such as room proportions, size and position of the daylight opening or window, and the reflectance factors in the room. The sample room is located in Basle (47.5 degrees north). The calculation was done for a medium overcast sky, and the measuring plane for the illuminance is 0.20 m above the floor.

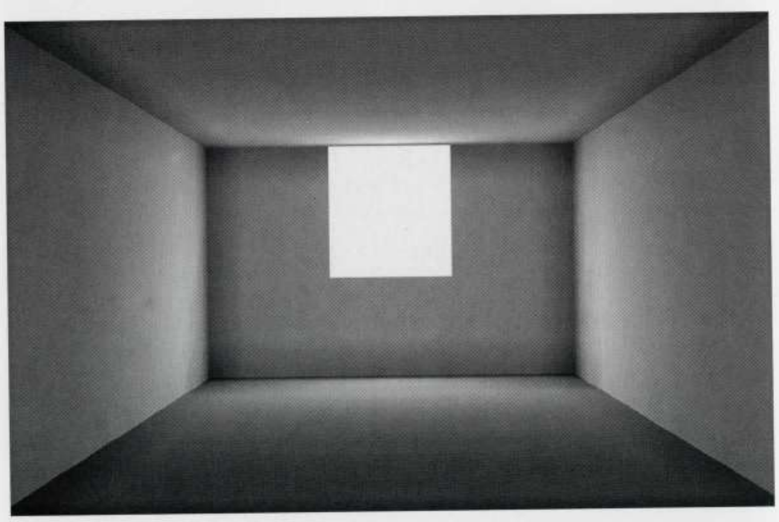
In addition to carrying out the comparisons just mentioned, it is advisable to compare examples from the five tables before planning daylight openings. This should be followed by some project-specific experiments.

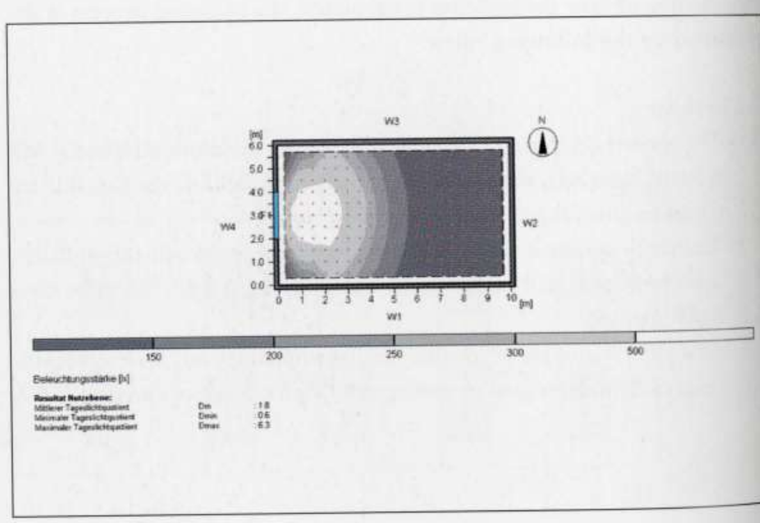
Please note that in the following illustrations, the software for the calculations does not represent the rooms true to scale. The numerical specifications on the floor plans provide the actual measurements. The line of sight into the rooms changes, i.e. the view is not always from south towards north. The first table shows the effect of the position and the distribution of the windows on the daylight factor and the illuminances in the room relative to an exterior illuminance of 10 000 lx. The room measures 6 x 10 m² with a ceiling height of 3.50 m. The window surface area is 4 m² for rooms I – VI. The level of reflection of the walls was changed between Fig. I and Fig. II. In Fig. III and Fig. IV, the windows are at different vertical positions. In Fig. V, four windows are located in one wall, while in Fig. VI, each wall has one window.





I





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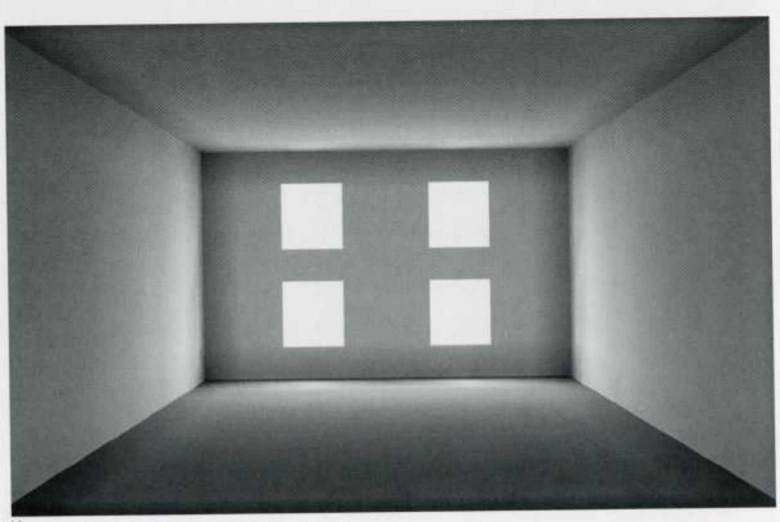
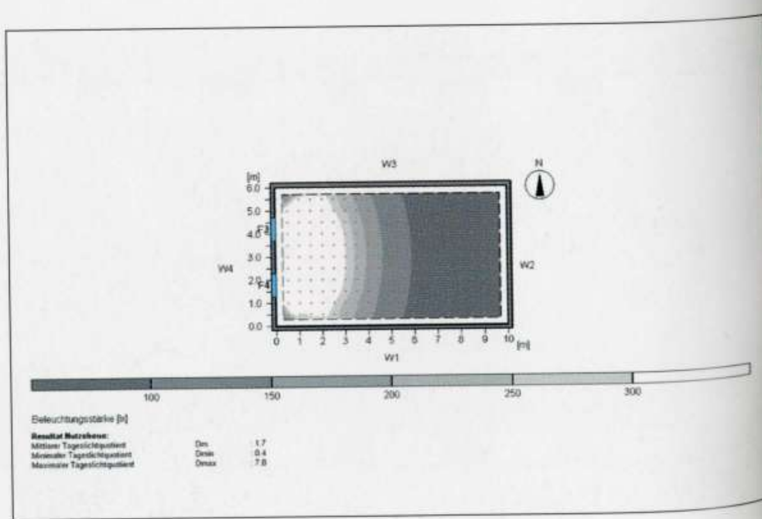
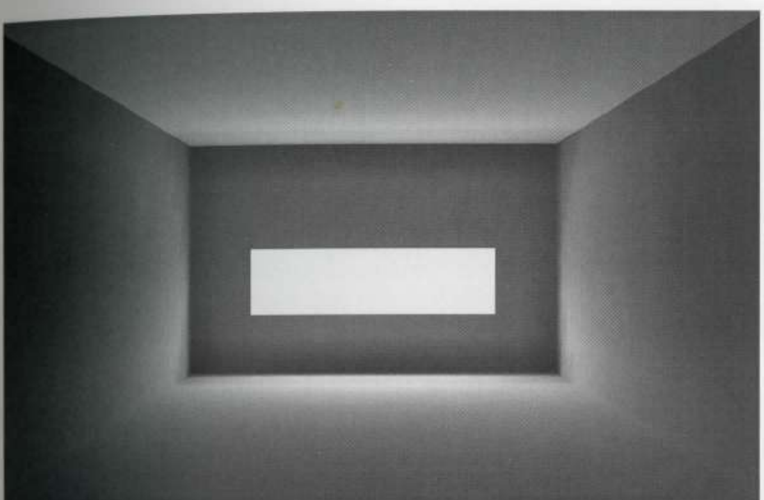
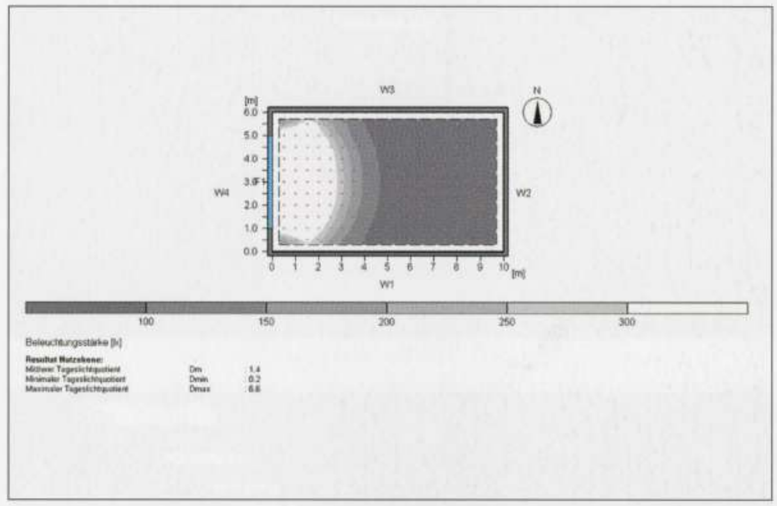


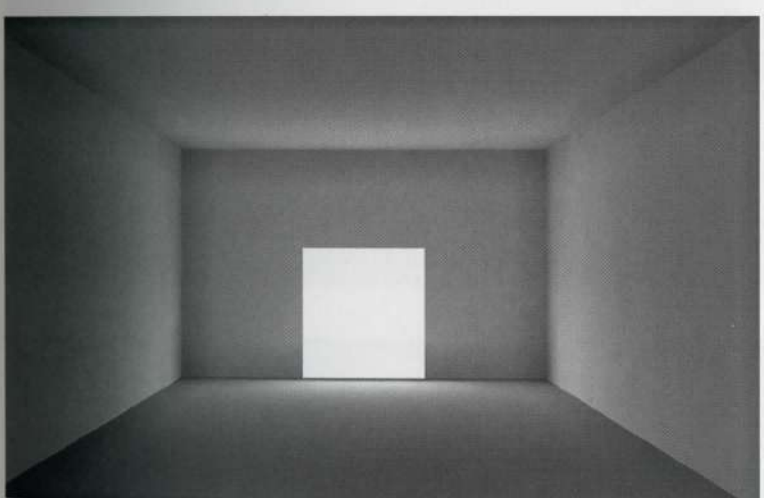


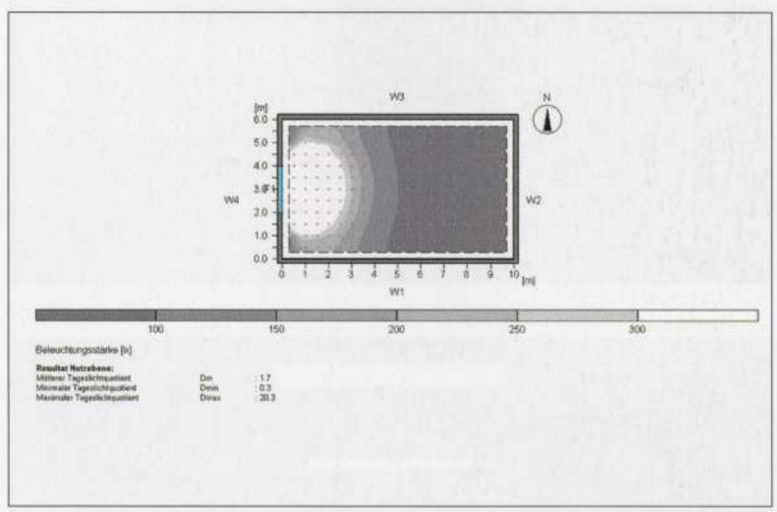
V



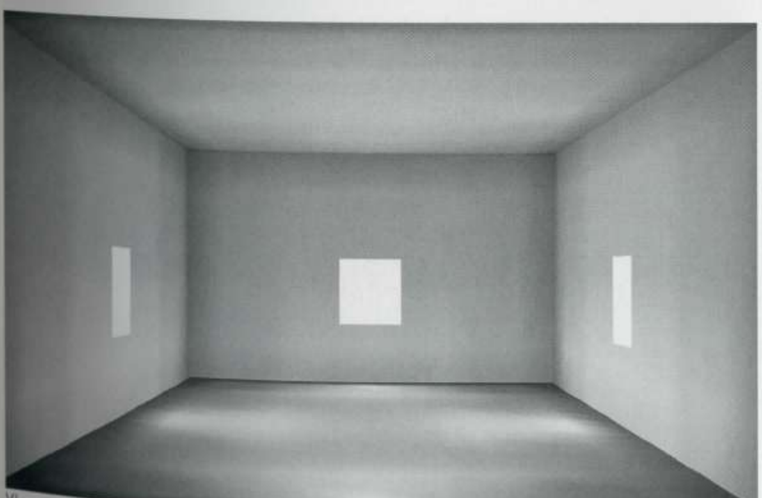

W3
N
[m]
6.0
5.0
4.0
3.0
F4
2.0
1.0
0.0
W4
W2
0 1 2 3 4 5 6 7 8 9 10 [m]
W1
100
150
200
250
300
Beleuchtungsstärke [lx]
Resultat Nutzebene:
Mittlerer Tageslichtquotient Dm : 1.4
Minimaler Tageslichtquotient Dmin : 0.2
Maximaler Tageslichtquotient Dmax : 6.6

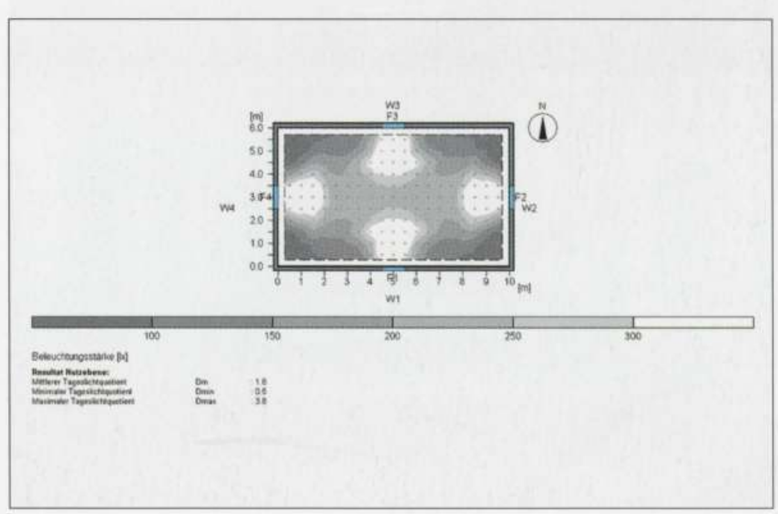
II




W3
N
[m]
6.0
5.0
4.0
3.0
F4
2.0
1.0
0.0
W4
W2
0 1 2 3 4 5 6 7 8 9 10 [m]
W1
100
150
200
250
300
Beleuchtungsstärke [lx]
Resultat Nutzebene:
Mittlerer Tageslichtquotient Dm : 1.7
Minimaler Tageslichtquotient Dmin : 0.3
Maximaler Tageslichtquotient Dmax : 20.3

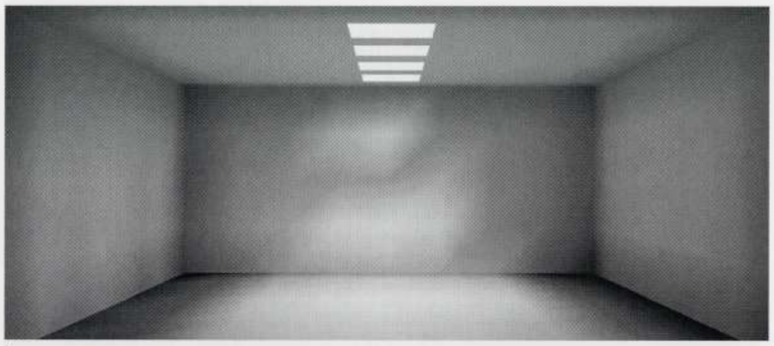
IV



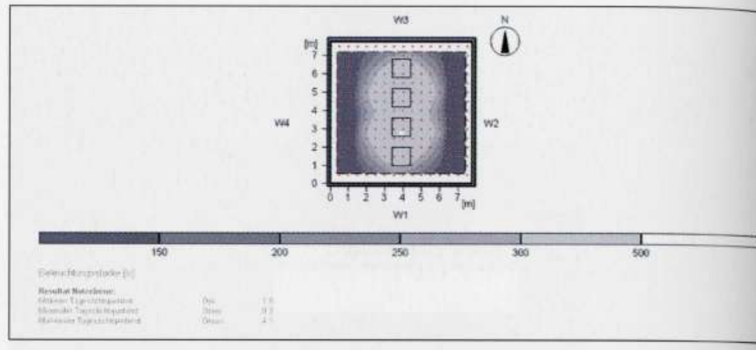

W3
F3
N
[m]
6.0
5.0
4.0
3.0
F4
F2
2.0
1.0
0.0
W4
W2
F1
0 1 2 3 4 5 6 7 8 9 10 [m]
W1
100
150
200
250
300
Beleuchtungsstärke [lx]
Resultat Nutzebene:
Mittlerer Tageslichtquotient Dm : 1.8
Minimaler Tageslichtquotient Dmin : 0.6
Maximaler Tageslichtquotient Dmax : 3.8

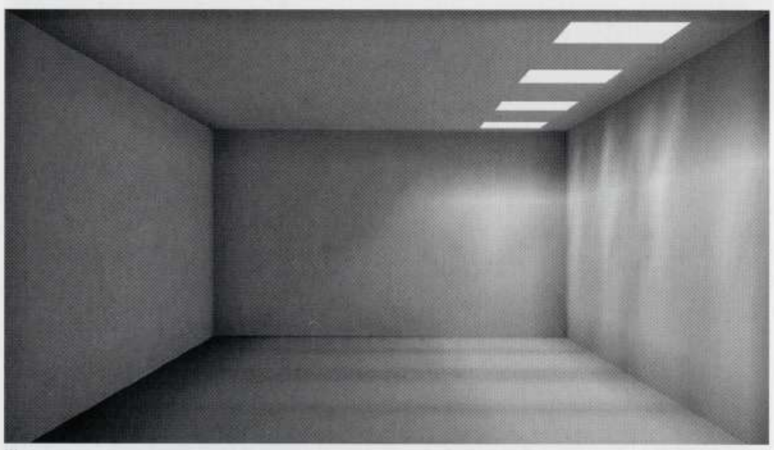
VI

aThe following table shows the influence of room proportions on the daylight factor and the illuminances in the room. All rooms have the same surface area and a ceiling height of 3.50 m. In Fig. I – VI, the total window or skylight surface area is constant at 4 m².
In Fig. I and Fig. II, the room is square (7.75 x 7.75 m²), in Fig. III and Fig. IV it is rectangular (6 x 10 m²) and in Fig. V and VI, it forms a long rectangle (3 x 20 m²).



I





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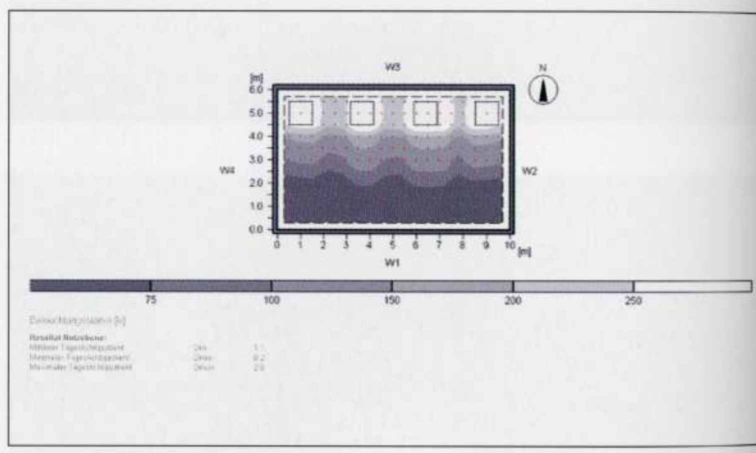

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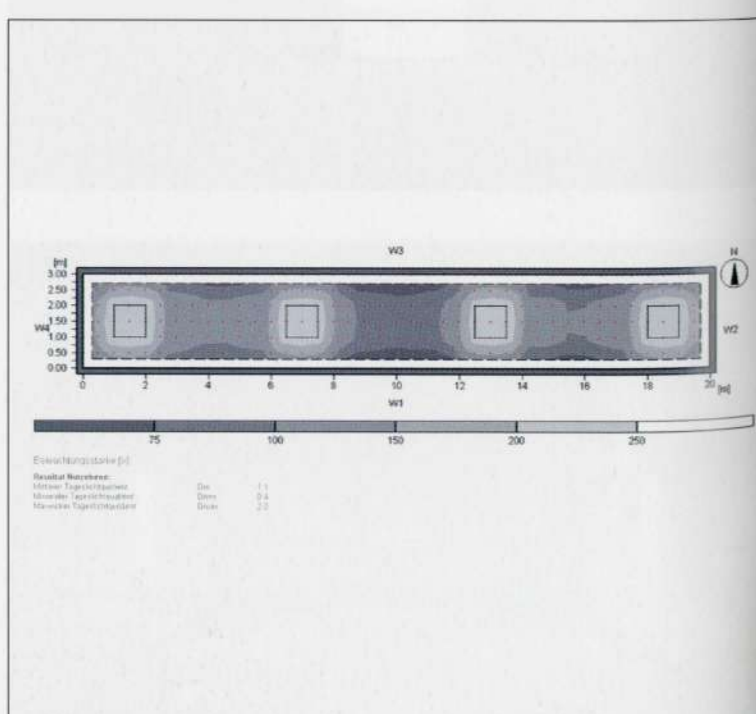
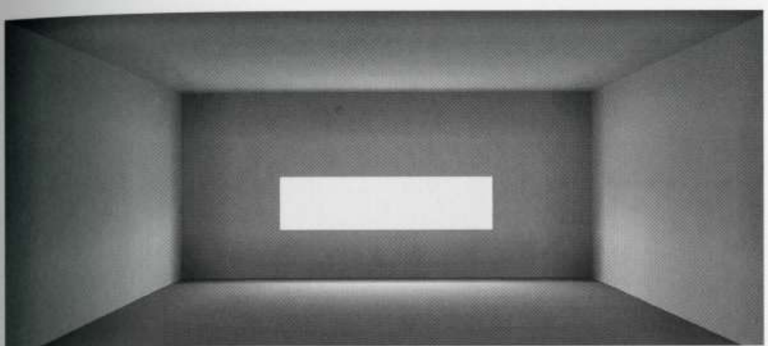
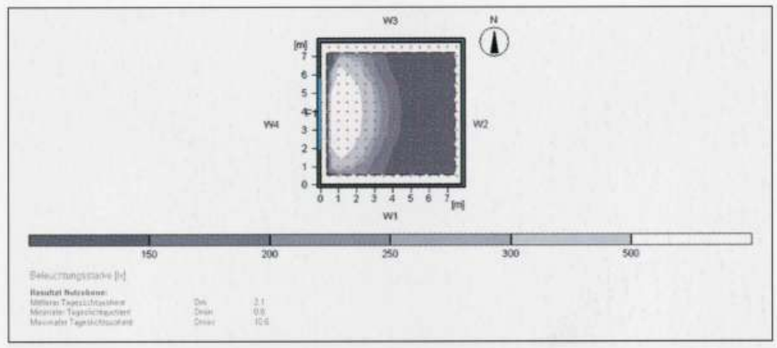
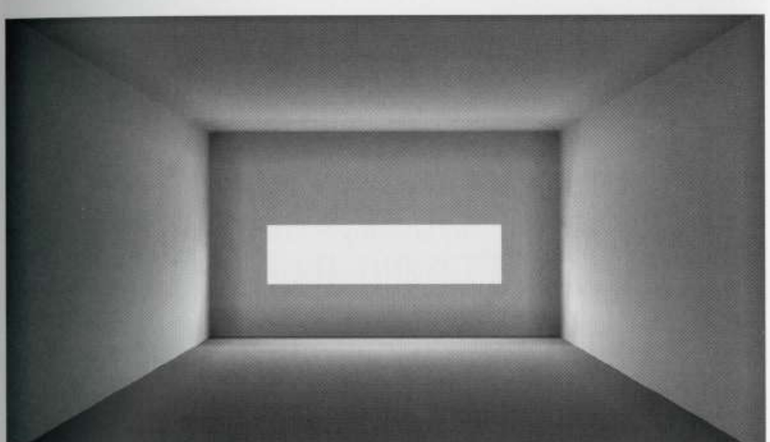


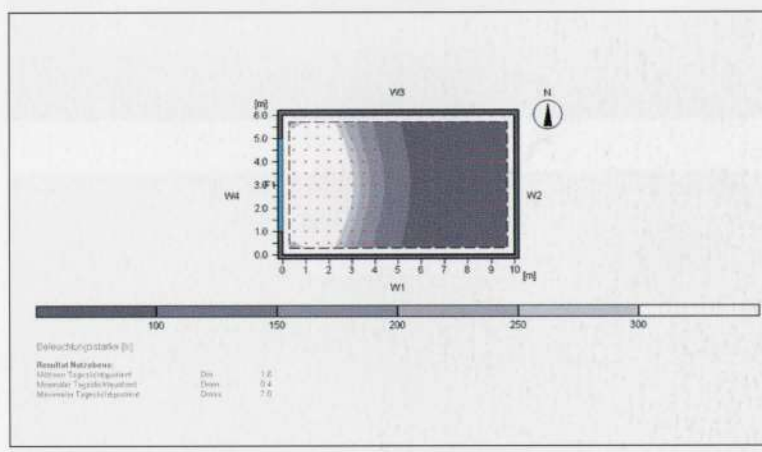


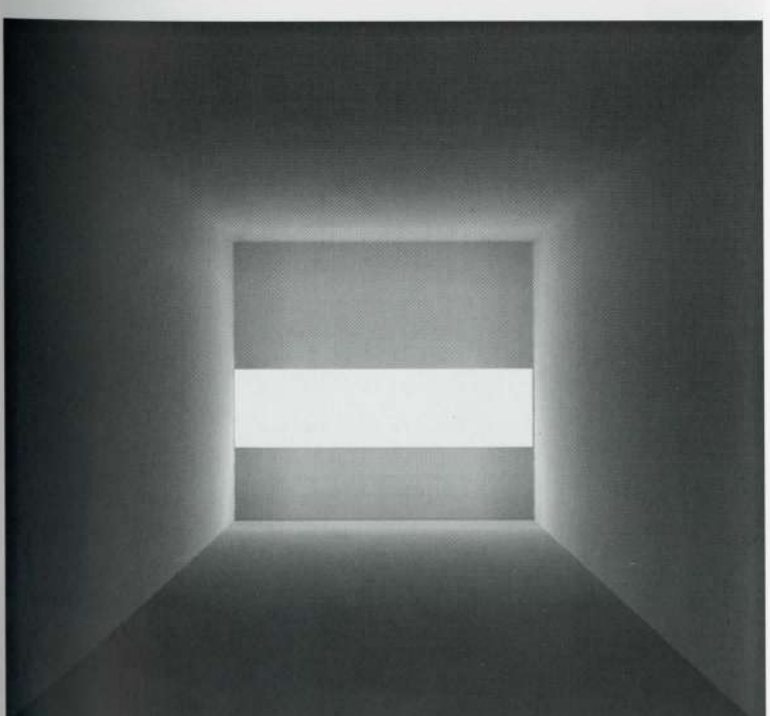
II


W3
N
[m]
7
6
5
4
3
2
1
0
W4
W2
0 1 2 3 4 5 6 7 [m]
W1
150
200
250
300
500

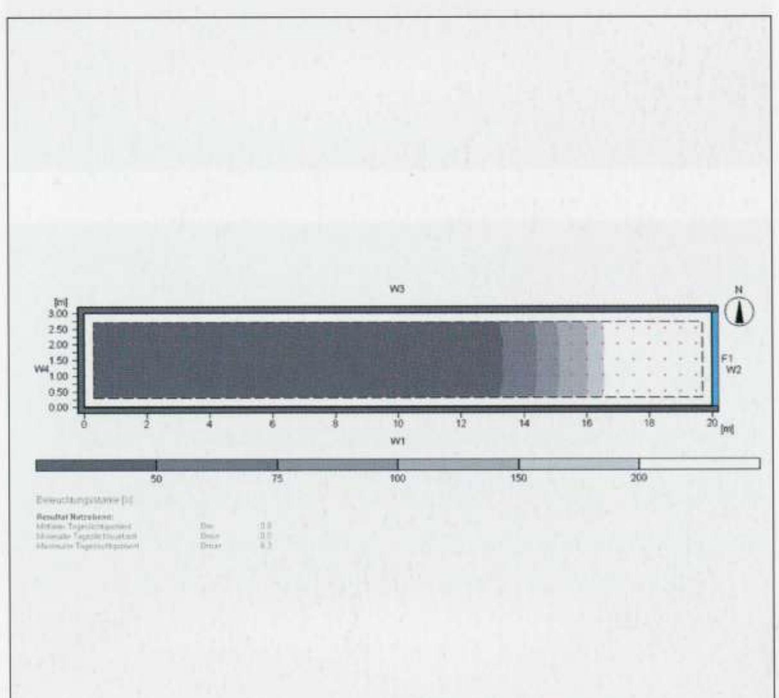


IV

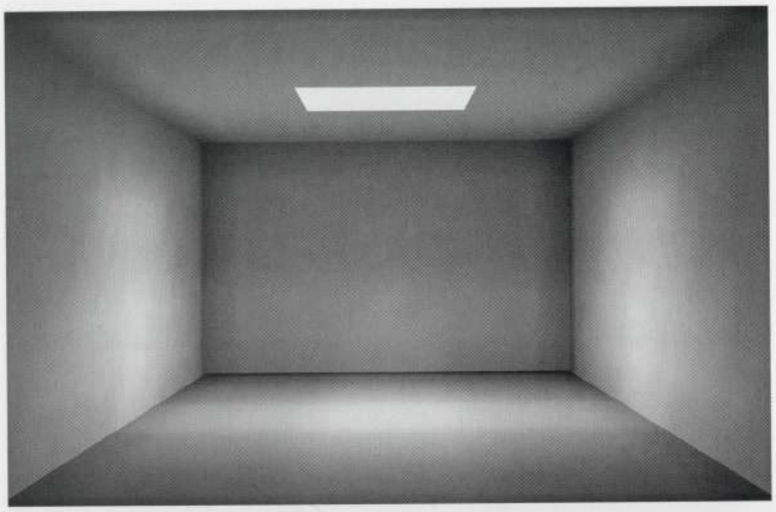

W3
N
[m]
6.0
5.0
4.0
3.0
2.0
1.0
0.0
W4
W2
0 1 2 3 4 5 6 7 8 9 10 [m]
W1
100
150
200
250
300



VI


W3
N
[m]
3.00
2.50
2.00
1.50
1.00
0.50
0.00
W4
F1
W2
0 2 4 6 8 10 12 14 16 18 20 [m]
W1
50
75
100
150
200

**The next table shows the influence of the reflectance factor of the walls on the daylight conditions in the room.
In Fig. I and II, the walls reflect at 70 %, in Fig. III and IV at 20 %, and in Fig. V and VI at 0 %.**



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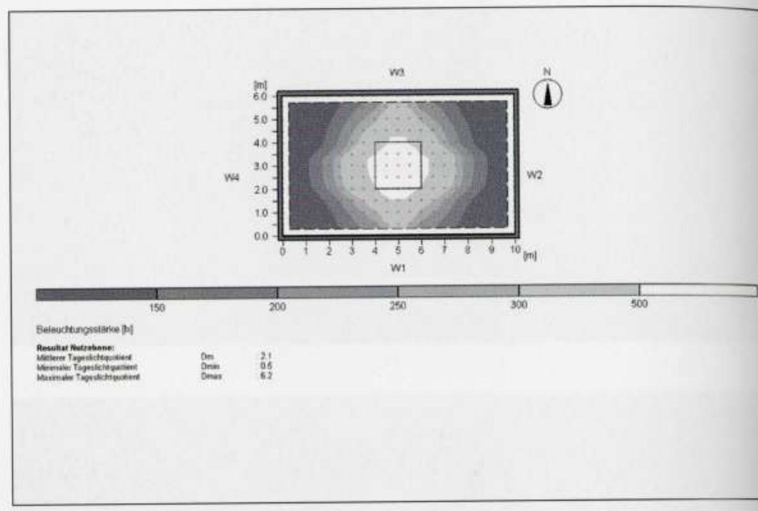
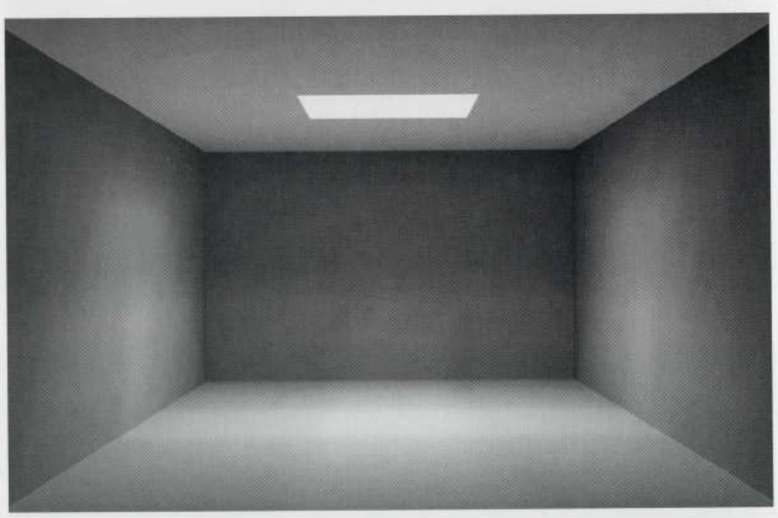
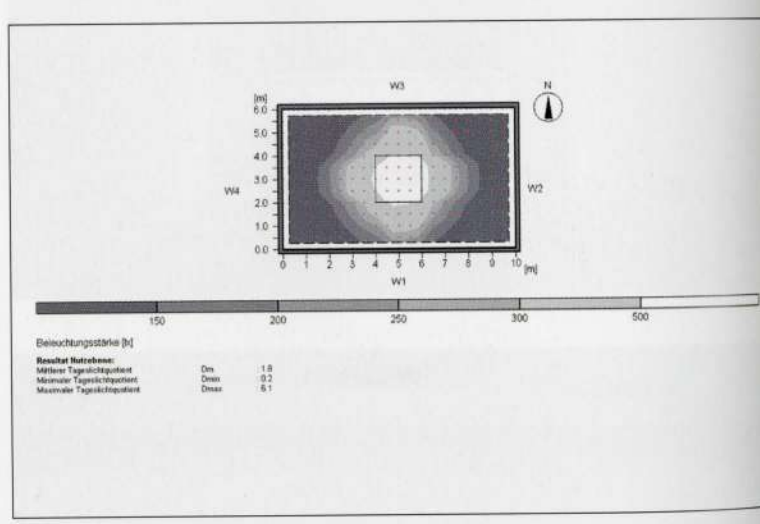
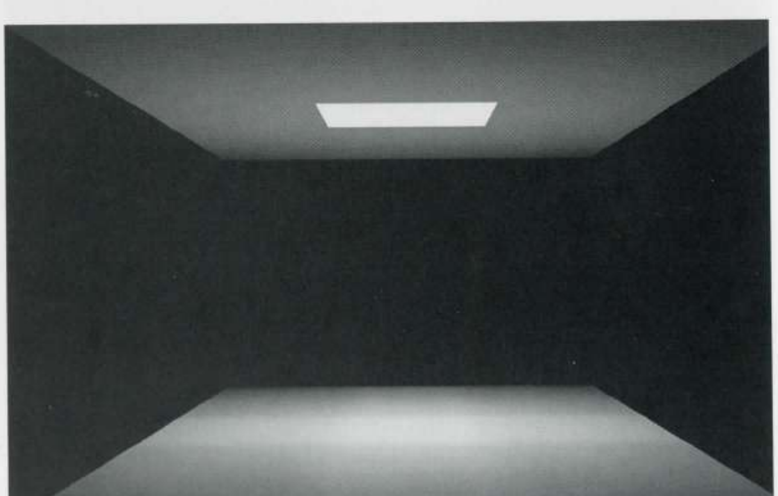




III





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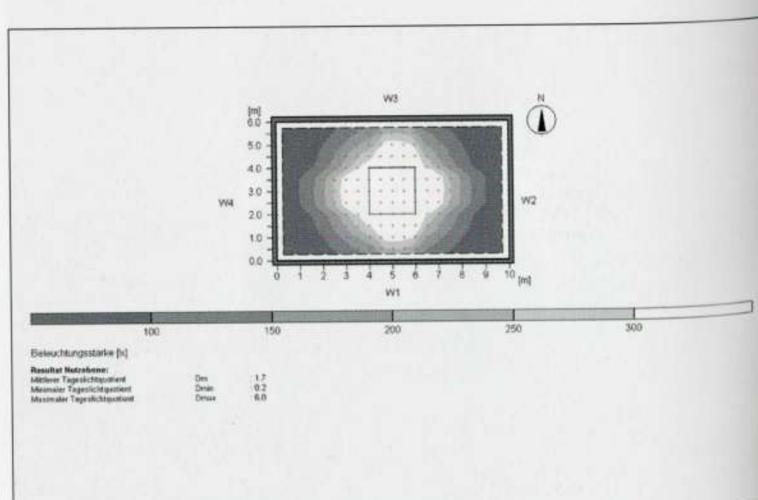
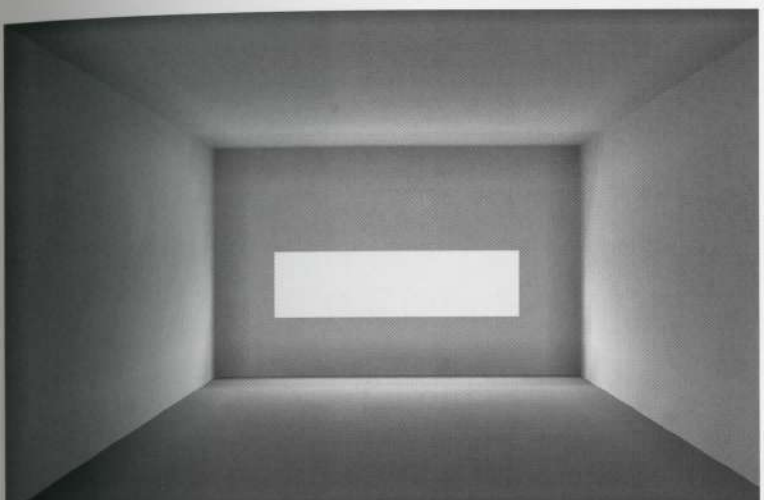
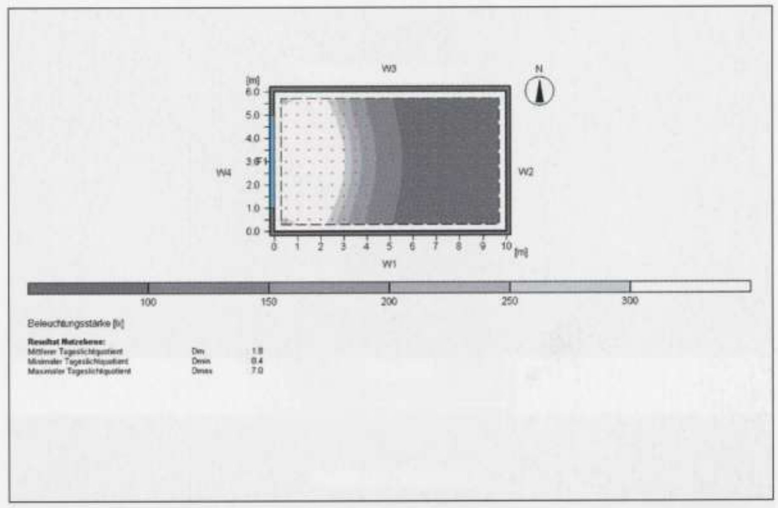
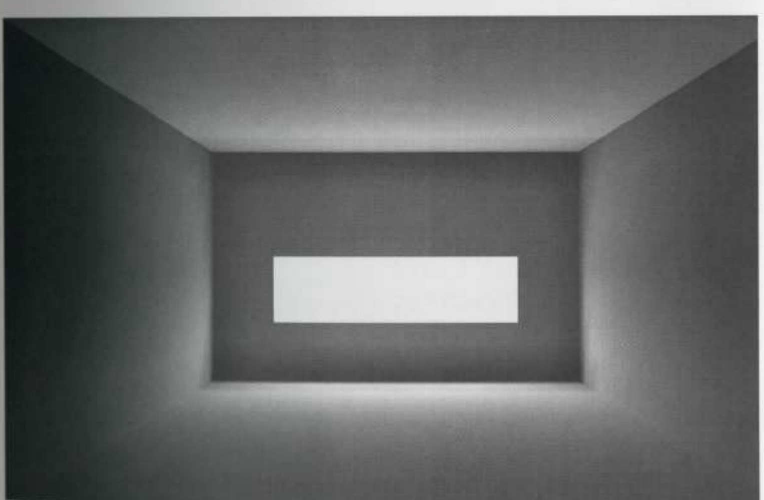


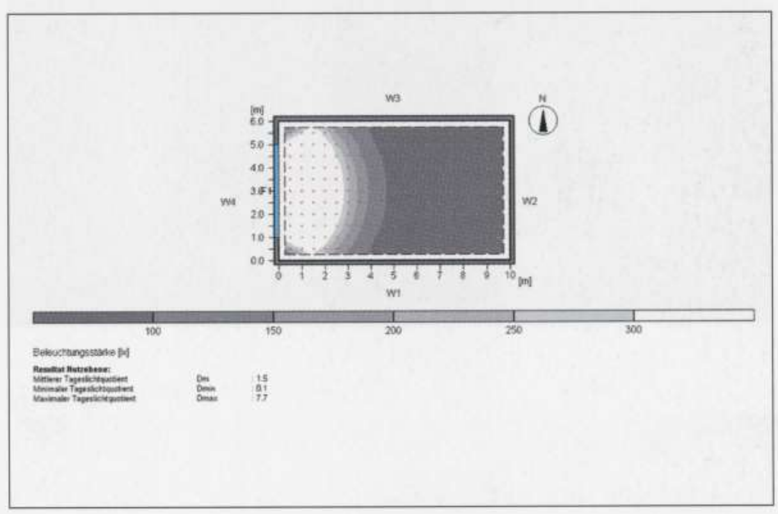


II


W3
[m]
6.0
5.0
4.0
3.0
2.0
1.0
0.0
W4
W2
N
0 1 2 3 4 5 6 7 8 9 10 [m]
W1
100
150
200
250
300
Beleuchtungsstärke [lx]
Resultat Nutzebene:
Mittlerer Tageslichtquotient
Minimaler Tageslichtquotient
Maximaler Tageslichtquotient
Dm
Dmin
Dmax
1.8
0.4
7.0



IV


W3
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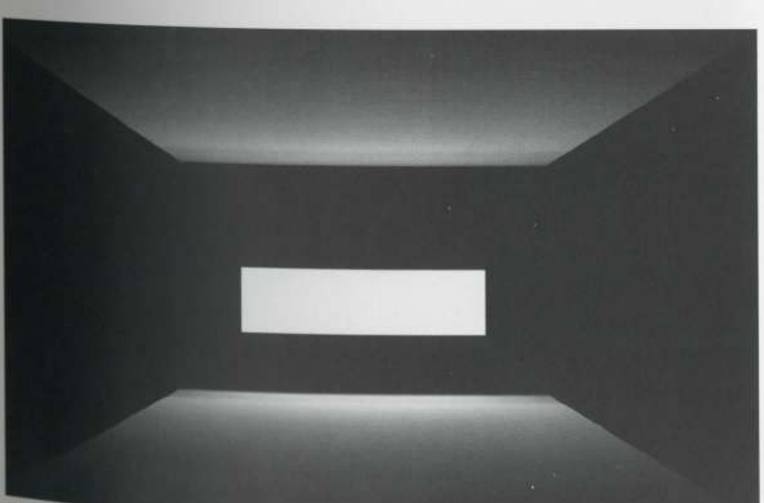
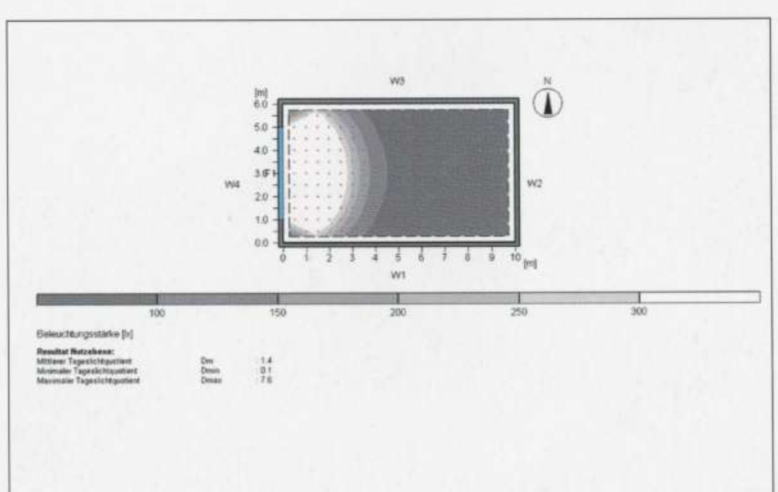
4.0
3.0
2.0
1.0
0.0
W4
W2
N
0 1 2 3 4 5 6 7 8 9 10 [m]
W1
100
150
200
250
300
Beleuchtungsstärke [lx]
Resultat Nutzebene:
Mittlerer Tageslichtquotient
Minimaler Tageslichtquotient
Maximaler Tageslichtquotient
Dm
Dmin
Dmax
1.5
0.1
7.7



VI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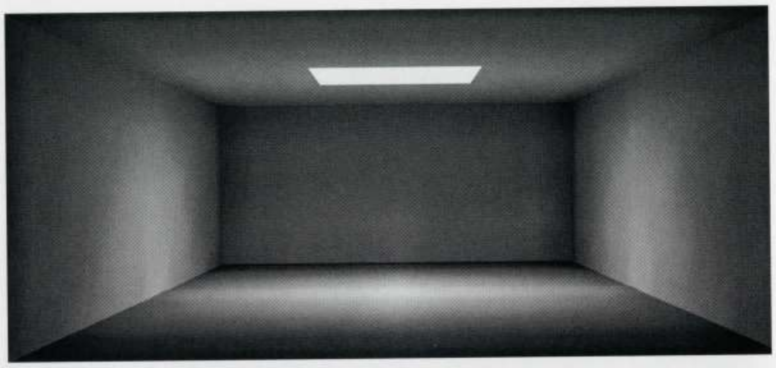
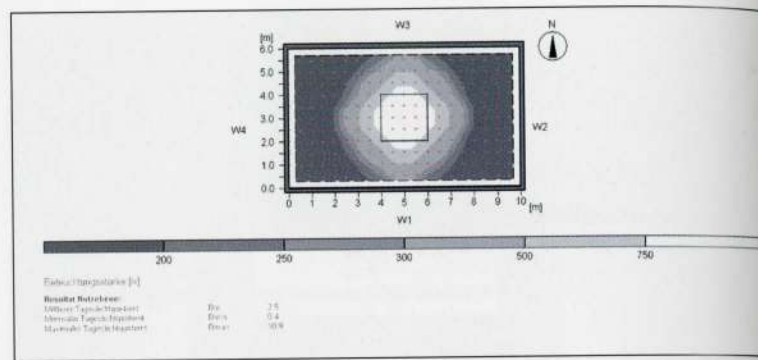
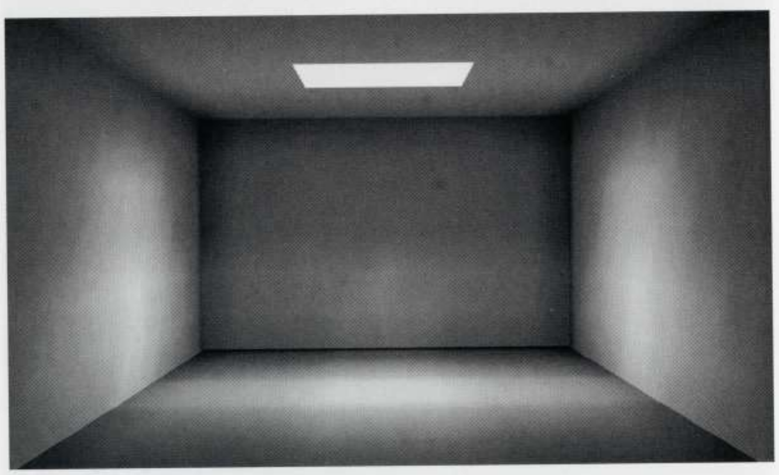
6.0
5.0
4.0
3.0
2.0
1.0
0.0
W4
W2
N
0 1 2 3 4 5 6 7 8 9 10 [m]
W1
100
150
200
250
300
Beleuchtungsstärke [lx]
Resultat Nutzebene:
Mittlerer Tageslichtquotient
Minimaler Tageslichtquotient
Maximaler Tageslichtquotient
Dm
Dmin
Dmax
1.4
0.1
7.6

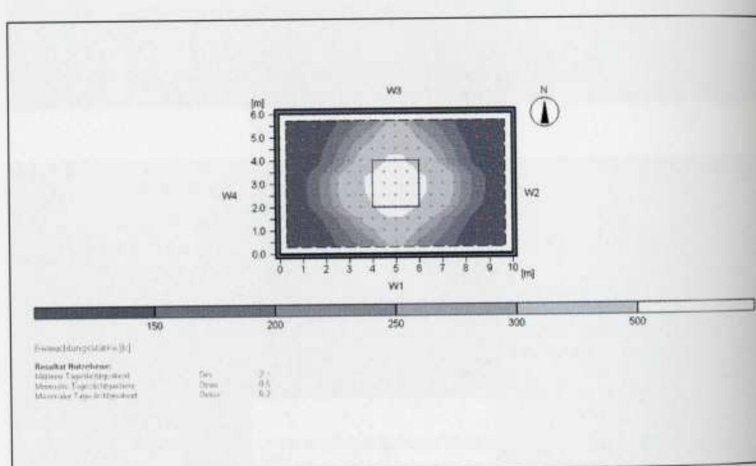
The final table shows the influence of the height of the ceiling on daylight conditions: at a constant surface area of 6 x 10 m², the height of the room is 2.50 m in Fig. I, 3.50 m in Fig. II, and 5 m in Fig. III.



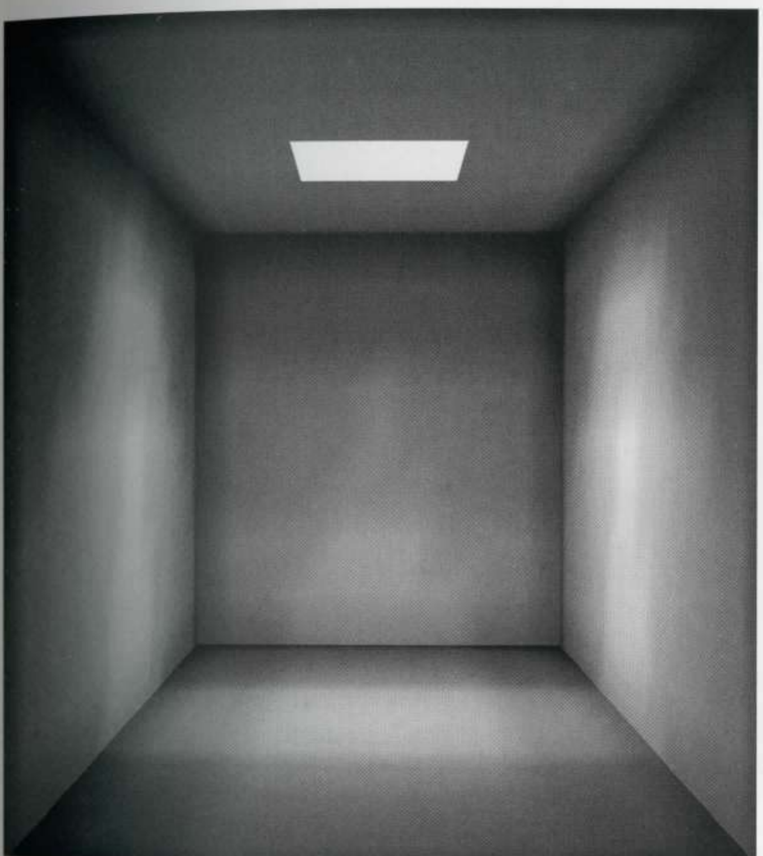


I

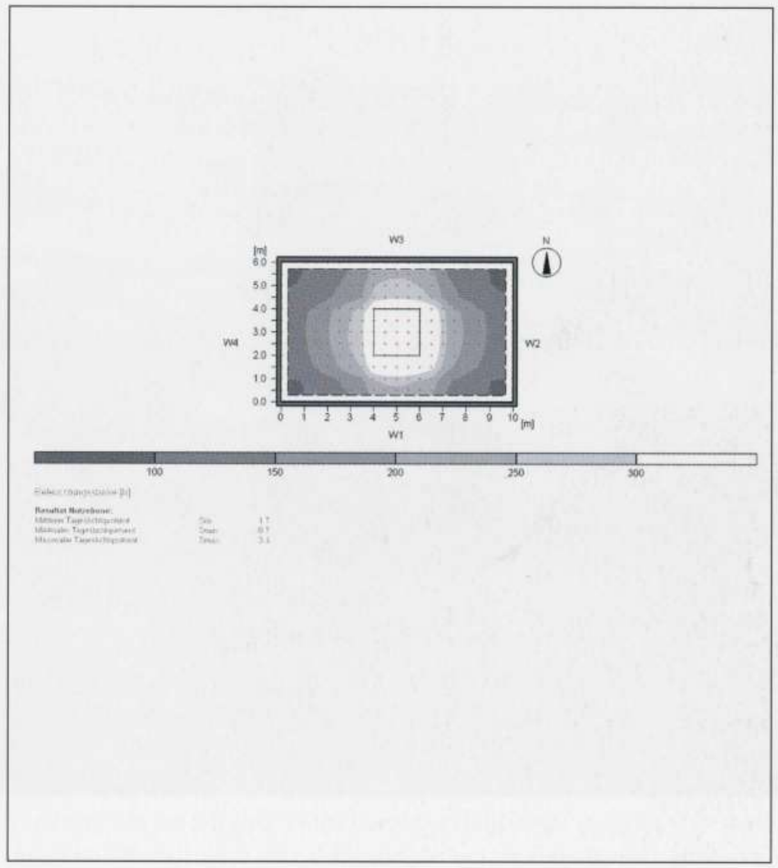




II



III


W3
N
[m]
6.0
5.0
4.0
3.0
2.0
1.0
0.0
W4
W2
0
1
2
3
4
5
6
7
8
9
10
[m]
W1
100
150
200
250
300

1

1 Rough surfaces in the landscape reflect light diffusely, while the sun is reflected in the water. The reflection moves with the observer across the surface of the water.

2 On this old photograph, the light of the window subtly retraces the faces and the pleats of the dress.

3 On a reflective surface (and on other smooth surfaces), the angle of reflection corresponds to the angle of incidence.

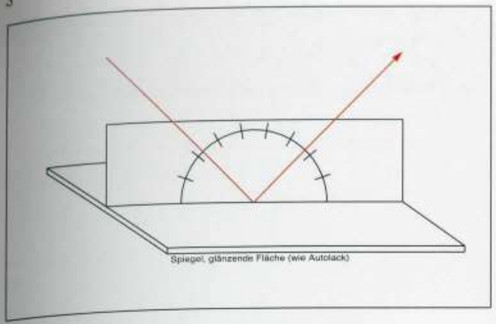
4 The snow appears in various shades of white: here, the smooth surface appears darker than the plowed uneven field, which reflects light more diffusely.

5 Rough surfaces reflect light unevenly.

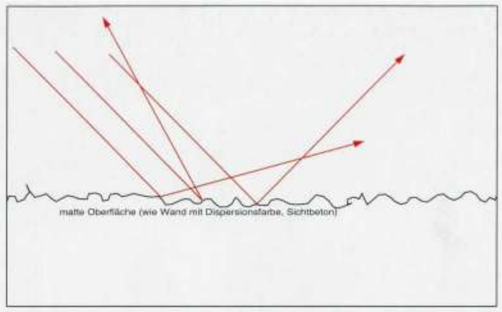
6 Direct sunlight produces harsh shadows. Diffuse soft light of the sky brightens the shadows.

2

3



5



Artificial Light

Light as "Material"

The Spreading of Light

The sun, the fixed stars, candles and lamps are all sources of light or luminous bodies. There are natural and artificial sources of light. On the other hand, there are the illuminated bodies such as the planets, the moons, or a wall which cast light back into our eyes as a reflection. The abilities of the eyes are tied to the surrounding light. Light only becomes visible where it strikes surfaces and "creates" them in such a marvelous way. In the process, shadows are created which look like "holes" in the light. They are part of the ordinary perception of everyone: however, we are not always conscious of the shadows, nor are they always noticeable. Yet, they bear witness to the manifest relation between light and space. Three gradations of shadows may be distinguished; shade, half-shade and cast shadow. Shadows are formed on the imaging body itself through the light that falls on it, producing brightness, semi-darkness, and complete darkness. The zones of transition from brightness to darkness lie in half-shade. The dark shadow is the image of a body on the ground or on other surfaces onto which a shadow falls.

The various shadows are produced by light; they inform the eye, whose power depends on the presence of light, well about the visible characteristics of what is seen. The first element touched upon is the surface: how light is absorbed, reproduced and reflected. We see whether the body is translucent, whether it refracts, filters, or absorbs light. Indeed, this observation, however, quickly illustrates the many varieties of light.

Diffuse light portrays a surface differently than direct sunlight, and artificial light creates different shadows than the residual light at the onset of night, as the light of the sky creates differently shaped shadows than those visible through artificial light. The shape of the shadow depends on the proximity of the source of the light that produces it.

Materials have various degrees of translucency (transmittance). There are transparent materials such as clear glass, water, air, translucent materials such as opal glass, and non-transparent materials such as wood and metal. The boundaries between these types are blurred. As a thin layer, wood can be translucent, as a very thick layer, water can be non-transparent. Light passing through gold leaf looks green, while light passing through thin silver foil looks blue.

Reflection

Most of the time, it is indirect light that enters our eyes. In the form of candlelight, direct light may be pleasant; as a bare electrical lamp, however, it may blind and thus be a nuisance: the blinding headlights of oncoming traffic at night are a familiar and unpleasant experience.

Flat glass mirrors or high-gloss reflecting materials can produce reflections that are just as powerfull as direct light. Luminaire manufacturers exploit the effect of a directed reflection in their darklight downlights. The reflectors are adjusted to the corresponding lamps in such a way that they give off their light over the darklight mirror reflector at a precisely defined angle. The luminaire has no glare and, from a distance, seems completely inconspicuous.

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