DAYLIGHT CONTROL SYSTEMS USING MIRROR OPTICS

Dr. Köster, H.[1]; Stephan, A.[2]; Wolfrath, E.[2]; Weismann, S.[2]
1 Köster Lichtplanung Integraldesign für Tageslicht und Kunstlicht
2 Bayerisches Zentrum für Angewandte Energietechnik (ZAE Bayern), Bereich Energieeffizienz

Mirror optics of internal louvre blades from RETROSolar in combination with special solar control glazing allow g_{ges} values of only 5%

On the subject:

Daylighting technology is an interdisciplinary field between building physics and lighting technology and realizes by means of novel mirror optics by Dr. Helmut Köster improved protection function against overheating, but simultaneous supply function with natural daylight, enabling an overall energy saving of glazed buildings of up to 30%.

Preface:

Daylight deflection systems use precision mirrors to provide indirect daylight distribution and significantly improve room illumination. Overexposure and overheating can be avoided in sunshine by means of bifocal optics through proportional sunlight deflection.

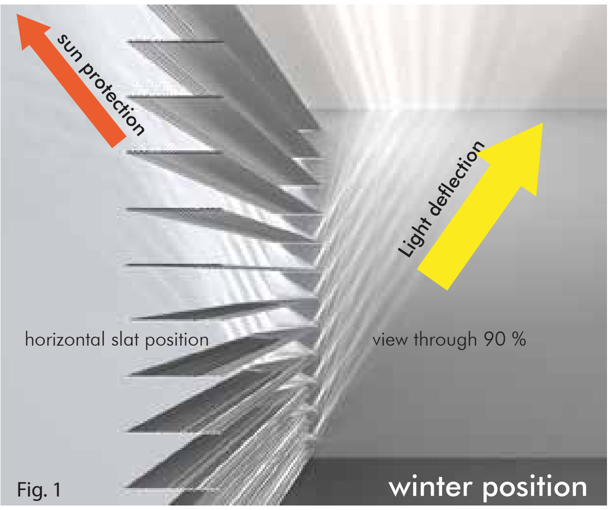


Fig. 1

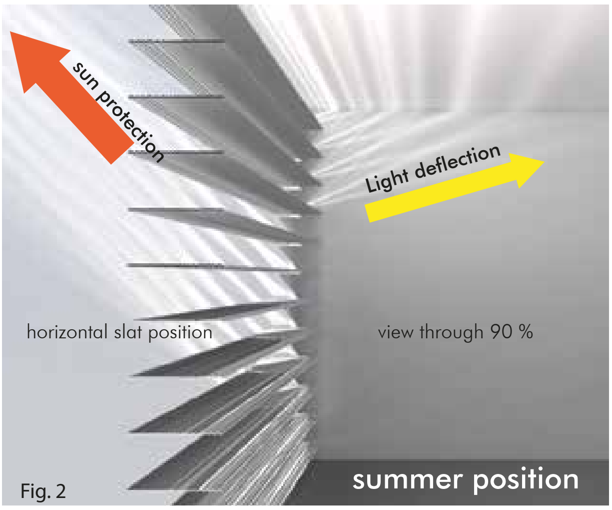


Fig. 2

Optical heat control using bifocal light control systems with light input and light deflection function depending on the angle of incidence of the sun in a horizontal slat position.

Light control systems enable indirect daylight illumination, which leads to a reduction in the illuminance near the window and to an increased illuminance in the depths of the room. This favors a balanced room illumination profile.

Bifocal slat optics enable ambivalent functions: SHGC-values (sun protection) and T-values (daylight illumination) are to be set in relation to one another, taking heating and cooling periods into account.

DIN requirements

Until now, it was permissible according to DIN 5034 to optimize the window sizes in relation to the room size. Since March 2019, DIN EN 17037 has come into force and replaces the previous dimensioning of windows by minimum illuminance levels in the interior: in some cases, this leads to a doubling of window sizes.

Daylight coefficient calculations without light redirection show an overexposed window zone and inadequate room depth illumination. DIN EN 17037 fails to set the maximum and minimum values of illuminance in relation to each other. The possibility of improving the uniformity of daylight illumination by means of light control systems has so far been ignored in standardization.

Standards and guidelines for daylighting are limited to times with diffuse sky light and neglect the times of tanning under consideration of solar control systems. Procedures for an annual simulation taking into account the sun's position are a necessary next step in standardization. A calculation using the daylight quotients can be used as a verification method for illuminance levels. The BDTF or OLDS data (bidirectional light distribution functions) of light control systems allow a very precise determination of the daylight quotients for different sun positions/seasons.

DIN EN 17037 also increasingly addresses the issues of view, tanning and glare: For the view to the outside, the standard provides quality requirements (e.g. view to street level or to the sky) so far without evaluating the transparency of the shading systems in %. Also, the issue of "glare" is only defined as an allowable probability time value of 5% of the time of use as an allowable source of disturbance, without defining the type of glare. DGNB neglects daylight autonomy at the time of active solar shading in the scoring system.

To prove the connection between light input and energy input/ SHGC-value optimization would be a desirable future requirement of the DIN and must find its reflection in the certification system, but also in the KfW funding, so that sun protection that darkens the rooms and consumes energy for additional artificial light is questioned.

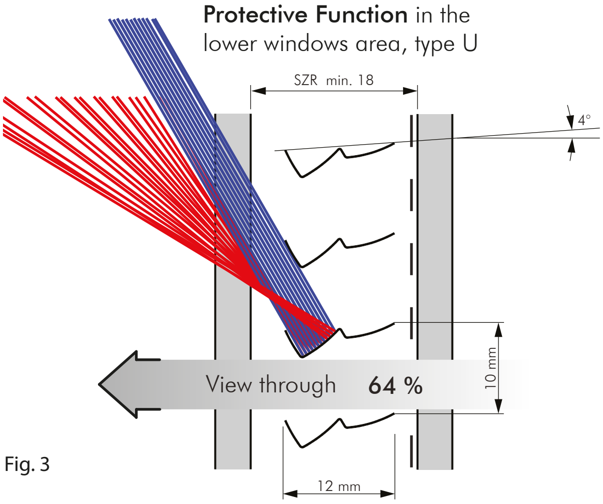


Fig. 3

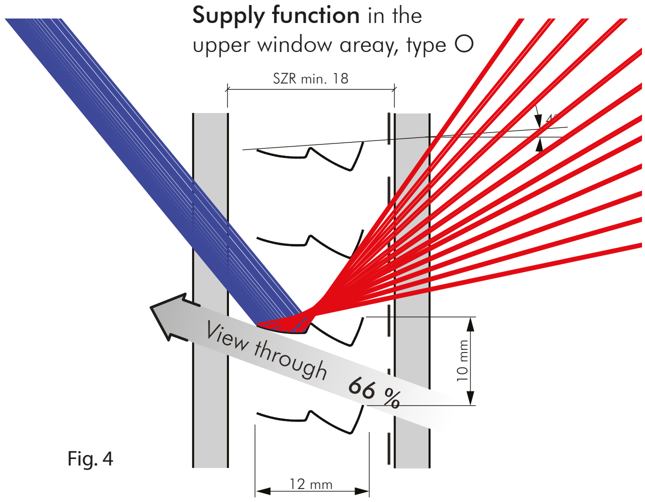


Fig. 4

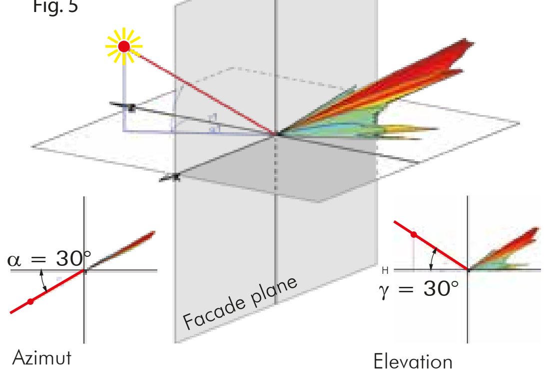
Light and energy balance using bifocal lamella optics

Protective Function *(Abb.3)*
The V-shaped section facing the sun serves as a retro-reflector. This system is primarily used in the lower window area and protects against overheating in the high summer sun. The flat sun is deflected steeply onto the ceiling without glare.

Zenith Light Extraction *(Abb.4)*
RETRO*LuxTherm 12 mm 12 mm was also developed for zenith light extraction. The* RETRO*LuxTherm 12 mm slats are installed at a height > 1.80 m < 2.20 m in a reverse position and thus ensure - despite summer shading - a simultaneous daylight yield in a large room depth without overheating the window zone.*

Light distribution to the interior by
RETRO*Lux* blinds

Fig. 5



KfW funding for sun protection measures

The KfW currently promotes every type of sun protection without differentiating the actual energy saving potential. Against this background, daylighting technology is to be investigated with regard to its effectiveness in order to make precise suggestions for funding. However, this also raises the question of which criteria should be used to evaluate sun protection at all.

Daylighting technology offers options for a better supply of daylight in favor of switching off artificial lighting. The sun protection also has a protective function against overheating and/or glare. However, this also raises the question of what kind of glare occurs and when and how the risk of overheating arises.

Glare protection

There are primarily three types of glare: Direct glare (sun falling into the viewer's eye), reflected glare (annoying reflections and mirroring on shiny surfaces, such as screens), and background or contrast glare (dark screen in front of bright, white, sunlit wall).

All these glare effects can be easily controlled by means of known sun protection measures. More difficult to control is the reflected glare in the glass panes with white, transparent sun protection from interior white blind slats. Everyone knows the problem of glare on glass surfaces from cars: a white sheet of paper in the cockpit obstructs the view. The same problem occurs with white interior sunshades. More on this later.

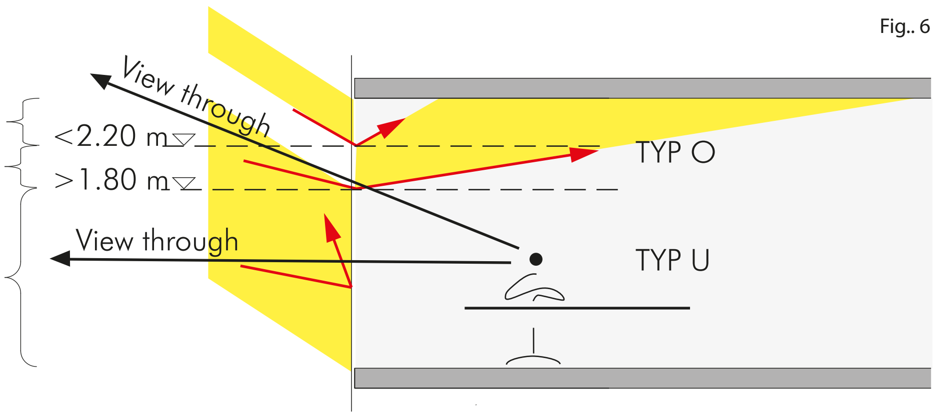
Fig.. 6

Zoning

Retro-Funktion

Zenith light extraction

Retro-Funktion



Overheating protection

Summer overheating can have three causes:

- Excessively high interior temperature due to solar irradiation
- Disturbing heat radiation from the glass facades due to heating up of the interior panes.
- Excessively high internal loads (e.g. as a result of switched-on electrical lighting due to closed and retracted sunshades darkening the interior).

The external sun protection - so it is commonly claimed - protects best from overheating, because the heat stays outside. This is true - but only as long as the windows remain closed! If the windows are opened for ventilation purposes in summer, the heat that accumulates in the reveal between the sunshade and the window will flow inwards due to convection through tilted windows!

But even without tilting the windows, the accumulation of heat causes the entire glass structure to heat up and thus radiate heat inside. The pane temperatures exceed the room temperatures. This raises the question of alternatives. The new paradigm is "redirecting light back to the sky" by means of mirror optics.

Mirror optics for light illumination and room depth illumination

On the market, daylight control by means of mirrors is becoming increasingly important with precise optics for light control (daylight autonomy) and/or light deflection (protection against overheating).

A distinction is made between

- Monofocal optics (primarily directing light outwards)
- Bifocal optics (light deflection to the outside and/or inside)

The optics are either embossed with mirror lamellae, e.g. in the form of a microstructure, or the lamellae are shaped like profiles in a macrostructure.

Microstructured louvers

Known are Fresnel optics, which are imprinted on a concave-convex lamella and reflect light incident from the outside back to the outside. The advantage of Fresnel optics is the openness of the curtain. The slats stand horizontally and reflect the sunlight hitting them back to the outside - ideally without converting the solar radiation into heat.

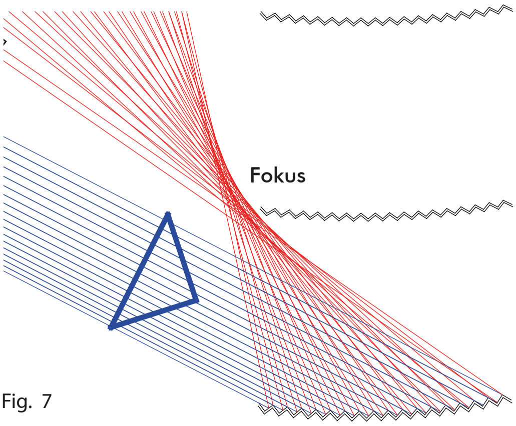


Fig. 7

Monofocal =
Light deflection with a single focus

Monoreflektive =
Light deflection with a single reflection in open lamella position by means of Fresnel reflector arrangement of the small partial surfaces

- *Slat width from 12 - 80 mm*
- *Suitable as a blind or also for a fixed arrangement e.g. in insulating glass*

Excursus on the wavelength of light

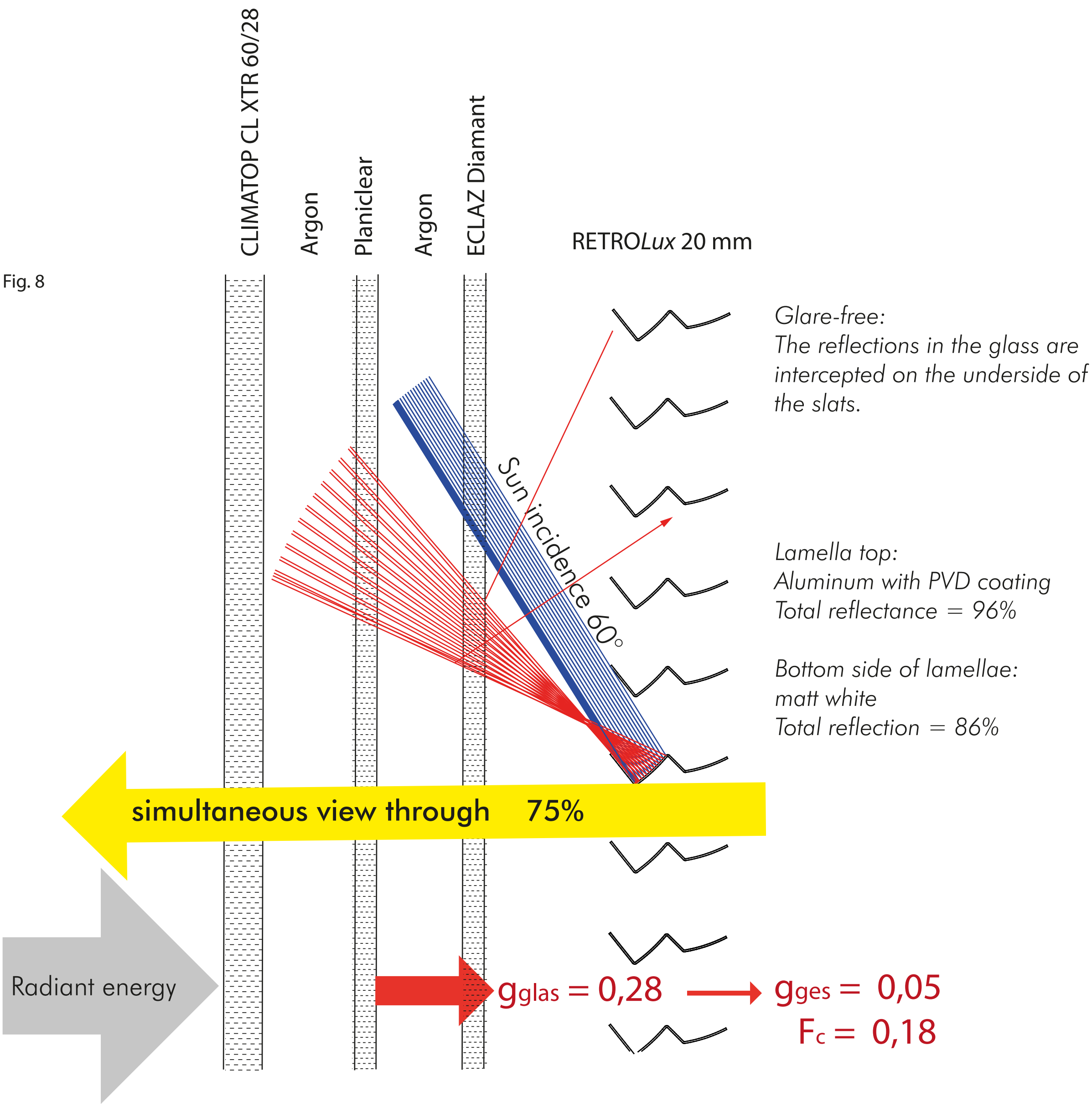
The electromagnetic wave spectrum includes all wavelengths from ultraviolet radiation to light and long-wave radiation to radio waves. Light radiation is short-wave and is converted into longer-wave thermal radiation when absorbed. Non-reflective louvers absorb light and heat up as a result. Reflective louvers with a total reflectance of up to 96% have only 4% absorption. The solar radiation is primarily reflected back to the outside without any appreciable heat being generated on the lamella.

Mirrors are thus able to reflect light radiation that has penetrated through the window back to the outside without any significant heating of the interior. This raises the question: What can an interior mirror system achieve? What g values are possible?

Measurements

The question can be answered mathematically as well as metrologically. ZAE Bayern carried out measurements on the RETRO*Lux* 20mm system with an outdoor test stand at its site in Würzburg. In advance, a suitable solar control glass was selected, which is characterized by high light transmission and thus low heating. The solar control layers are located at position 1. The panes themselves are designed in "extra clear", i.e. without color effects.

Fig. 8



RETROLux 20mm behind glass in the window casement, glazing bead installation:
The g-value is reduced from g= 0.28 to g= 0.05 in the open slat position of the blind according to the measurement for 60° incidence of sunlight. This results in an FC value of 0.18. When closed, the g value drops further to 0.04.
Note: The g-value readings have been corrected to gnorm values by subtracting out the diffuse radiation.

Sun incidence γ	slat tilt angle	gmess	gnorm
0°	closed (cut off)	0,06 ± 0,02	0,04 ± 0,02
60°	open	0,11 ± 0,02	0,05 ± 0,02

Fig. 9

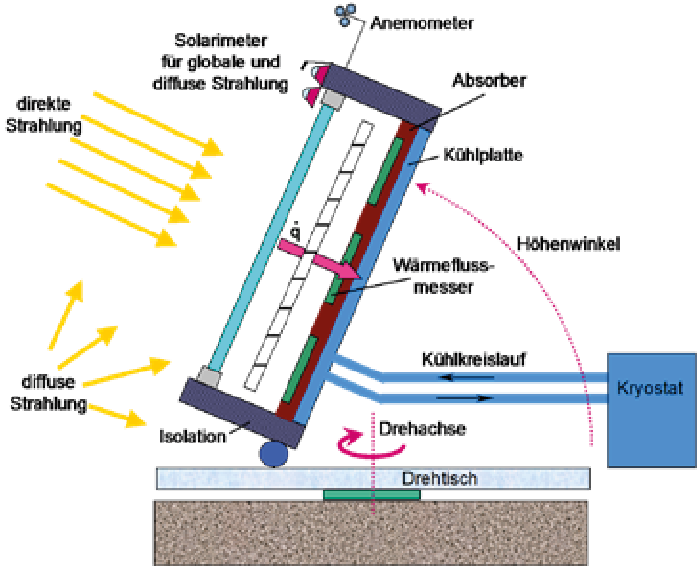


Fig. 10

The photo shows the test stand at ZAE Bayern in Würz-burg with built-in glazing and light-directing blinds. The measure-ments were carried out under natural solar radiation. The measuring box with the built-in sample tracked the sun's path over the course of the day, the changed azimuth in the horizontal circle around a vertical axis. The desired sun elevation angle was realized by tilting the apparatus around a horizontal axis

The RETRO*Lux 20mm system was installed in the cavity of the measuring box on the back of which the heat flows in a cooled absorber were recorded using several heat flow meters. In addition, the climate data (irradiation, wind, tempera-ture) were recorded. To determine the g-value, the diffuse component was subtracted out in order to determine a gnorm value in accordance with DIN EN 410 as the sum of the direct transmittance and the secondary heat input.*

$g = \tau_{Enorm} + qi_{norm}$

Measurement method:

The g-value measuring stand offers the possibility to determine the g-value based on DIN EN 410. With the sun as the radiation source, it is ensured that the spectrum during the measure-ment represents the solar spectral distribution as best as possible. Since the measuring stand can be controlled both horizontally and vertically, measurements are possible under vertical irradiation as well as under constant offset angles. To perform the measurement, the measuring stand is tracked by the sun at the fixed angle. The irradiation partially penetrates the glazing system and is absorbed behind it by an absorber. The heat flux density of the absorber plate is related to the irradiance flux density to determine the g-value. It is important to consider the real absorptance of the absorber as well as multiple reflections between the absorber and the glazing system to determine the fraction penetrated through the glazing system from the absor-bed irradiance. In addition, the thermal power loss of the measuring stand, resulting from the temperature difference between the measuring stand and the outside air, must be taken into account. Furthermore, the convection between the absorber plate depending on the angle of inclination must be taken into account accordingly.

Result of the measurements of the RETRO*Lux* 20mm louver

The measurements show that a very low g-value is achieved by using the mirror louvers. In addition to the glazing itself, the optical system is important. In this case, a bifocal louvre type RETRO*Lux* 20mm of the company RETROSolar was measured, which has two sections, a retroreflector (v-shaped first louvre section) and an attached lightshelf. The high summer sun (angle of incidence 60°) is reflected back to the exterior with a single reflection (monoreflectivity). Since the glass panes are largely colorless (extra clear) and solar radiation is largely reflected back through the outer pane, the inner pane heats up very little, so qi (secondary heat dissipation to the interior) is very low.

The intelligence of the optical louvre system lies in the precise beam guidance, which makes it possible to leave the blind in a horizontal louvre position in summer - i.e. in a position with optimum transparency - so that, despite the low g-value, external access (transparency) through the window is ensured, as specified in DIN EN17037 and DIN 14501 and the European Directives 89/654/EEC and 89/391/EEC.

The combination with the right glass coatings is essential. In the future, Saint Gobain will provide an even better COOL-LITE XTREME 61/29 coating on extra clear, low-iron glass. This ensures that the glass panes facing the interior in particular heat up less and reduces unwanted thermal radiation (qi). The louvre system itself hardly heats up at all.

Glare-free

Surface reflection takes place on any smooth surface. This is especially true for a 3-pane glazing with thermal insulation and solar control coating. In Fig. 8, it is demonstrated on individual rays how the glare caused by reflection is controlled on the glass: The reflection occurs according to the law "angle of incidence = angle of reflection". The present optical system intercepts the reflections on the underside of the upper lamellae, so that no disturbing glare occurs in the interior. The correct functioning of this optical system requires a high precision of the mirror contour of the lamellas.

Summary

By means of a light-optimized curtain on the inside of a window sash, highly effective solar control is achieved. Compared to the state of the art (according to DIN 4108-2, Tab. 7, Fc approx. 0.75 - 0.9), an Fc value of significantly less than 0.2 is realized. The low gges value of 0.05 is not only equivalent to an external sunshade, but can be rated as significantly better, since the windows can be tilted without burdening the interior with trapped heat. The very good transparency and the simultaneous daylight illumination is another clear comfort factor and reduces the energy consumption for electric lighting.
For a measurement according to DIN with closed curtains and vertical irradiation of the window, the result is a g-value of 0.04. Only 4% of the incident solar energy penetrates into the interior!

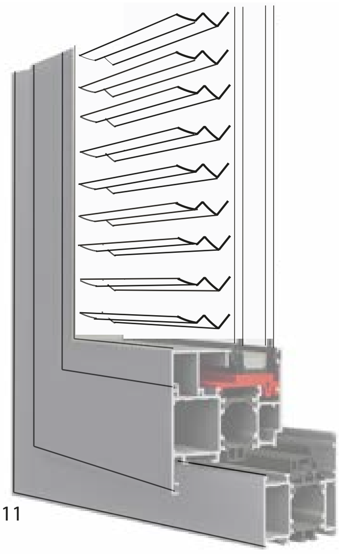


Abb. 11

The measurements apply to a casement installation in an arrangement of the RETROLux 20mm blind behind glass.

Application example Toro1, Zürich

In Toro1, an administrative building built in 1995/97 in Zurich, a double-skin, non-ventilated facade was renovated by installing RETRO*Lux* 20mm blinds from RETROSolar in 2020/21. A total of 2,300 blinds were installed in 10,000 m^2 of facade. 24V Maxon motors were used to raise and lower blinds up to $5m^2$ in size. As a result, it was not necessary to install the air conditioning system at a higher level - an enormous cost and energy saving in cooling technology and electricity consumption (daylight autonomy).

Fig. 12

Two-shell, non-ventilated facade (closed cavity)

Fig. 13

Inspection of the curtain during active sun protection. Despite the light control and sun protection, the slats are barely visible.

Conclusion:

As part of the Green Deal, the EU Commission is initiating a Directive on the Energy Performance of Buildings (EPBD), which is part of a comprehensive legislative package with the ambitious goal of defining zero-emission buildings and thus driving forward the reduction of CO2 emissions in Europe. To this end, an EU energy efficiency scale "A" to "G" is in preparation, so that by 2033 all residential and non-residential buildings will achieve energy efficiency class "F". By 2050, all buildings are to be emission-free. A renovation passport will be introduced for this purpose. The member states are to submit national action plans by 2025 and demonstrate strategies for eliminating the use of fossil fuels for heating.

Furthermore, legal foundations are to be developed to even prohibit the use of fossil fuels. These regulations will then also cover the refrigeration systems used to air-condition buildings. Daylight redirection technology, which promotes solar gains in winter, protection against overheating in summer, and daylight autonomy all year round, will play a very important role in the implementation of these ambitious goals.

About the authors:

This article was written in a collaboration between Dr. Helmut Köster and ZAE Bayern in Würzburg, A. Stephan, E. Wolfrath and S. Weismann. Dr. Köster is the owner of the property rights for the lamellar optics. ZAE Bayern carries out characterizations of complex glazing and glazing systems in Würzburg. All illustrations of the systems are taken from Dr. Köster's book "Tageslichttechnik" (Daylighting Technology), which is currently in preparation and will soon be published by Springer Verlag, Heidelberg.