

# Designing with Daylight

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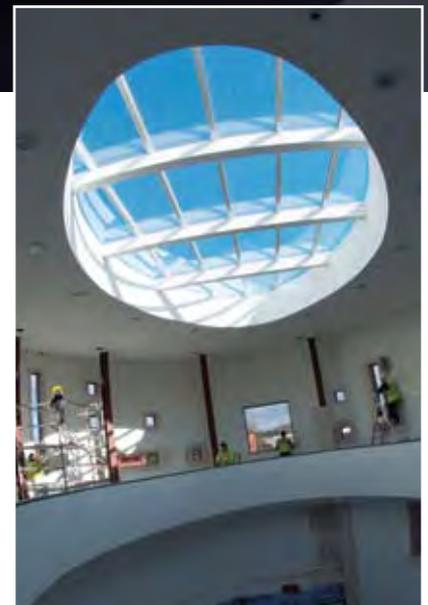
# Designing with Daylight Overview



Until the advent of gas and then electric lighting, building designers were always striving to find a balance between the need for large windows to allow daylight access and small windows to minimise heat loss. Today, even allowing for the many different types of artificial lighting, it is accepted that natural daylight is a vital element in creating a more efficient and eminently more rewarding interior environment.

The different colour spectra provided by the various types of light have psychological and physiological effects on humans. Research conducted by Ott Biolight Systems Inc. in 1997 showed

that the body uses light as a nutrient for metabolic processes in a similar way to its use of food and water. Natural light stimulates biological functions that are essential to human health. On cloudy days or in poorly lit environments, the inability to perceive colours from light can affect an individual's mood and energy levels.



# Designing with Daylight Benefits for Buildings of all Types

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Rooflights can offer real benefits in all types of buildings. They can form part of an effective technical lighting scheme, particularly in conjunction with efficiently-controlled artificial lighting, to produce specified illumination levels for particular tasks. According to leading consultants, horizontal rooflights provide two and a half times more light than vertical windows. In the next section we shall see how this approach can save energy and reduce the carbon footprint of any building type.

In addition to satisfying objective technical requirements, rooflights can also add to the more subjective qualities of spaces as an integral part of the building's architecture. They can provide views of the sky and promote a sense of well-being and connection with the outside without the distractions encountered with views through vertical windows. Introducing daylight into a building has been proven to be crucial for the well-being, safety and efficiency of the people using the building. Workplace (Health, Safety and Welfare) Regulations 1992 state that: *'Every workplace shall have suitable and sufficient lighting which shall, so far as is reasonably practicable, be by natural light'*. This is restated in the HSG38 'Lighting at Work' booklet.

Unlike most building types, for schools specific guidance on natural lighting and rooflights is available, in Building Bulletin 90—'Lighting Design for Schools'. This provides essential guidance for both primary and secondary schools, whether for new or refurbishment projects, and helpful background for other similar building types. It stresses that natural lighting during daylight hours should always be the major source, supplemented by electric light when needed. Designers should assume that daylighting will be the prime means of lighting in all areas unless there are specific, over-riding reasons for artificial lighting in certain rooms. BB90 contains a comprehensive section covering lighting design, including rooflights. As it points out, rooflights let in light from the brightest part of the sky and are not generally affected by external obstructions, such as trees or other buildings. They also provide a more even pattern of light than vertical windows.

Rooflights are favoured in areas where vertical windows with views are not possible, so that 'daylight contact' is maintained. Guidance is included on avoiding discomfort glare, which can occur if the rooflight glazing can be seen directly from normal viewing positions at less than 35° above the horizontal. Rooflights

with 'coffers' or kerbs help to avoid this, particularly with high reflectance sides to 'soften' light distribution. When recommended daylight levels cannot be achieved throughout a space, supplemental electric lighting can be introduced with suitable control systems, which probably need to be separate from night-time electric lighting controls.

Specific applications where rooflights may be particularly helpful are cited in BB90. For example, where Display Screen Equipment (DSE) is used, vertical windows can be problematic for users and rooflighting offers an alternative, higher-level light source. Various examples of room lighting designs are also included, exploring alternatives such as adding rooflights above the furthest wall from a window to even-out natural lighting and use of central rooflights to give consistent light distribution. Rooflights are also regarded as important for—often internal—communal spaces such as atria and circulation 'streets'.

## Definition of Daylight

The CIE (Commission Internationale de l'Éclairage) Overcast Sky is the standard used throughout northern Europe for all daylighting calculations.

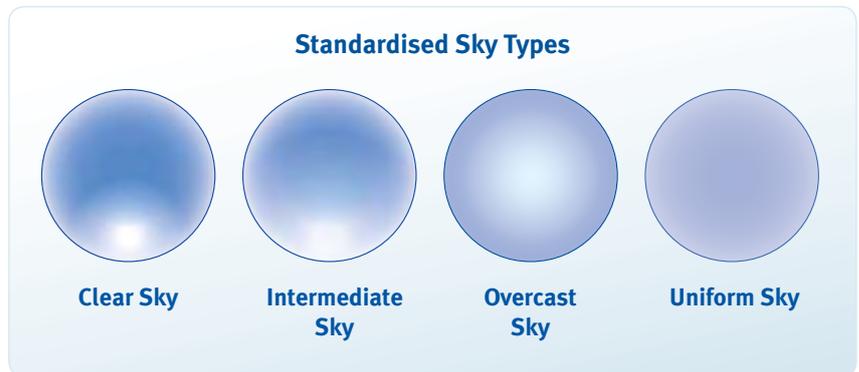
- Daylight is classified as the natural light from an overcast sky.
- Sunlight is the natural light from a direct sunbeam, not obscured by clouds.

The standard CIE Overcast Sky is considered to be:

- Three times as bright overhead than it is on the horizon.
- Of the same brightness in all compass directions.

Convention assumes that if a building is designed for daylighting according to the CIE Overcast Sky conditions then when outdoor illuminance is brighter, the natural lighting performance will be significantly better.

It is assumed that the minimum yearly average outdoor illumination is 5,000 lux for 85% of a normal working day. This represents a dull day. By the same standard a sunny day is assumed to be 100,000 lux—the maximum design illuminance.



### Clear Sky

The luminance of the standard CIE Clear Sky varies over both altitude and azimuth. It is brightest around the sun and dimmest opposite it. The brightness of the horizon lies in between those two extremes.

### Intermediate Sky

The standard CIE Intermediate Sky is a somewhat hazy variant of the clear sky. The sun is not as bright as with the clear sky and the brightness changes are not as drastic.

### Overcast Sky

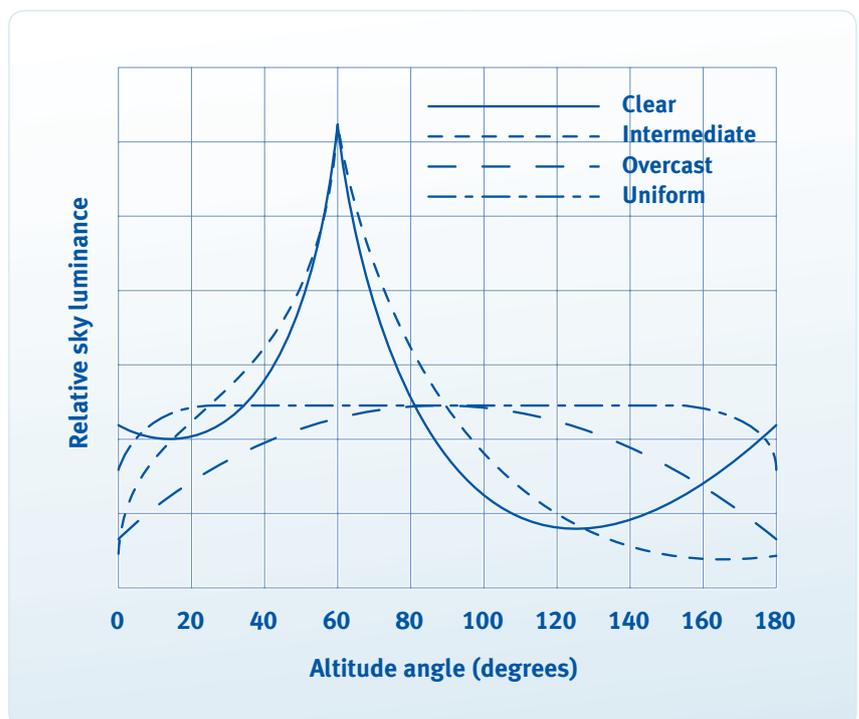
The luminance of the standard CIE Overcast Sky changes with altitude. It is three times as bright in the zenith as it is near the horizon. The overcast sky is used when measuring daylight factors. It can be modelled under an artificial sky.

### Uniform Sky

The standard Uniform Sky is characterised by a uniform luminance that does not change with altitude or azimuth. It is a remnant from the days when calculations were done by hand or with tables. Today, it is hardly used at all.

## Sky Distributions

The sky distributions graphs were generated with the RADIANCE synthetic imaging system. The sun was assumed to be at an altitude of 60° due South. The sky luminance was then mapped between the Southern (0°) and the Northern (180°) horizon passing through the zenith (90°). Please note that graphs should not be compared to one another, i.e. it is not correct to say that uniform and overcast skies always have the same zenith brightness.



# Designing with Daylight Design Principles

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## The Daylight Factor

The daylight factor is the CIE recommended method for determining the performance of a daylighting system. It is useful for estimating the amount of glazing needed to daylight a space.

The daylight factor uses a ratio between indoor and outdoor illuminance levels which, in turn, is dependent on the rooflight design and location.

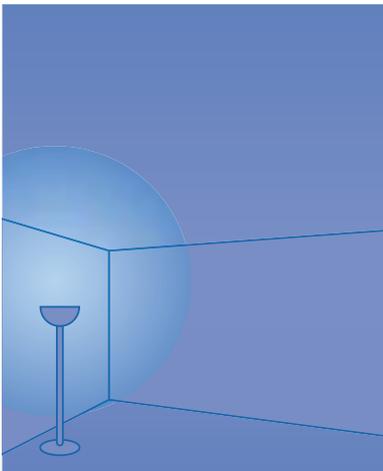
The daylight factor does not have a specific value of illuminance. It is defined as *'the ratio of interior illuminance on a horizontal surface to the exterior illuminance on a horizontal surface from the CIE Overcast Sky'*.

The greater the amount of light entering through a rooflight, relative to the outside illuminance, the higher the daylight factor will be.

The illuminance in a daylight interior will vary, depending on the sky luminance, but the daylight factor remains the same.

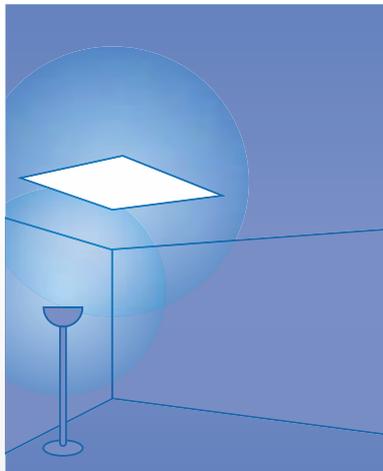
The daylight factor is affected by aspects such as maintenance and cleanliness of the rooflight, internal decorative finishes and surface distance from the opening.

## Practical Examples of Daylight Factors



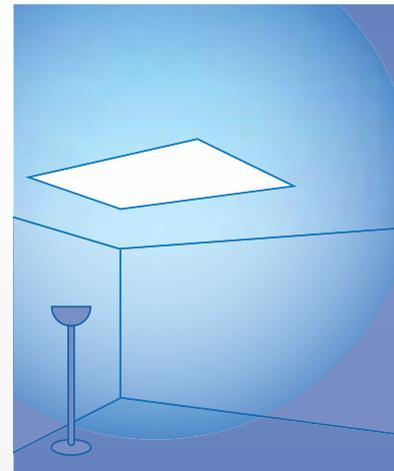
### Daylight Factor less than 2%

- Room looks gloomy
- Often needs full artificial lighting during the day
- Decor is dominated by the appearance of artificial lights



### Daylight Factor between 2 – 5%

- The optimum range of daylighting for efficient energy use
- Room appears to be predominantly lit by daylight
- Artificial lighting is required away from rooflights and on dull days



### Daylight Factor greater than 5%

- Room appears to be strongly lit by daylight
- Artificial lighting rarely required during the day
- Potential solar gain is a consideration and therefore careful specification is required

## Predicting Daylight

During the early periods of design it may be desirable to ascertain the area of glazing required to give a set daylight factor. Predicting daylight can be estimated using the daylight factor equation. This uses the following formula to calculate the daylight factor at a single point in the centre of the room:

$$DF = \frac{A_w}{A} \frac{\theta T}{(1-R^2)}$$

Where:

**DF** is the daylight factor (%).

**A<sub>w</sub>** is the glazed area (m<sup>2</sup>).

**A** is the total area of all the surfaces in the room (including glazed area).

**T** is the transmittance of the glazing to diffuse light; it includes the maintenance factor (to account for dirt on the glazing).

**θ** is the angle of visible sky, measured in section from a point in the centre of the glazing (degrees).

**R** is the area-weighted mean reflectance of the room surface.

Additional practical information can be found in CIBSE's Lighting Guide *LG10: 1999—'Daylighting and window design.'*

Using the formula at the end of Design Principles, calculating the daylight factor for a single point in a room cannot always be relied on to ensure that rooflights and windows are positioned to greatest effect within a room. Xtralite has recognised this and offers customers a free consulting service in which an advanced computer modelling system is used to predict the best location and size of rooflights and windows. Using the Xtralite service a designer can confidently build rooflights into the architectural proposition and ensure their ideal positioning to achieve the desired level of daylighting.

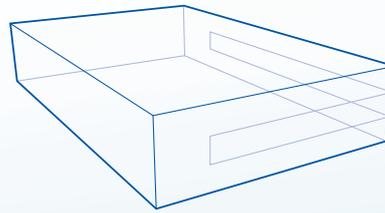
For example, diagram 1A illustrates a standard-sized room featuring windows along two sides. When this is analysed within the Xtralite modelling system it can be seen in diagram 1B that the daylight factor is exceptionally high close to the windows and low in the rest of the room.

Diagram 2A shows the same sized room but with a series of smaller windows along two sides and an even distribution of rooflights in the roof. Using the Xtralite modelling system it can be seen in diagram 2B that daylight is distributed much more evenly.

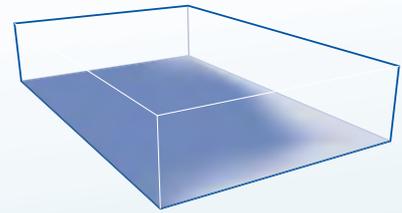
Comparing the two layouts, the window and rooflight configuration in 2A/2B has a smaller glazed area than 1A/1B and yet produces a higher average daylight factor, therefore representing better daylighting throughout the room.

To take advantage of the Xtralite consulting service email [sales@xtralite.co.uk](mailto:sales@xtralite.co.uk) or visit our website [www.xtralite.co.uk](http://www.xtralite.co.uk)

1A

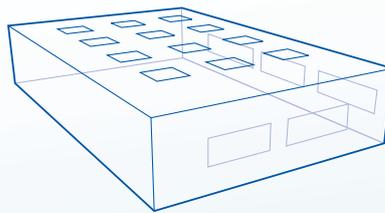


1B

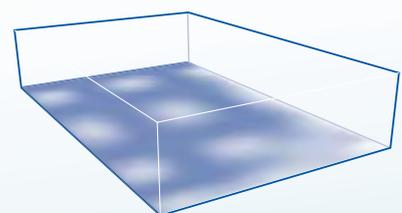


Room dimensions:	20 m x 15 m x 3 m
Windows:	18 m x 1.2 m and 13 m x 1.2 m
Total glazed area:	37.2 m <sup>2</sup>
Minimum daylight factor:	0.6%
Average daylight factor:	3.5%
Maximum daylight factor:	25.8%

2A



2B



Room dimensions:	20 m x 15 m x 3 m
Windows: 5 windows, each being 2 m x 1.2 m. Total area:	12 m <sup>2</sup>
Rooflights: 12 rooflights, each being 1.2 m x 1.2 m. Total area:	17.28 m <sup>2</sup>
Total glazed area:	29.28 m <sup>2</sup>
Minimum daylight factor:	1.1%
Average daylight factor:	4.3%
Maximum daylight factor:	26.2%

# Designing with Daylight Illumination Levels

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The onus is on the building designer to select the light level most appropriate to the intended use of the building. Recommended illuminances for specific

activities are contained within the CIBSE Guide for interior lighting 1994.

Examples include:

Daylight Factor %	Standard maintained illuminance (lux)	Interior / activity	Examples
2 – 3	50 – 100	Interiors used occasionally, with visual tasks confined to movement, limited perception of detail.	Corridors, bulk stores.
3 – 4	150 – 200	Continuously occupied interiors, visual tasks not requiring perception or detail.	Loading bays, plant rooms.
6 – 10	300 – 500	Moderately-difficult visual tasks, colour judgement may be required.	Packing, general offices, engine assembly, retail shops.
12 – 20	750 – 1000	Difficult visual tasks, accurate colour judgement required.	Drawing offices, chain stores, general inspection, electronic assembly, supermarkets.
30 – 40	1500 – 2000	Extremely difficult visual tasks.	Precision assembly, fabric inspection.

A standard overcast sky is generally represented as 5000 lux. However, this is not constant for all times of the day or parts of the year.

## Horizontal or Vertical Measurements?

For greatest relevance, light levels can be measured vertically or horizontally depending on the use of the building.

- In office and manufacturing environments it is usually best to measure light levels horizontally because the tasks being undertaken tend to happen in a regular horizontal plane.
- In warehouses or storage areas where racking is used, it is better to analyse light levels vertically.



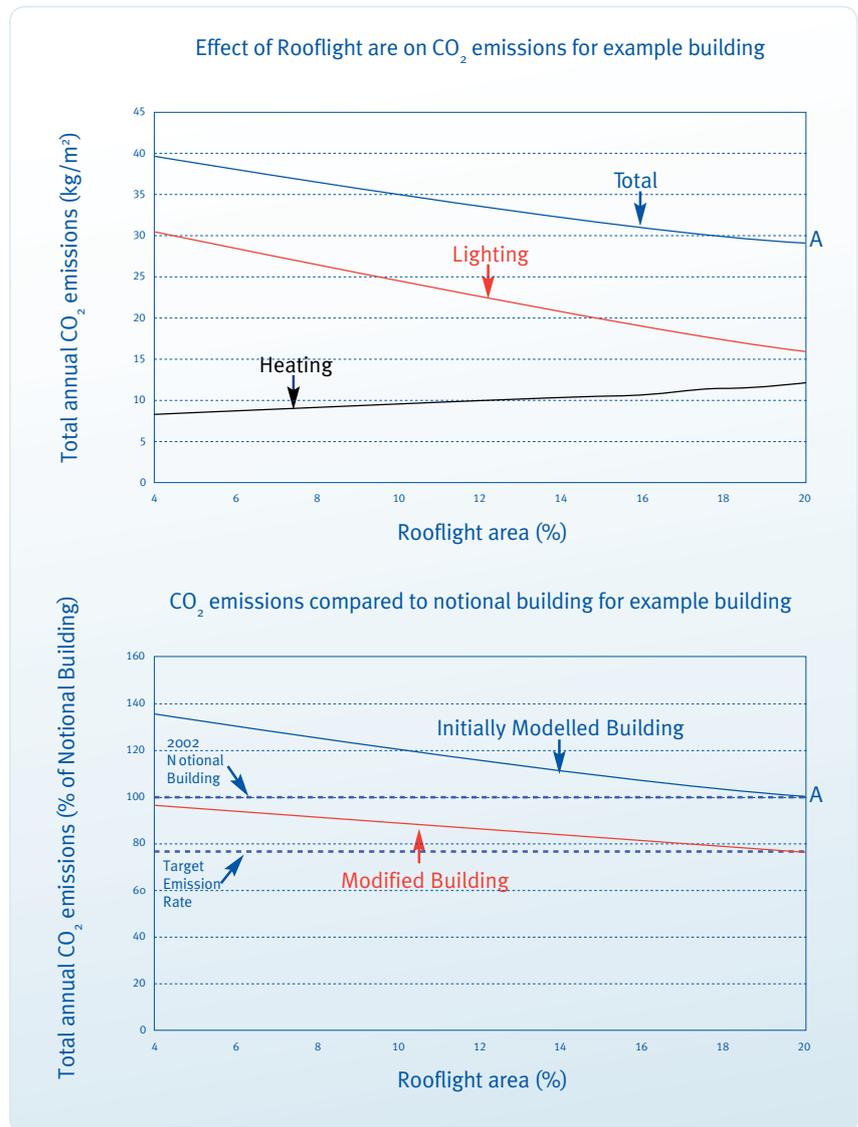
# Designing with Daylight Maximising Energy Efficiency

Taken at face value, the Building Regulations Part L Approved Documents (and other similar national regulatory guidelines) seem to approach rooflights purely from the perspective of limitation due to a lower insulation value than typical roof constructions, as we shall see later. This approach ignores rooflights as an effective light source in their own right, with substantial potential for reduction in energy used by artificial lighting. A more holistic approach is needed, as exemplified by recent research.

Carried out by De Montfort University, the research brings together thermal effects with energy used for heating and illumination effects with energy used for artificial lighting—applied to a range of buildings. The findings proved conclusively that rooflights provide an overall energy benefit—with the level of that benefit depending on various factors, particularly the total area of rooflights, design illumination level, type of artificial lighting control used and the pattern of building use. Increasing the rooflight area reduces the need for artificial light, cuts the energy requirement of the building and reduces CO<sub>2</sub> emissions. It is therefore a straightforward means of meeting a building's target emission levels under the current Building Regulations and reducing its carbon footprint.

By considering insulation values alone, it might be expected that heating requirements would grow as rooflight area increased. However, the research proves that for a building occupied primarily during the day this is not the case, as passive solar gain through the rooflights actually balances the insulation value. Therefore, heating requirements are barely affected and the most dominant effect by far is the decreasing requirement for artificial light as rooflight area is increased, as illustrated in the graph.

In the case of a building occupied between 9am – 5pm every day of the year, with a lighting requirement of 300 lux, some 23 kg CO<sub>2</sub>/m<sup>2</sup>—a massive 85%—saving in emissions will result from using 20% rooflights. For a building occupied 24 hours a day—the worst case scenario for rooflights, with no night-time benefits from natural light or passive solar gain—they still provide a very significant energy benefit. In almost all cases, a rooflight area of 15% – 20% will achieve almost all



the available savings in overall energy use and CO<sub>2</sub> emissions. To maximize these benefits, designers need to carefully consider interaction with artificial lighting, which will be essential during parts of the working day—particularly in the winter months—and specifically in working areas where light levels need to remain constant. Automatic controls will be needed to minimise the use of artificial lighting, so maximising energy savings from daylight.

# Designing with Daylight Properties of Glazing Materials and Configurations

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In addition to allowing the passage of daylight, the material used in a rooflight must be durable and meet the regulatory requirements for thermal, fire and safety performance. In the UK the main rooflight materials are glass and polycarbonates and these are the only glazing materials used in Xtralite products.

## Polycarbonate

Polycarbonate is a clear thermoplastic formed under heat and fixed in shape by cooling. It can be recycled and reused by re-heating to a plastic state.

- Exceptional impact resistance
- High levels of light transmission
- High levels of UV resistance
- Good fire resisting properties
- Wide range of clear, tinted, patterned and opaque finishes
- Co-extruded UV protection eliminates up to 95% of UV radiation from the inside of the building
- Can be moulded into many different shapes including domes and pyramids

## Glass

Safety glass is commonly used in atria for commercial and retail environments and also in traditional pitched roofs. Glass provides the benchmark against which the optical performance of other glazing solutions are measured.

- Excellent fire retarding properties
- Good impact performance
- High light transmission
- Long life expectancy with no UV discolouration
- Can be supplied with various laminates, surface treatments and interlayers to provide coloured and textured surfaces, for obscure and diffused finishes, solar control and total UV protection

## Other Thermoplastics

PVC is rarely used in industrial, domestic, commercial or retail environments because it has poor impact resistance, limited UV resistance and is susceptible to degradation, discolouration and demoulding.

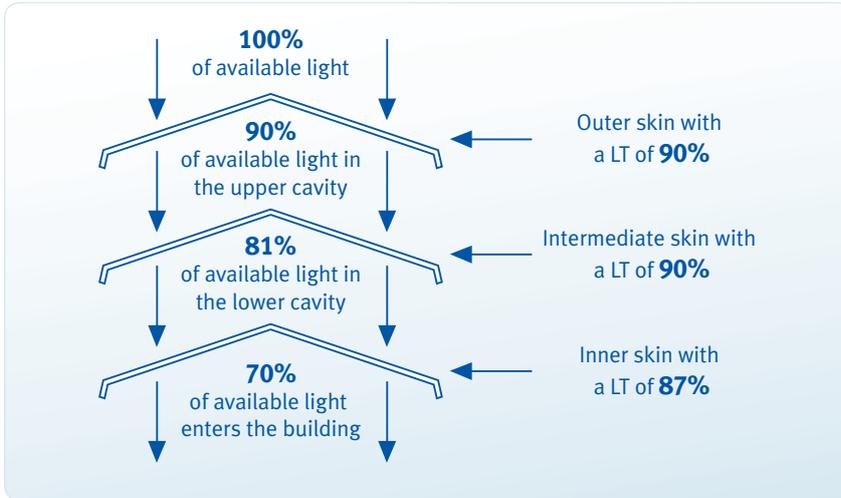
Acrylic does not meet the UK standards for fire resistance.

PET is a high impact thermoplastic with good clarity but it has a low temperature distortion value, which makes it unsuitable for rooflights.

## Nanogel® Sheet Technology

Xtralite has introduced innovative Nanogel® technology which combines impressive thermal, light transmission and acoustic characteristics. Nanogel® consists of translucent aerogel granules—filling clear polycarbonate multi-wall rooflight constructions—that allow light to pass through whilst serving as a highly effective thermal insulation. The extremely small pore size means that air molecules collide with the silica lattice, rather than each other, transferring energy to it, substantially limiting heat conduction. So, insulation performance is vastly improved, with U values for a triple-walled rooflight reduced from 2.4 W/m<sup>2</sup>K without Nanogel® to 1.3 W/m<sup>2</sup>K with the new technology. Nanogel® also offers excellent light transmission with diffusion giving a 'shadow-less' light quality, as well as a 25% reduction in sound transmittance (at 1,000Hz frequency).





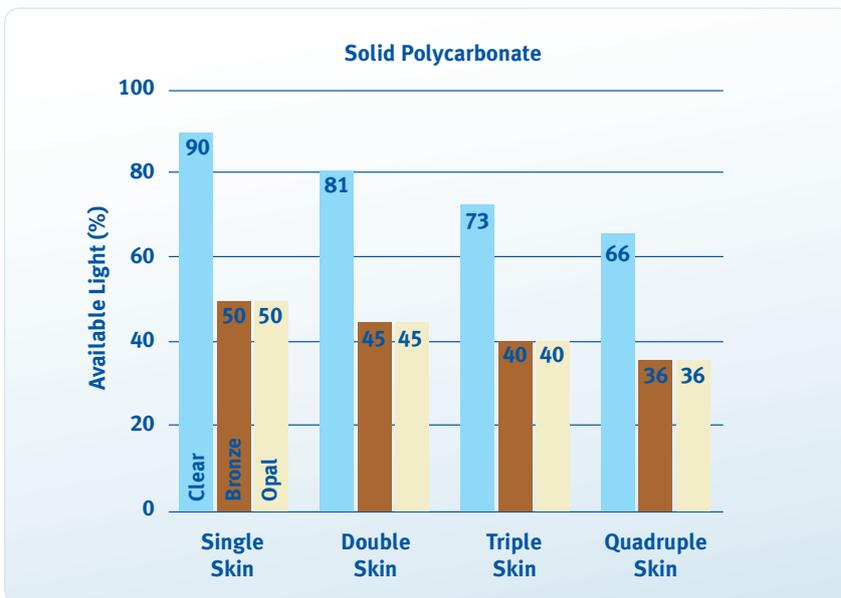
The light transmission (LT) qualities of complete rooflights vary according to the glazing configuration and the LT of materials used. As it passes through each layer, the light transmitted is reduced cumulatively, as shown in the example.

The four charts show the percentage reduction in available light within a building using various rooflight materials and configurations, as follows. Where appropriate, intermediate and inner skins are assumed to be clear polycarbonate.

### Solid Polycarbonate

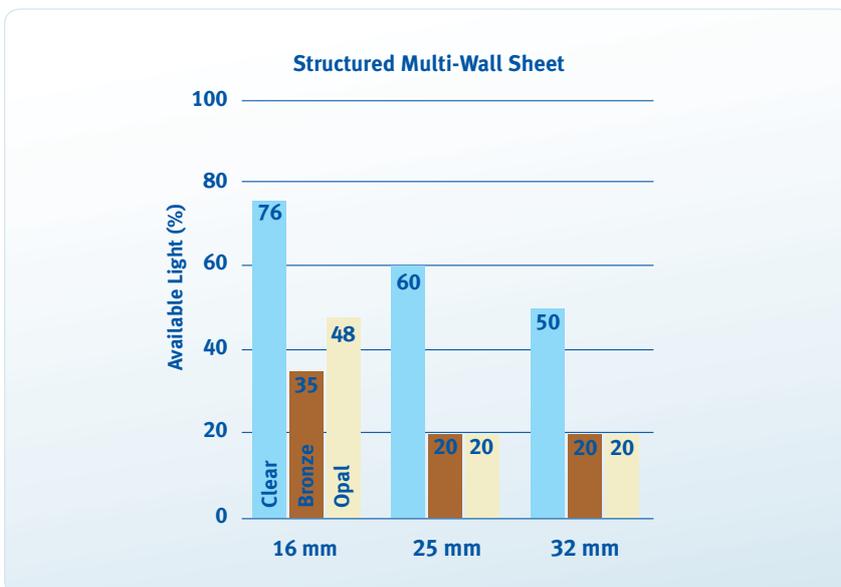
- Single skin—only recommended for unheated areas.
- Double skin—non-preferred as it does not meet current Part L requirements.
- Triple skin—meets Part L and gives improved sound insulation.
- Quadruple skin—further improvement of performance characteristics.

There are substantial differences between various types of polycarbonate with 'Opal' giving only half the LT of clear, while the popular 'Diffused' transmits just 1% less than clear with a very good light spread.



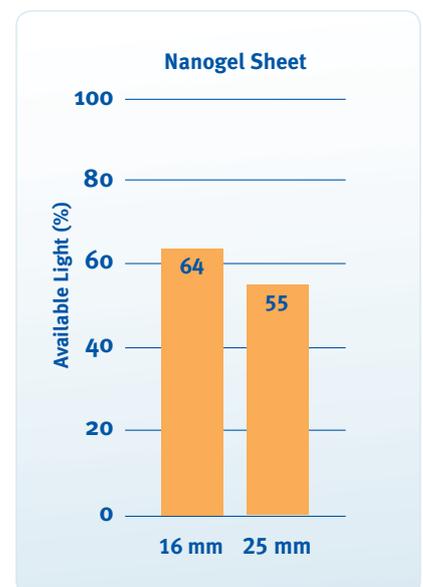
### Structured Multi-Wall Sheet

Available in three thicknesses to suit thermal and other requirements.



### Nanogel® Sheet

The latest advanced glazing technology with excellent thermal, light transmission and acoustic performance characteristics.



# Designing with Daylight

## Types of Daylight

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The materials specified in rooflights can play a major role in determining the type of light, either direct or diffused, and amount of light entering a building. If direct light and diffused light materials have the same light transmission rating they will let equal amounts of light into a building, the light is simply distributed in a different way.

### Direct Light

Direct light passes through rooflight glazing without any disruption or interference and enters the building as a straight beam.

Polycarbonate and clear glass materials may provide direct light.

Direct light:

- Gives strong light in the area of the beam but less general light in the surrounding areas.
- Produces shadows and glare on sunny days.
- Is ideal for environments where the designer wants to create a natural environment and allow the sky to be viewed.
- Gives uninterrupted external vision.

### Diffused Light

Diffused light is when the light passing through rooflight glazing is diffused (scattered) by the materials used for the rooflight.

Polycarbonate, Nanogel® and some patterned and opal-tinted glass materials diffuse light.

Diffused light:

- More evenly distributes light into the building.
- Is useful for creating ambient light over a larger area with minimal shadows.
- Is commonly used for industrial, commercial and sporting facilities.
- Provides privacy.

