Understanding Daylighting of Sports Halls

INTRODUCTION

sportscotland is committed to delivering attractive, healthy, affordable and manageable sports facilities which minimise pollution and hence are environmentally responsible in relation to users and in their impact on the wider world. **sport**scotland is also keen to encourage participation in sporting activity by people of all ages and backgrounds who can benefit from enhanced fitness and social interaction. Improving daytime indoor environments is seen as a significant aspect of improving utilisation by some groups. **sport**scotland is intensely aware of the need for buildings with low running costs, thereby enabling cost of participation to be maintained at an affordable level. Hence they have identified the need to explore best practice in lighting which optimises the use of natural lighting.

Tollcross Park Leisure Centre, Glasgow.
The sports hall with the artificial lighting switched off.

The design issues are complex, even when the building form is not. Optimising natural daylight and integrating it with well designed electric light requires that the form, fabric, internal layout and systems of a building are considered holistically. Problems are real, including glare, overheating and local cooling. Variation in light quality and quantity can be unmanageable and fenestration can lead to unwelcome distractions. Care is required to ensure that inappropriate natural lighting and/or poor control does not give rise to thermal discomfort, which might increase the need for compensatory heating or cooling, or to visual discomfort or impediment. Also window openings are more expensive than opaque alternatives and any life cycle cost, environmental and amenity benefits need to be communicated to clients and funders. Good lighting control is essential if cost benefits are to be achieved.

In recent years there has been extensive research and interest in design guidance for daylit buildings generally, however this publication has been produced to assist designers and cost professionals by providing contemporary, concise guidance on the use of daylight in sports halls in a beneficial and integrated manner. It includes information on sports halls built in recent years where daylight is used and also includes some simple modelling tools to assist designers.

It will be a success if it excites interest and encourages an improved understanding of daylighting design principles and control. It should also provide assistance in communication between the disciplines which can follow through into better quality playing spaces.

SUMMARY

Lighting is a major factor in determining the way in which people experience the internal environment and how they are able to respond to certain tasks. The positive contribution of natural light, in particular, is presently being revisited, following a period when it was largely devalued by artificial alternatives.

Traditional dry sports hall design has tended to exclude natural light. This is a consequence of technical and professional guidance. The resulting designs are rarely compatible with attractive architecture and pleasing indoor environments. This “black box” approach is also incompatible with resource conservation, pollution prevention and cost-in-use savings. The situation in sports halls is exacerbated by the constraints that this approach places on other servicing strategies, in particular ventilation.

It is now more acceptable that daylight, when available, should be the predominant form of lighting in most types of building. If appropriately designed and integrated, it can contribute significantly to distinctive and attractive architecture, and to occupants’ sense of well-being. Daylight, if properly designed into a sports hall, and well controlled, can also offset the energy consumption associated with artificial lighting. This is a significant proportion of overall energy consumption of sports buildings.

This document intentionally focuses on the provision of useful, controllable daylight, however there are wide ranging issues associated with daylighting which also need consideration.

Large buildings such as sports halls have a number of inter-related spaces. The sports hall itself cannot exploit direct sunlight, and passive solar gain. However the building as a whole might benefit by consideration of the appropriate layout.

Large buildings may deny light to neighbouring buildings and this should be considered at the outset if a proper designed response is to be found. Outside playing spaces need attention if they produce light pollution and energy wastage. This should not compromise safety and security.

There is an immense amount of quality documentation on lighting and daylighting and the reader is encouraged to investigate other guidance, including the short list of publications identified, and to seek guidance from those organisations also listed.

The report is intended to be a stand alone guide but the supporting research document - **Daylighting in Sports Halls** - can be obtained from Gaia Research or **sport**scotland

ELEMENTS OF LIGHTING DESIGN

Light Quantity

It is important for sports halls to provide adequate lighting to facilitate safe play to an appropriate standard. The design illuminance (or maintained illuminance) is the minimum amount of light that should be available for a particular task. The minimum quantity of lighting required will depend on the activity and the level of play. The artificial lighting needs to provide this. Daylight can supplement the artificial lighting to add quality and if properly controlled it can replace artificial lighting with savings in cost and energy.

Design illuminance levels for artificial lighting of badminton:-

300 lux for recreational play.
400 lux for training.
500 lux up to and including club and county matches.
1000 lux for television coverage and cricket.

This compares with a recommended illuminance of 100-200 lux for corridors, stairs and lobbies and 300-500 for reading, writing and computer use.

Advice on lux levels is provided by the relevant professional body and this should be followed when designing specialist facilities. However, the majority of halls are multi-purpose and some compromise is required. In the case of multi-purpose halls, it is advisable to design the lighting to meet the requirements of badminton as it is one of the most popular indoor sports and particularly sensitive to appropriate lighting. If the criteria for badminton have been met, then for most recreational and training standards of play the majority of other sports needs will generally be satisfied too.

Lighting Requirements for Sports

Tollcross Park Leisure Centre, Glasgow.
The sports hall with the artificial lighting switched off.

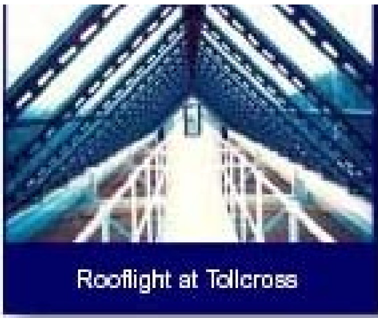
Badminton - Design night time illuminance for a minimum of 300 lux. Uniform, glare free light is vital. Aim for high illuminance levels on all surfaces. Uniformity should be high to prevent fluctuations in brightness from one part of the hall to another. Vertical illuminance should be even as the shuttlecock needs to be visible at height. Artificial lighting should be parallel with the length of the court but outside the boundary lines to avoid glare. There should be no lighting beyond the end of the court. Wall finishes should be matt. Thought should be given to providing a ceiling as bright, or brighter, than other surfaces. Daylighting should be integrated into this scheme. Walls and ceilings should not have strong patterns. To provide good daylighting then rooflights will be required and need to be designed to avoid strong visual patterns appearing from reflected sun on roof structure and other elements .

Basketball, Netball & Volleyball - Lighting advice for these sports is similar to that for badminton hall design. Volleyball uses a white ball, and so has similar colour requirements to badminton in terms of surface colours.

Table Tennis - This sport has strict advice against the use of daylighting. For recreational purposes, a daylit hall might be acceptable to players - if correctly designed. However, club level and above will probably require any daylight to be blacked-out. If daylighting can be tolerated then it should follow a design similar to badminton.

Gymnastics - The British Amateur Gymnastics Association does not encourage daylighting and does not condone the inclusion of gymnastics in the same hall as other sports, due to the specialist nature of the activity.

Fencing & Cricket - Fencing can be satisfied in a badminton designed hall if the luminance can be raised to 400 lux or higher, to counteract the visual impediment of the mask.
Cricket requires high light levelsand evenly distributed light is important with a background contrasting with the ball. In a multi purpose sports hall this can be achieved with white nets.


Rooflight at Tollcross

Integrating Artificial Light and Daylight
All good lighting strategies benefit from a combination of natural lighting and artificial lighting. Most sports facilities accommodate recreational to club level play for the majority of the time. In such situations daylight is generally welcomed. The success of a scheme (aesthetically, functionally and in terms of energy efficiency) will rely on these being well integrated. Proper integration relies on consideration at an early stage of a large range of factors:

window location and design;
how the building will be used, maintained and managed;
the shape and orientation of spaces in relation to activities;
surface finishes, and choice of lamps, luminaires, switches and controls.

It is important to consider the effect of partial daylight and the requirements for artificial lighting at night.
A room needs to be visually bright if it is to be successfully daylit. Sports halls have suffered in the past because they have not been designed to be visually bright. The use of daylight will aid the designer to create a visually bright scheme and to incorporate both artificial lighting and natural lighting with relative ease. This means that it is very important to blend the transition between daylight and artificial light. This can be achieved by using lamps of similar colour temperature to daylight to illuminate ceiling voids and walls.

DAYLIGHT QUALITIES FOR SPORTS

Light Quality

Good lighting enhances the quality of a sports hall and contributes to creating an atmosphere which can add to the enjoyment of play. Both artificial and natural light needs to be of a high standard if players are to be satisfied. Colour and brightness of lighting, its interaction with surface colours, patterns and reflectances are all important aspects.

Martley High School (Hereford & Worcester): showing modern colour scheme - ceiling still has corrugations and shadows but is uplit

People generally prefer a space to be 'visually light' and 'visually interesting'. This is brought about by designing for all surfaces to receive some light, but not all surfaces to be of the same illuminance. Contrasts and colours are welcome. However, too much light coming from a single source, a bright light or relatively small window in a large room, will make it appear gloomy even if it is lit to the correct level. Bright sources also cause glare. In sports facilities this sets up particular constraints especially for competitive play.

Narrow, hidden clerestories and uplighting to the ceiling have the potential to be successful, but the purlins and dark surfaces cast shadows and create contrast. A player will find it difficult to track a fast moving ball or shuttlecock in these circumstances. The window area is too small to provide sufficient daylighting to have an impact on reducing use of artificial lighting. The uplighting is not the most energy efficient solution, despite its potential benefits.

People enjoy daylight in particular but only if it does not distract from the task in hand. People are tolerant of varying light levels if they know that the light is daylight. Daylighting has excellent direction, colour rendering and colour appearance characteristics. It can create illuminance levels which exceed the minimum standards for the particular sport and make it easier to play, as perception of detail increases with increasing illuminance. However, care needs to be taken with glare control.

Capital & Running Costs

Capital cost and running costs are important to the long term viability of a sports facility. Dry sports centres use 11% of their total energy for lighting, and savings to be gained by the correct use of daylighting are significant in economic and environmental terms. Electricity costing is more expensive during the day and hence savings during daylit hours are particularly economic. However, capital costs for incorporating daylighting can be 2 - 3 times that of a plain wall or roof, and maintenance costs are increased. It is therefore difficult to justify on purely economic grounds and it is important that amenity benefits are appreciated and energy efficiency maximised.

Energy efficiency from lighting design relies on the interplay of a number of effects including

- the availability of usable natural lighting;
- how the building is used and managed;
- choice of lamp and luminaire;

- maintenance, decorating and cleaning regimes of lamps, luminaires and surfaces;
- heat gains and losses through glazed areas, and the extent of personal and overriding control including glare management.

All lighting is subject to diminishing output because of ageing and dirt on windows, lamps, luminaires and surfaces. It is important to understand and communicate an appropriate and responsible approach to maintenance at the outset. All of these aspects need to be considered and compared at the design stage if savings are to be maximised.

Good lighting controls are amongst the most cost effective energy measures. An average sports centre could reduce its energy consumption by 30% with better controls, and payback on investment in less than 3 years.

Optimum glazing

The benefits of daylight, and the savings in artificial lighting use, must be weighed up against the energy penalties of rooflights or north facing windows. Sports halls differ from many other buildings due to the need to exclude solar ingress. Hence they are unable to make use of passive solar gains which could also contribute to energy efficiency. A reasonable estimate would be a maximum of 20% glazing area for North facing windows and an optimum of approximately 9% of the floor area for rooflights. See LT Method on Page 15.

Windows should be well insulated to compensate for the lack of solar gain. A minimum specification would be double-glazing and low-e coating. Gas filled cavities and exceptionally low U-values, are usually outside the feasibility of most halls. More coatings and layers of glass reduce the light transmission, but improve the thermal performance.

Using daylighting and good quality controls and artificial lighting is inevitably more expensive than alternatives.
It is therefore important to be able to maximise, calculate and communicate the cost in use benefits as well as the benefits of improved quality of internal environments.
Calculations methods are available with varying degrees of sophistication. The more sophisticated methods do not always transpose well for use in sports facilities because sports halls cannot take advantage of solar gain and because adaptation is a crucial aspect.

COLOUR

> **Classifications of correlated colour temperature**
>
> warm<3300 K
> intermediate 3300 K - 5300 K
> cold > 5300 K

Colour of lighting and surfaces plays a very important part in the appearance, operation and ambience of a space. The most commonly used light sources are classified according to their colour temperature, measured in Kelvin (K). A tungsten bulb has a low correlated colour temperature (CCT) which indicates a warm appearance. Fluorescent tubes get increasingly closer to daylight quality and have a high colour temperature.
The colour temperature of daylight varies throughout the day. Strong midday sun will have an extremely high CCT, whilst sunset will be lower, and therefore warmer in appearance.

Colour Rendering

The colour rendering index (CRI) affects how people view surface colours. It is is independent of the CCT. It is measured and specified as an Ra value, ranging from 0 to 100. Daylit sports halls will have a perfect CRI (Ra100). Sports halls require a CRI of Ra40 or greater so that line markings and playing objects may be easily distinguished. Tungsten filament lamps also have an excellent Ra. Tubular fluorescent lamps have a CRI of Ra50. Lamps such as low-pressure sodium (orange street lighting) have a very poor CRI. If artificial lighting is used with daylight then the CRI of the lamps must be close to that of daylight to enable them to blend. However, it is recommended that designers should aim for Ra80 or more.

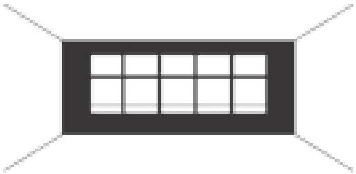
Surface Colour

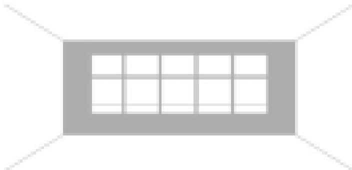
Colour in a sports hall has to be carefully considered, as it will affect the playing ability and comfort of occupants. Colour schemes should be of sufficient contrast to prevent balls, shuttlecocks, etc from ‘disappearing’. Surface colours should be considered alongside, and of equal importance to, the colour of the lighting. There are specific standards set out by the sports councils and associations, depending on what sports are to be played in the hall.

- **Walls (below 3m)** should be uniform, medium tones to contrast with white balls and shuttlecocks.
  - Greens and blues have been successful colours, with warmer colours becoming popular.
  - The recommended wall colour for badminton halls has been cornflower blue, BS 20E51, which gives a pleasant appearance whilst allowing good distinction between the shuttlecock and wall colour.
  - Mortar joints should be designed so that the edges do not catch the light and cause distraction.
- **Walls (above 3m)** should be lighter, to aid light distribution.
  - Pure white is good for lighting but can cause problems for viewing small white playing objects.
- **Floors** should be of a colour which gives contrast to walls. Light coloured timber floors (beech) with a matt varnish are recommended.

> **The Handbook for Sports and recreation Building Design states:**
>
> “Walls should be of a uniform unbroken colour with a relectance value to give sufficient contrast with small, fast moving objects such as shuttlecocks and table tennis balls or for activities like fencing and martial arts”

- **Ceilings** should be of an unbroken light colour with a reflectance value which ensures minimum contrast with sources of illumination in order to reduce glare. White ceilings are least likely to cause complaints.
  - Ceilings are often the worst aspects of a design, often featuring dark purlins, corrugated surfaces and little or no uplighting.
- **All surfaces** should be devoid of any specular reflections, where the image of a window or light source can be discerned.
  - White has been found to be the best background colour and it is recommended that all structural elements, including purlins, are painted to match the soffit.





Reveals

The glare from a window can be minimised by the use of light coloured frames and a light coloured adjacent wall.

Uniformity

The uniformity ratio gives an indication of the variation in light levels throughout a room. Uniformity is the minimum illuminance divided by the average illuminance in a space. It applies equally to daylight and artificial light. Complete uniformity creates a bland appearance, whereas excessive variation can be distracting and have a risk of glare. Sports halls require a relatively high uniformity to allow fast moving players and objects to be tracked with ease across the whole floor area.

Recommended Daylighting Uniformity for Sports Halls

E_{min} / E_{max} >0.7

GLARE

People can carry out tasks over a wide range of lighting levels but this can be impaired when the brightness range within a field of view is too great or when light levels change rapidly. This is because the eye takes time to adapt to different light levels.

The effect of any bright artificial or natural light source, either directly or by reflection, is to create glare and it will cause discomfort or disable a player from performing. Glare cannot be easily classified, other than as disability or discomfort glare. It is complex to estimate, as it depends on light level and location of light source.

Glare is not tolerated at all in a properly designed sports hall. Badminton has the greatest requirement for glare free lighting because players spend a great deal of time looking towards the ceiling, following high level shots of a small, fast moving shuttlecock. Glare free natural and artificial lighting is difficult to achieve and many existing halls have given it inadequate consideration.

A dark ceiling and dark window frames create poor internal light distribution and risk glare problems. The windows have solar control tint which does reduce the sky brightness. However, with direct sunlight there is little effect and the daylight has little opportunity to spread within the hall due to the poor refectivity of the ceiling. Artificial lighting is therefore always required.
There is a one-metre roof overhang, which reduces sunlight access in the summer, but, as this photo shows, is ineffective in winter.

Glare risk can be calculated using the Glare Index calculations found in the CIBSE Code for Interior Lighting. The glare index calculation appears at first sight to be immensely complex and relies on tabulated data for a particular luminaire. One such table and worked examples of the calculation procedure are reproduced in the above publication - Page 13. The information is generally provided by luminaire manufacturers for a particular room, luminaire, mounting height, surface reflectance and luminaire orientation. A Glare Index of 19, or less, is recommended for sports halls.
In an artificially lit hall, glare will come from incorrect luminaire design and layout. High-intensity discharge lamps and other point light sources can create a problem as can poor ceiling illuminance which creates a contrast between light sources and the general backgrounds. Fluorescent lighting has less risk of glare due to lower surface luminance.

South facing clerestorey with sunlight glare

Daylighting poses a greater problem when designing to avoid glare. A clear blue sky, viewed away from the sun, poses little risk of glare although large white clouds can have high luminance and can be a source of glare. Eliminating direct sunlight at all times of the day limits the problem to those periods when the high luminance of the sky near the sun might enter.

When considering both artificial and natural lighting there should be no direct light source above the courts. Halls designed for badminton use fluorescent lighting aligned to the side and parallel to the length of each court. Daylighting should follow this consideration.

Sports Hall with poor window and shading design.
Unwelcome sunlight can enter giving rise to reflections,disability glare and overheating.
Clerestorey lighting can make a space feel gloomy.

Reflectivity

The reflectivity of the walls, ceiling and floor greatly affect the distribution of light within a room. Low reflectivities and dark colours can severely reduce the amount of available daylight. The reflectivity of a surface depends on its reflectance (R), which is defined between 0 and 1. A perfect black surface absorbs all light and R = 0; if all incident light is reflected, R = 1. Reflectance can be specular or diffuse; mirror like or matt. For sports halls, diffuse reflectances are required.

How to Avoid Glare

- Avoid point light sources.
- Hide the source, light the walls.
- Locate luminaires and daylighting above and to the side of badminton courts.
- Light the ceiling, which should be white and uniform inappearance.
- Prevent occupants from seeing bright sources, directly or reflected.
- Diffuse as much light within the space as is feasible, and as efficiently as possible.
- Consider colours that will liven the appearance of a room.

Typical reflectances are: Internal Materials

White Paper	0.8
Stainless Steel	0.4
Cement Screed	0.4
Carpet (Light Coloured)	0.4
Wood (light finish)	0.4
Wood (medium finish)	0.2
Wood (dark finish)	0.1
Quarry Tiles	0.1
Window Glass	0.1
Carpet (Dark Coloured)	0.1

Recommended Reflectance Factors for Sports Halls

walls	0.3 - 0.5
back wall, screens, etc.	0.2
ceilings	0.6 - 0.9
floors	0.2 - 0.4

DAYLIGHT

Daylight

Sunlight is the direct beam of the sun after it has been diffused by the atmosphere. Sunlight is welcome in some buildings, such as homes and intermediate spaces for pleasure and because it is an energy source. In others it can cause a problem. In offices it frequently leads to discomfort and disability glare,and to overheating. It is a major factor in occupant dissatisfaction. In sports halls it should be avoided completely, because of problems from glare. In our latitude the sun is difficult to control because the path is lower in the sky. This means that the biggest problems in terms of solar penetration can be in winter.

Skylight

Light from the sky, which excludes any direct sunlight, is termed skylight. It is now the accepted description for daylight. In the UK, the sky is predominantly overcast. For North European countries the European lighting organisation or Commission Internationale de l'Eclairage (CIE) Standard Overcast Sky is used for modelling and calculating daylight in buildings. It allows for the worst case scenario, in terms of minimum levels of daylight, and refers to a completely clouded sky with an average illuminance of 5000 lux, and the zenith three times brighter than the horizon. This sky type is the basis for daylight factor calculations and measurements. However, for at least 80% of daylit hours, the external daytime illuminance will frequently and greatly exceed 5000 lux. A cloudy day with white clouds and sunlight nearly breaking through will have a horizontal illuminance of about 12,000 lux. .On a sunny summer day, with white clouds, the outdoor illuminance can be as much as 100,000 lux. In much of Scotland the external illuminance exceeds 10,000 lux for 60% of daylight hours and this can make a significant contribution to lighting needs.

Seasonal Affects

The changeability of the weather in Scotland gives rise to problems when seeking to integrate natural and artificial light, but benefit can be made of daylight. The different weather conditions in each season greatly affect the length and quality of daylight. In summer the sun rises high in the sky and hours of daylight are long. It is not the most popular time for people to be indoors, in a "black box", but it is generally believed that daylit sports halls are more likely to encourage year round use. High level sunlight - which is most likely to cause overheating - can be blocked by designed overhangs on south facades, but east and west facades will still receive low level sun. The problem is likely to be more apparent in the west because facilities are used in the evening more than the early morning.

In winter, there are often clear skies, especially in the east. Hours of daylight are short. The sun is low in the sky all day and will enter a building despite any overhangs if adequate shading is not provided.

In spring and autumn the sun rises higher, but dwells for long periods at a low altitude in the mornings and evenings. Rainfall is greatest in the spring and cloud cover can be dense.

Windows

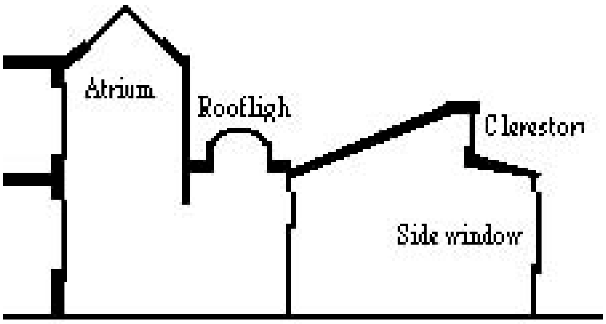
People like daylight and encouraging more daytime use of sports halls is part of the motivation for identifying proper design guidance for daylighting. However achieving the correct window and shading design can be difficult.

Windows have many roles - providing daylight, orientation, views, ventilation, insulation, a sound barrier and glare protection. They affect the internal acoustics, energy consumption and delight and the designer will inevitably struggle to reconcile all the conflicts to a fully satisfactory solution. Noise may be a problem and there may be conflicts in managing the orientation of window openings. Windows are a magnet for thieves and vandals and high impact resistance is required. They also need to be adequately designed and controlled to prevent rain penetration.

Views provided by windows allow people inside a building to relate to the outdoors, relax their eyes and check on the weather. In the case of sports facilities the view out is less important than the quality of light that daylight brings to a space. Daylight can create distractions to occupants who might be involved in intense concentration and becomes an important consideration at high standards of play. Windows at high level, such as clerestories or rooflights, minimise the risk of distractions from movement of people and animals.

Window Types

- Side windows;
- Clerestories;
- Flat rooflights;
- Curved rooflights;
- Roof monitors;
- Atria;
- Sun pipes.



Various Types of Windows

WINDOW DESIGN

Window Type and Orientation

With many building types good daylighting requires attention to space planning. Placing rooms which do not require sunlight or daylight on the north, and leaving spaces for daylight enjoyment and with connections to the outside on the south is generally sought after. For sports halls because sunlight is particularly unwelcome, glazing on the south should be avoided.

Factors Affecting Daylight Through a Window

- The shape of the window opening
- The position of the building
- Orientation
- External obstructions
- Reflectivity of internal and external surfaces
- Cleanliness of the glazing and surrounding surfaces
- Type of glazing

The use of side windows can offset the perimeter lighting but is unlikely to be adequate for full daylighting in deep plan spaces without causing interference with the sporting requirements through lack of privacy, glare or sunlight. Clerestories can provide some connection with outdoors but do not provide an even light distribution and are generally insufficient to daylight a deep space. Rooflights provide a more even daylight distribution. Both clerestories and rooflights are potential sources of glare. Light coloured surrounds and reveals are recommended. Rooflighting is less likely to cause glare than side windows. This, coupled with them being away from the playing area, makes them valuable for sports halls. Rooflights tend to be more expensive than windows due to the structural requirements. They also lose more heat than equivalent glazing specification windows, so increasing the payback period. However, they do provide more light per square metre than windows due to rooflights facing the unobstructed sky vault.

Increasingly clerestories are being combined with rooflights to create a more uniform and higher level of daylight further into a space and this is more suitable for a single storey deep plan space such as a sports hall. North facing windows or rooflights (monitors) are most appropriate. East or west facing windows are prone to low level sunlight access at dawn and dusk, and in winter - requiring careful shading design.

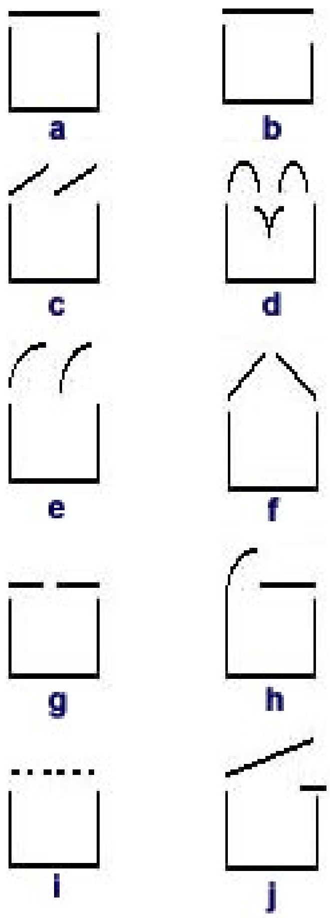
Atria can be designed into the overall space planning of a sports facility and can be used to provide borrowed light into a sports hall. Borrowed light from an internal corridor can also add to the daylighting provision and atmosphere. In all case care should be taken to avoid internal reflections.

Discussion of glazing options

The options for glazing are infinite and the following, along with the case studies, are intended to indicate some approaches. The most popular form of providing natural light is through correctly shaded clerestories and rooflights. Central rooflights or rows of barrel-vaulted rooflights in between courts can be found, and the daylight available from these is sometimes diffused through sailcloth. Other successful daylighting comes from light-coloured, splayed window reveals; light-coloured framing; curved surface transitions between daylit surfaces, and adjustable shading systems. Reflective or diffusive daylighting strategies lower the DFave significantly, but can help reduce any tendencies for glare. Much can be learned from observing daylighting in museums and art galleries.

(a) Clerestories:- north, west, east, - will give rise to solar ingress from morning and evening sun and shading will be required. The extent of intrusion from the West is more evident because our sports behaviour is not symmetrical around midday. We are more inclined to be playing sport at 6 in the evening than 6 in the morning.

(b) North facing clerestorey - it is advisable to provide more glazing to the North which receives sun only for a short period during the midsummer.



(c) North facing roof monitor - properly angled can create good lighting deep into a space

(d) Barrel vault(s) -

(e) North facing curved roof monitors - designing this roof profile can distribute light more effectively.

(f) clerestorey combined with rooflight - increasingly used as a way of evening out the daylight distribution.

(g) as (f) flat roof)

(h) North facing roof light combined with clerestorey - less likely to lead to solar penetration and glare than a central rooflight.

(i) Sunpipes are increasingly popular. They provide daylight from the brightest source (unobstructed sky) but do not require extra shading. The quality of light is excellent but they do not provide the amenity value of windows with views out and hall users may not be aware that it is daylight. They have not yet been incorporated into a sports hall.

(j) Clerestorey and roof monitor combined with light shelf - to reflect light upwards and deep into a space. The overall light available will be reduced but it will be better distributed and reduce glare. Light shelves have special maintenance requirements if they are to be effective but work well with high ceilings with good surface reflectance.

DESIGNING FOR DAYLIGHT

Average Daylight Factor

Average Daylight Factor can be found from summing the daylight available from each window

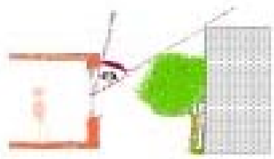
$$DF_{ave} = \sum \frac{T_1 A_1 \theta_1 M_1 + T_2 A_2 \theta_2 M_2 + \ldots}{A(1 - R^2)}$$

T = diffuse transmittance of glazing
M = maintenance factor for glazing
Aw = window area, excluding area of window framing
Θ = angle of visible sky above horizon from centre of window
A = combined area of walls, floor and ceiling (including windows)
R = average reflectivity of room surfaces. **An average reflectances of 0.5 is recommended for sports hall surfaces**

The Average Daylight Factor (DFave) is useful tool for daylighting design. It predicts the brightness of an interior space under daylighting. The concept is best understood by practical experience. It is worthwhile taking time to calculate the DFave in a number of rooms with which you are familiar, and then perhaps to compare your calculations with actual measurements using illuminance meters. This will give a sense of the numbers involved.
The Daylight Factor (DF) defines a constant relationship between a place on the inside of a space and the outside. It is the percentage of the daylight available at an unobstructed place outside which is received at a point inside. [Technically it is the percentage of the unobstructed outdoor horizontal diffuse illuminance which is received indoors on the working plane and walls below.] The Daylight Factor varies throughout a space, tending to be very high near the windows and rapidly decreasing further from them, hence the use of the Average Daylight Factor (DFave) for approximation.
The DFave, across the horizontal plane in the case of sports hall this would be the floor, can be estimated, for an existing design, by using the calculation shown opposite. Daylighting should be designed to compliment or displace artificial lighting for as long as possible during daylight hours. The Average Daylight Factors (DFave) below give interior illuminances as shown. Aiming for a DFave of 2.5% will ensure that on most occasions the illuminance inside due to daylighting will suffice for recreational activities, and during bright conditions may even satisfy club activities. However, it will be found that most sports bodies will prefer the artificial lighting to be on during critical activities to achieve target light levels.

Estimating DFave

For a 3 -court badminton hall, measuring 18m x 27m x 7.6m
With double glazed clerestorey to the north only of 2m x 27m
In a rural clean air environment
With highly reflective internal finishes R=0.5
Angle of visible sky = 70 degrees



$$DFave = \frac{T \times \text{maintenance factor} \times \text{window area} \times \text{sky visible angle}}{\text{Total surface area internal} \times (1 - R^*R)}$$

$$= \frac{0.7 \times 0.9 \times 54 \times 70}{1656 \times 0.75} = 1.9\%$$

The figure is a little on the low side and a re-estimate/ redesign could be undertaken based on some additional North east/north west glazing or rooflights.

Less than 2% a room appears gloomy under daylight alone. Full electric lighting is often needed during daytime and dominates the daytime appearance. Sensitive spaces, such as art galleries, may require low DFave, but generally it is preferred to aim higher.

2% - 5% is usually the optimum range of daylighting for overall energy use. Rooms have a predominantly daylit appearance but supplementary electric lighting is needed away from windows and during dull weather. Most room types benefit from this range of DFave, such as offices, shops, sports halls, warehouses and factories.

Above 5% a room is strongly daylit and daytime electric lighting is rarely needed except perhaps to balance illuminance in dark recesses with the general light level, to avoid glare problems. Such DFave's tend to be found in atria, conservatories, and other large, glazed spaces. In other buildings, with a DFave of 5% or more, unwanted thermal and acoustic effects may arise due to large window areas.

The Angle of visible sky can be measured from scale drawings. Two lines are drawn, converging through the centre of the window, and spreading out to the visible horizon, which are then measured using a protractor

section through rooflight showing angle of sky

Approximate **diffuse transmittance** of clean glazing- T

Clear single glazing	0.8
Clear double Glazing	0.7
Low Emissivity Double Glazing	0.65

This should be multiplied by the appropriate Maintenance factor from the table in the Colour section. Values of Glazing Transmittance (T) for other glazing systems can be found in the CIBSE Daylighting and Window Design Guide Code and from manufacturers.

Average Daylight Factors (%)	Interior Illuminance	
	CIE Standard Overcast Sky 5000 lux	Bright Overcast Day 12,000 lux
1.0% - 2.0%	50 - 100 lux	120 - 240 lux,
2.5% - 3.5%	125 - 175 lux	300 - 420 lux,
4.0% - 5.0%	200 - 250 lux	480 - 600 lux

SIMULATION

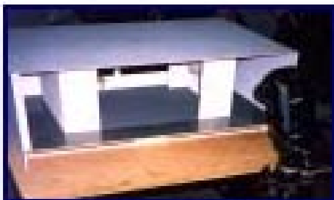
To calculate and judge the effectiveness of any daylighting design strategy it is necessary to perform some form of modelling exercise. Simple hand calculations of average daylight factors to the fully rendered computer images of simulation programs, such as Radiance can be used. The more complex methods are not necessarily the most effective for all situations. Numerical analysis beyond daylight factors can be difficult. Instead, architects and engineers are advised to develop computer visualisation, shaded perspectives and/or models.

Computer simulation requires designers to be fluent in a particular program but it becoming increasingly simpler to undertake. Many engineers are familiar with Cymap, which provides simple daylight factor modelling. Complex tools are now available in PC versions and can be downloaded free from the internet. However, the cost comes in the length of the learning process. This usually requires at least 3 months of training, usually by external tutors.
Programs such as Radiance, allow fully rendered interior and exterior images to be made. Scenes can be input using standard CAD packages and built-up within the simulator. Outputs range from visual representation of a daylit space; full simulation of a year, including sunlight; modelling of infinite forms of structure, glazing, shading and orientations; accurate values of Daylight Factors, illuminance, glare index, colours and the incorporation of artificial lighting schemes.

The Bartlett School of Architecture's computer controlled artificial sun and sky, with model

Modelling

The method traditionally used for daylighting assessment is the scale model. Importantly, light is independent of scale, so a model of any scale can reasonably accurately show the effect of light through windows. A model allows the designer to judge the effectiveness of any daylighting design, if used under a real sky or in a designed artificial sky. Models provide an objective assessment to be made, but are less able to provide detailed measurements. They are an excellent way for design practices to extend their skills without having to invest heavily in computer simulation.
It is usually sufficient to construct a model no larger than a desktop. Surfaces should have the same reflectance and colours as in the completed room. Sensors mounted inside a model can allow a designer to take readings and assess the daylight factors and the physical intensity of light received by, or emitted by, a surface. Window location, shading options and sunlight access - a frequently overlooked part of daylighting in sports hall design - can be assessed.



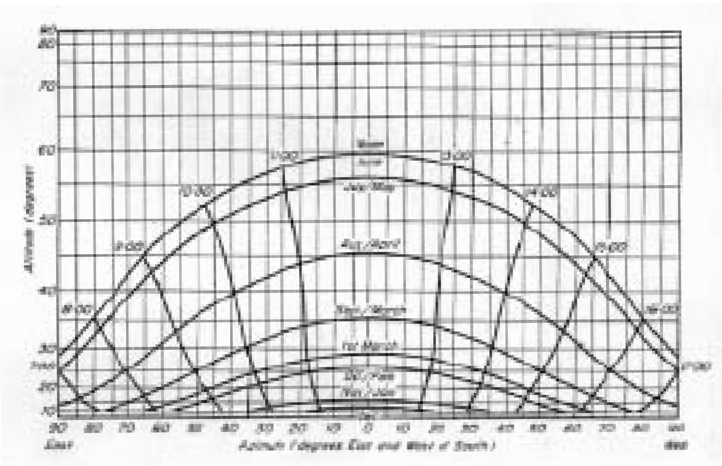
Daylight factors are measured, by placing illuminance meters on a model's roof and on the working plane inside either in a designed space such as an artificial sky or even a simple model in daylight

Experiment in daylight modelling

The DF_{ave} formula can be used in reverse to provide a first estimate of total window size for a particular space with a particular type of glazing for a chosen DF_{ave}, giving information to enable a scale model to be constructed. This should also consider optimum glazing ratios to avoid excessive solar gains or heat loss.

A productive approach for designers is to observe and record the daylighting characteristics of existing buildings. Visual assessment of an interior, and measurement of light levels with an illuminance meter will provide a useful basis for daylighting design. The DFave can be roughly measured to aid comparison between calculation and reality, by using two illuminance meters simultaneously to measure indoor and external illuminance under daylight. The internal measurements should be averaged over the whole floor area. Even a simple box model combined with use of two lux meters and a compass can generate a lot of information.

Orientation to Avoid Solar Penetration



Sunpath diagrams are available for all regions. These provide information on the path of the sunpath for particular times of year and day. These sunpath diagrams are useful in estimating depth of solar penetration into a space and in designing appropriate overhangs and louvres.

The example above indicates the need to prevent solar ingress from high level in the summer but the sources of glare extend into the winter with low level sun a particular problem.

The fact that we do not carry out social activity symmetrically around mid day means that the low level sun in the evening to the west is likely to give rise to more complaints than the early morning sun to the east.

DESIGNING ARTIFICIAL LIGHTING FOR DAYLIT SPORTS HALLS

Energy Efficient Lighting

- maximise natural daylight.
- avoid unnecessarily high illuminance.
- incorporate the most efficient luminaires, control gear and lamps.
- include effective lighting controls.

The CIBSE recommends that for energy efficient lighting the criteria shown on the left should be followed. For sports halls, 'optimise' replaces 'maximise' for natural lighting. This is because daylight in a sports hall must not contain any direct solar component. Therefore, optimising the available natural light in conjunction with the expected heat losses, internal gains; ventilation and heating requirements, will produce a hall that is energy efficient and functional.

Artificial Lighting

Buildings should utilise daylight as much as possible. However, electric lighting will be required on dull days and at night. The source of artificial light for a sports hall will greatly affect its lifetime energy consumption. Good control is essential. Combined lighting requires lamps with a colour temperature of about 4000K, to match daylight, and these should be screened from view to avoid glare and direct comparison between daylight and a bare lamp. Luminaires must be compatible with sport, and as such usually feature anti-glare louvres.

The Apollo Corso, dimmable flourescent luminaire for sports halls
© Apollo Lighting

Most "black box" halls have tended to use high-intensity discharge lamps, but modern preference is for high frequency dimmable fluorescent tubes in luminaires with deep louvres. A study by Sport England of energy efficiency and ambience indicated that compact fluorescent represented best value and should be specified for sports halls. The efficiency of high frequency fluorescent lighting is up to 30% better than standard fluorescent, and also has the benefit of dimming. Initial costs are greater, but this is soon paid back in reduced running costs. For daylit halls, fluorescent lighting is the only acceptable light source to match the daylight. Alternatives, such as mercury halide and sodium are less popular, as they are difficult or impossible to dim; have long warm-up periods and are point light sources. Fluorescent lighting is less prone to glare problems and, in both linear and compact form, can be integrated successfully with daylighting because of their good colour matching. There are several types of fluorescent luminaire on the market, one was specially designed for sports halls. Other, linear types, can be used successfully if fitted with louvres to avoid glare.

Flickering lights are a source of discomfort. It is common practice to use high frequency control gear in fluorescent lighting systems to raise the oscillation rate to one which is indetectable to humans and increases lamp efficiency.

Low Illuminance and High Illuminance

Attitudes towards office and sports hall lighting have both changed dramatically in recent years. Previously lighting design tended to focus on illuminating the workplane, be it desk or sports hall floor, to a specific illuminance. For offices and sports halls, 500 lux was normal, when 300 lux could often suffice for most situations. More recently a lower background lighting level with task lighting has improved energy efficiency in offices, however this is not recommended for sports halls, where large distances and heights are covered in a short time by people and objects. Offices and sports halls are now benefiting from the use of ‘high illuminance’ lighting. This refers to the appearance that a room takes on when the light is allowed to shine on all surfaces, such as walls and ceiling, rather than just the work/playing plane. A room appears much brighter and pleasant, and does not necessarily require increased energy use - especially if daylighting is included in the design.

Sport & Community Centre: Dark coloured ceiling and point light sources

The lighting design needs to consider the colours and reflectances of the hall, and vice versa, so that areas such as ceilings are illuminated correctly. The photo on the left shows the ceiling of a daylit hall, which is grey and is of a low reflectance. The chosen luminaires are capable of providing uplighting, but this facility has not been used here, and even if it were, the poor ceiling reflectance would not help. The ceiling also appears cluttered, which does not help badminton players.

One reason for the ceiling’s poor appearance may be the incorporation of the perforated acoustic panel because the hall is multi-purpose, hence demonstrating the conflicts to be resolved in much sports hall design. The inclusion of facilities for theatre and music can be assumed from the row of stage lights on the beam.

COLOUR RECOGNITION

Colour recognition in sports halls is important for distinguishing the various court markings and playing objects. Modern fluorescent lighting can be designed to closely imitate natural light. Fluorescent lamps can have a CCT range between Ra50 and Ra80. High temperature light sources (such as tungsten halogen) can achieve higher values of Ra, but are inefficient for sports halls. Fluorescent lighting and that from mercury halide lamps are most suitable. Low pressure sodium lamps (street lamps) are unsuitable for sports halls.

The transition between daylit and artificially lit areas of the hall are helped by the close match between the daylight and fluorescent lighting.
Luminaire layout should co-ordinate with the badminton courts. Other sports will then be satisfied too.

In order to achieve the best of artificial lighting and daylighting levels it is imperative to design the lighting and its control system so that the artificial lighting attains an illuminance suitable to the sport taking place, but will set-back to allow daylight to replace it, when available. This requires a lighting system of similar characteristics to daylight in terms of both colour temperature and colour rendering, see photo on right.

Other methods of integrating daylight with artificial light include hiding the light - either the artificial or daylight source - so that differences between the two are indistinguishable. Hiding sources could involve uplighting, but this can also increase the energy consumption of artificial lighting due to the losses encountered when reflecting light. A compromise is often sought, which must not be to the detriment of the occupants.

Reflectivity

Surface reflectances are the same for daylit and artificially lit halls, with perhaps higher reflectances on the surfaces around and “visible to” the windows. This reduces contrast and avoids glare. Ceilings must have a high reflectance (0.8) and this is especially true for halls with rooflights.

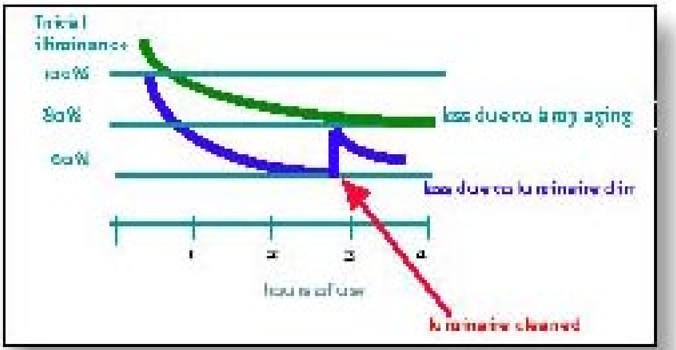
Uniformity

The uniformity of an artificial lighting installation must be close to that for the daylighting in order to provide an integrated light source. It is possible to increase the uniformity of artificial lighting so that it can counteract any offset from the daylight. Particular care must be taken when arranging the layout of the luminaires. For badminton halls, the lights must be placed outside the area of the courts, as can be seen in the photo (right). This avoids players having to look up directly into the lights. Doing this also decreases the uniformity, which must be counteracted by increasing the number of luminaires, with an increase in energy consumption being an unfortunate by-product.

The Shape of a Sports Hall

The shape of a sports hall is largely governed by the number and types of sports taking place in it. For instance, halls are usually based on numbers of badminton courts. Common layouts are 3 , 4 , 6 and 8 court. For a badminton based sports hall, a minimum ceiling height of 7.6 metres is recommended by sportscotland. Floor dimensions for the principle sports can be found from the sportscotland guidance publications.

The designs can therefore be based around simple box forms and any windows should be part of the structure outwith the playing volumes. The orientation of the hall is very important when it comes to daylighting, and is directly related to how the windows will be placed in the structure.



Lamp Selection

Factors to consider in selecting lamps:

modelling of projectiles
dim or stepped switching
Installed cost
power consumption
re-lamping cost
sensible lamp life
colour quality
colour stability
frequency/strobe
warm up time
presence detection/economy
emergency use
black hole if lamp fails
perceived brightness

Maintenance

The maintenence requirement of a glazed area depends in part on its vulnerability to dirt and these need to be factored into any calculations about light transmission.

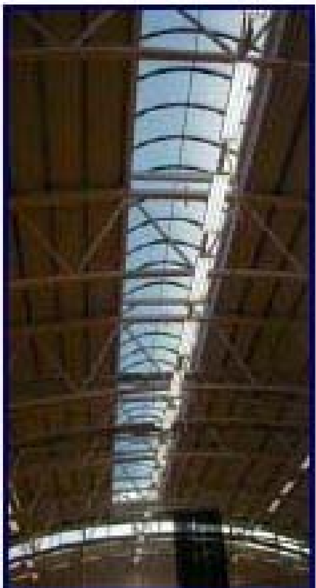
Maintenance Factors for Daylighting Calculations

Angle of glazing	Atmosphere: clean	urban	industrial
Vertical	0.9	0.8	0.7
Sloping	0.8	0.7	0.6
Horizontal	0.7	0.6	0.5

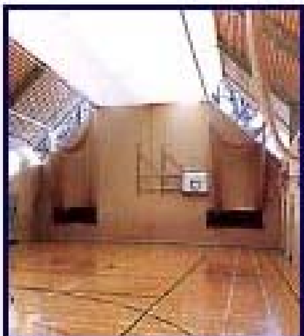
CONTROL AND INTEGRATION OF LIGHTING

Daylight Linking

If designers go to the trouble of producing a daylit sports hall, they must be prepared to include the correct lighting and daylighting controls. Otherwise, the hall will not be popular with users and it will be expensive to run.



Holyrood Sports Centre, Glasgow: central barrel-vaulted roof light and clerestories on end walls.



Brune Park School, Hampshire

Daylight alone does not deliver energy efficiency. Daylit sports halls are only energy efficient if the artificial lighting can respond to the levels of daylight. Although there will be amenity benefits, energy and running cost savings will not be achieved. Staff and users cannot be expected to control the lighting in response to daylight. Where possible, lighting should be zoned to enable fewer lights to be used with intermediate daylighting strategies (where possible photocell control to adapt to daylight) and to suit the activity taking place and the areas in use.

The flexibility required will depend on the type of space and the way in which it is used and should be discussed at the design stage. A sports facility requires zoning to respond to use of individual courts and play areas and will require consideration of the varying occupancy patterns, including cleaning regimes.

Daylighting control

Lighting control consists of switches or dimmers or a combination of the two. Time switches, occupancy or absence detectors, light sensors (photo-cells can all contribute on their own or in combination. Control is best achieved by using daylight-linked, dimmable, high frequency fluorescent lighting with occupancy sensing altjough there is a cost. Problems often occur with automatic lighting and good commissioning is important if these problems are to be minimised. ON/OFFphoto-electric switches are not always enjoyed by users, who like to have some control over their lighting environment. Occupants are particularly frustrated when lights are on when they need not be and provision of a manual switch will often be beneficial. They can have a place in spaces where users do not readily take control but should always be unobtrusive. In general absence as well as occupancy sensors are useful. Care is needed in design and repeat commissioning of stepped switching if it is to be popular with users. Too often the levels set mean that users have an additional complication to deal with. Typical problems include all the lights coming on and dimming and control over the wrong banks of lights.

Shading Types

An early example of a daylit sports hall can be seen on the left. The mercury halide lighting and rooflights are hidden behind a large sailcloth canopy (velarium). The result is successful in terms of occupant satisfaction, but the diffusion cuts down on both the efficiency of the natural and the artificial lighting.

It is imperative that good quality shading is provided, which is effective all year round, in order to provide effective daylighting in a Scottish sports hall. Many halls are constructed with fixed shading, for example, a one metre eaves overhang where clerestories are used. This is effective only when the sun is high in the sky, and does not effectively block out sky glare.

East and west facing windows require diagonal or vertical shading and louvres, whereas south facing windows are better suited to overhangs and horizontal louvres.

Rooflights can be effective for most of the day if orientated east to west along the highest part of the roof. Midday summer sun can enter for a short period and be controlled with movable shading.

- Movable elements, such as motorised external louvres and interpane Venetian blinds are effective, but cannot provide complete black-out;
- Blinds or louvres that are capable of allowing maximum daylight through when not required for shading sunlight will give greater savings on daylight-linked artificial lighting;
- All high level movable shading requires a form of remote control.

External Shading

- Reveals.
- Horizontal overhang.
- Vertical sun-screen.
- Rotating panels.
- Horizontal and vertical overhangs.
- Rollershades with vertical slide bar.
- Awnings.
- Shutters - sliding or rotating.
- Vertical or horizontal fixed louvres.
- Vertical or horizontal movable louvres.
- Lightshelves.
- Trees and vines.

Interpane Shading

- Ventian blinds.
- Roller blinds.
- Prismatic elements.

Internal Shading

- Roller blinds.
- Venetian blinds.
- Reflective blinds.
- Prismatic glazing.
- Curtains.
- Tilted and/or reflective surfaces.
- Lightshelves.

The Fabric of a Sports Hall

The materials from which a sports hall is constructed play an important part in its capital cost, running costs, acoustics, appearance and thermal response. Lightweight constructions, such as timber; steel frame and cladding, require less warm-up time, but are more prone to overheating in the summer. Heavyweight buildings use blockwork or monolithic construction and provide a more stable thermal response. Windows themselves create particular problems, especially in terms of thermal performance and acoustics. For many halls, it is the roof that provides the acoustic tuning opportunity, and for daylit halls, this is where windows are often located. Consideration for both, and the requirement to provide an unbroken, light coloured appearance mean that the ceiling is often one of the most

An alternative glazing system, Kalwall, is now available from the USA which incorporates the light transmission properties of an opaque window and the insulating properties of super-glazing. The light qualities are a significant improvement on plain glass, with the light being totally diffused and spreads further within the room.

critical areas of design, and frequently the one that suffers due to poor attention to detail. Surface finishes can be a source of problems. Reflections from floors and backboards are common. Poor selection of window surrounds contributes to problems of glare. Even standard blockwork finishes can be problematic with light reflecting off edges giving rise to unwelcome patterns of light which can disrupt play.

Ventilation

Window design should be an intrinsic part of the ventilation strategy and the building manageability will be much reduced if this is not planned at the outset.
In general sports halls do not have to account for high heat loads or require humidity control and well designed natural ventilation will often be adequate. Trickle vents can provide background ventilation. Openable windows at high level allow excess warm air to be released and cooler air to be drawn in at lower level.

For the majority of sports facilities mechanical vent should only be required when the hall is in continual use or is occupied by a large number of people. It should be variable volume and effectively controlled. Interlocking window openings, occupancy and ventilation will improve efficiency

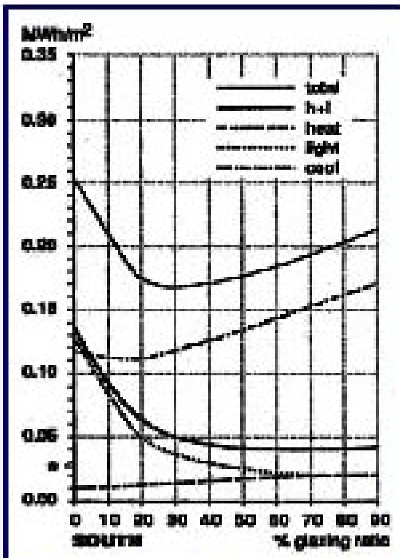
However conflicts arise with some sports because of the internal air movement which can be generated by natural ventilation and for this reason some kind of mechanical ventilation is often preferred. Dynamic Insulation has been shown to have benefits in delivering pre-heated ventilation air at low velocity to a space in combination with natural ventilation in summer conditions - but air movement may be unacceptable

Situations may also arise where high level play requires that daylight is excluded and windows closed to keep air movement to a minimum. These issues need to be resolved at the outset and either fully designed solutions sought or clients and funders need to be made aware of the design limits. Contingency sums or charges established as part of any cost model may be identified to provide for occasional temporary shading for example.

LT Method

The Lighting and Thermal (LT) Method provides a means of estimating, during the initial design stages, the optimum amount of glazing needed. Consideration of efficiency gains from daylighting and thermal losses due to glazing generates an optimum for a particular set of criteria.

Designed mainly for office and institutional buildings, it can be applied to sports halls as general guidance. The principal difference encountered when using LT for sports halls is that all solar gain should be excluded from a hall. Therefore, whilst the LT method indicates the optimum proportion of glazing to wall area is 30% for a south facing aspect, this is inappropriate for sports halls. The method is more appropriate for designing the ancillary spaces of sports facilities but is a useful guide.



A typical graph from the LT Method showing optimum glazing ratios.

CASE STUDIES OF DAYLIT SPORTS HALLS

Tollcross Leisure Centre, Glasgow

The sports hall exterior, showing the central rooflight and end window.

The centre was opened in 1996 and was designed by the City Council's architects

Measurements

- Date: 15/2/01 Time: 11:00 - 14:00
- Weather: Overcast with some sun later on.
- Daylight Factors in the hall were measured between **1.8** to **2.3**.
- Average daylight illuminance: **212 lux**.
- Average fully lit illuminance: **445 lux**.

The hall with daylighting only. Looking southwest.

Looking up into the rooflight. The sun is shining on the white painted metalwork. The catwalk adds significant cost to the hall, but is a necessity at these heights, for cleaning and maintenance.

Bright patches shining on the wall and floor, from the bright sky close to the sun. Direct sunlight was not entering.

Lighting

The central rooflight provides a reasonable level of daylight into the hall, as it is not shaded. Sunlight is not supposed to reach the players as it is blocked by the geometry of the rooflight and roof shape. However, during late afternoons in winter and lunchtime in the summer, players have complained about the sunlight.

The light levels in the hall are acceptable for recreational and club use for all the sports. However, daylight levels are too low (without any artificial lights) for most activities, although less critical ones could function with reduced use of artificial lighting.

Details:

- Length - 34.1 m, Width - 32 m, Height - 7 to 8.75 m.
- Window orientation is southeast to northwest, length ways.
- Orientated with the width facing southeast/northwest.
- Steel frame with profiled sheet metal cladding to roof and walls.
- Internal walls have MDF lining for rebound panels, painted turquoise, up to 4 m above floor level and white steel sheet and plasterboard above.
- Ceiling is white painted profiled sheet, with white trusses and unpainted galvanized purlins.
- A light coloured beech Junckers floor.
- Duopitch ridge rooflight runs the length of the hall at the roof apex.
- A small area of glazing is located below the end of the rooflight.
- The rooflight is a patent aluminium, double-glazed system, with dark blue frames and a solar control tint.
- Rooflight 3m high and 4.5m wide.

Glare and Occupant Satisfaction

Users and staff are generally satisfied with the hall. A few complaints are received about the sun access.

Sky light coming through the rooflight is glare free, due to the solar control tint in the glazing; reducing the brightness of the sky. Direct sunlight is the only cause for concern where it reflects off the roof trusses and shines through onto the wall. Any glare problems that are evident, on direct viewing of the glazing, might be due to the fact that the glazing bars are dark blue, rather than white. The dark blue contrasts with the bright sky.

Rooflights along the edges of the hall would help to make the daylight levels more uniform and brighter. Normal operation of the hall, at present, means that the artificial lights are on all day, which themselves are glare free due to their relationship with the badminton courts and the louvres in the luminaires. Ceiling brightness could be improved by having a degree of uplighting from the backs of the luminaires.

Costs

Life-cycle costs and cost in use were not considered for this hall. No external daylighting guidance was used for the costing of the hall, the architects had specified the glazing system previously and were building on this experience.

Forth Sports and Community Centre, South Lanarkshire

This facility, in Forth village in South lanarkshire, was opened in October 1999, and was designed by South Lanarkshire Council.

The southeast fascade. The sports hall is to the rear, left.

Measurements

- Date: 14/2/01 Time: 10:30 - 12:30
    - Weather: Clear blue skies, hence daylight factors could not be calculated.
    - Average daylight illuminance (sunshine outside): **150 lux**.
    - Average combined illuminance (75% lighting): **350 lux**.
    - Average fully lit illuminance: **390 lux**.
    - Sample sunpatch illuminance: **4300 lux**.

Looking northeast. Sunlight enters the hall for a large part of the day, during clear weather, and causes the players to be blinded. Shuttlecocks passing through the air were observed to 'flash' as they passed through the sunbeams. Drawing the divider curtains lowers the DF_{ave}, especially in the centre court.

Looking southwest, with the eaves overhang doing little to block out the glare from the sun. Window surrounds are white, but the ceiling is too dark.

Sunlight shining off walls, curtain and floor.

Lighting

The daylighting from the clerestories is from unshaded, transparent windows. This has resulted in glare complaints from the users. The one metre overhang of the roof does not stop the low level sun from entering the hall.

The readings across the hall vary widely due to the sunny conditions outside. On an overcast day the readings would be more uniform, due to the 360 degree clerestories and the regular spacing of the luminaires. Despite the very bright conditions outside, the daylight illuminance in the hall is poor. Most activities in the hall are recreational level and so the average level of 350 lux over the whole hall is acceptable, using two thirds of the artificial lighting capacity. This is the normal lighting level for the hall, with the full lighting capacity rarely being used.

Close up external view of clerestories and eaves overhang. Reflective coating can be seen on the windows.

Occupant Satisfaction

The sunlight was the main source of occupant complaints, exaggerated by the direct sunlight beaming in at certain points in the hall - causing disability and discomfort glare. The artificial lights were always on as it was too gloomy without them.

Construction

Length - 27.1 m, Width - 18.1 m, Height - approx. 8 m.
Blockwork walls, painted light blue with steel frame supported roof.
Internal walls have no rebound panels.
Ceiling is light grey coloured acoustic mesh, metal panels on white steel trusses.
A neutral coloured Granwood block, sprung floor.
Clerestorey windows, all around perimeter at approx. 7 m above floor.
Windows are 1 m2 sections of 5 or 6 sections per bay with green aluminium frames.
Double-glazing with reflective coating.
Window orientation is 360 degrees.

Do

Visit existing daylit sports halls to inform your design process.
Speak to the staff and users about their hall.
Check orientation, location and type of glazing.
Check lighting layout, type and control method.
Note the sunpath and any obstructions
Note successes and failings in relation to solar penetration, glare and controls
Use other building types for informing the design of the proposed hall.

Realise that each site will require a different solution.
Note the sunpath and external obstructions around proposed building.
Consider the impact of the proposed building on light available to nearby buildings.
Block sunlight access to the sports hall at all times.
Other spaces should maximise south facing aspects for views, solar gain and external space.

Seek a working knowledge of daylight to inform your design
Try to get a hands on feeling for lux levels
Understand Daylight Factors and how they inform the design process
Be aware of the differences between sunlight and daylight.
Understand the relationship between heat losses and gains through glazing.
Be aware of specific issues relevant to sports halls - avoid solar penetration & glare.

Use average daylight factor to estimate initial design proposals. Aim for 2% to 5%.
Be aware of glare from the sky, and the role of internal surfaces in creating glare problems.
Locate windows to ensure relatively uniform daylight distribution.
Remember that worst times for sun access can be during the winter, spring or autumn
Use double glazing as a minimum specification for windows.
Try to model or simulate the building before construction.
Avoid dark surfaces next to windows

Understand the requirements of the relevant sports bodies and agree the likely standard of play.
Design the artificial lighting to suit the sport requirements.
Achieve a visually bright interior but consider sports requirements (e.g. ball colour, speed & flight).
Avoid reflective floor finishes.
Light the ceiling - both night and daytime use.
Illuminate walls
Consider the need for and design of appropriate shading for specialist events (and any specialist budget)
Try to avoid unnecessary roof structural componenets which can cast gloomy shadows.

Passively ventilate if possible using the windows.
Consider remote opening, high level windows to aid ventilation.
Interlock window opening and heating/mechanical ventilation to aid efficiencies
Consider maintenance of shading and glazing systems.
Realise that high level windows require safe maintenance access.

Use simple and easily understood controls for lighting and other services.
Use occupancy sensor switching as a bare minimum to lighting control.
Control artificial lighting in relation to the available daylight.
Provide controllable shading.
Interlock blinds and lighting control if possible to avoid blinds down/lights on situations.
Train staff to use the controls, and explain the benefits of correct control.

Pay attention to the cost constraints particular to a sports hall.
Be aware that adding daylight to any space will add to the capital costs.
Ensure that the daylit design will actually save money when running.
Ensure that the daylit sports hall will be comfortable to use.
Put aside a contingency fund for post-occupancy adjustments.

Don’t

Proceed without considering the most contemporary lighting and daylighting advice
Miss the opportunity to investigate lighting and daylighting in real buildings and documented case studies.
Forget that many sports facilities are community centres.
Forget the amenity benefits of even a small amount of daylight.
Imagine that one size/design fits all.
Ignore the impact of the proposed building on light available to nearby buildings.
Miss the opportunity to maximise south facing aspects of other regions of the building for views, solar gain and external space.

Expect to get by with no working knowledge of lighting and daylighting.
Treat it as a burden - daylighting can be one of the most enjoyable and rewarding aspects of building design.
Design without considering all options for providing daylight.
Forget that modelling and simulation are relatively easy to do for lighting.
Forget that sunlight and daylight are different.
Proceed without an understanding of the likely standard of play and any special needs.
Forget that all sporting activities are prone to suffer from sunlight access and that badminton players are particularly susceptible to incorrect lighting (natural or artificial) from overhead..
Forget to provide blackout facilities if they will be needed or other controllable shading

Use excessive amounts of glazing.
Over illuminate - artificially or naturally.
Neglect heat losses through glazing or the influence of windows on ventilation.
Use single glazing
Allow glare to be a problem.
Ignore sky glare
Locate all windows so that daylight comes from one direction - as the rest of the space will seem gloomy.
Allow hall users to be distracted by external movement from people, cars, etc.

Leave the lights on if there is sufficient daylight.
Forget about night-time lighting requirements.

Create a dull interior - or forget to light the ceiling for day time and night time use
Use reflective finishes even on the floor.
Forget maintenance of shading and glazing systems.

Assume complex control systems will be used - most staff are not trained to deal with them.
Forget that adding daylight to any space will add to the capital costs.
Try to save money on controls at the expense of user comfort and efficiency.
Forget daylighting alone does not save money.
Neglect the benefits of occupancy sensor switching as a bare minimum.
Control artificial lighting in relation to the available daylight.

Forget about the seasons and the changes in daylight.
Forget that worst times for sun access are not just summer.
Expect a cheap design to be successful.
Ignore advice from sports bodies or colleagues.
Expect it to work perfectly from day one.

FURTHER READING

This report is intended as a stand-alone document. However, to achieve a greater understanding the following references could be consulted:

- **DfEE Lighting Design for Schools, Building Bulletin 90, HMSO, 1999**. An indispensable guide to lighting of schools which provides a good basic grasp for adaptation to other building types.
- **Designing Buildings for Daylight, Bell J. & Burt W., BRE 1995**. A thorough guide to daylighting in general and an excellent self-learning tool:
- **The Design of Lighting, Tregenza P. & Loe D., E. & F. N. Spon, 1998.** For an in-depth view of the whole lighting process, including daylighting:
- **CIBSE Daylighting and Window Design, LG10:1999**.
- **BRE Environmental Design Guide for Naturally Ventilated and daylit offices**

A large range of BRECSU publications give guidance on energy efficient design of sports halls lighting in general and some specific documentation of daylighting in sports halls. They can be contacted at brecsuenq@bre.co.uk
or 01923 664258. Free publications include:

- BRE IP 6/1996 People and lighting controls.
- BRE IP 16/1998 Interior lighting calculations: a guide to computer programs.
- BRE IP 2/1999 Photoelectric control of lighting: design, setup and installation issues, 1999.
- DETR GPG 272/1999 Lighting for people, energy efficiency and architecture.
- DETR GPG 245/1998 Desktop guide to daylighting - for architects.
- EEO Econ 19 Energy Efficiency in Offices, 1991

The Green Guide to the Architect's Job Book, RIBA Publications. 2000 is a guide to the design process and integration of life cycle thinking which underpins sustainable building design:-

Useful Organisations

BRE Building Research Establishment is a centre of expertise on many aspects of the built environment and has a wide range of facilities for daylight modelling.
www.bre.co.uk

BRECSU - BRE Construction Support Unit has published a great deal of usefull information on lighting and daylighting and has an active research programme. A large number of their publications are free and some of the most valuable are listed in the bibliography.
email: brecsuenq@bre.co.uk

CIBSE - Chartered Institute of Building Services Engineers. The professional body for services engineers in the UK. They have specialist groups involved with lighting and run events and produce publications on relevant aspects.
www.cibse.org

Of particular value is the Society of Light & Lighting which can be contacted through the CIBSE web site.

CIE - Commission Internationale de l'Éclairage
The International Commission on Illumination is an organisation devoted to international cooperation and exchange of information among its member countries on all matters relating to the art and science of lighting. Its membership consists of the National Committees in 34 countries and one geographical area and of 6 individual members. The CIE is recognised as the authority on all aspects of lighting.

GLOSSARY OF TERMS

A selective glossary has been included to assist readers in the understanding of the technical lighting terms used throughout this report.

Adaptation - The process which takes place as the visual system adjusts itself to the brightness or the colour of the visual field. Also used to denote the final state of this process. For example ‘dark adaptation’ when the visual system has become adapted to very low illuminance.

Average Daylight Factor - The average of daylight factors over a reference plane or planes. In the case of this report, it is the average over the floor surface level.

Average Illuminance -The mean illuminance over the specified surface.

Brightness - The subjective response to luminance in the field of view dependent upon the adaptation of the eye.

Colour Rendering - The appearance of surface colours when illuminated by light from a given source compared, consciously or unconsciously, with their appearance under light from some reference source. ‘Good colour rendering’ implies similarity of appearance to that under an acceptable light source, such as daylight.

Colour Rendering Index (CRI) - A measure of the degree to which the colours of surfaces illuminated by a given light source conform to those of the same surfaces under a reference illuminant, suitable allowance having been made for the state of chromatic adaptation.

Colour Temperature - The temperature of a ‘full radiator’ which emits radiation of the same chromaticity as the radiator being considered.

Contrast - Subjectively the difference in appearance (brightness or colour or both) of two parts of a visual field seen simultaneously or successively. Objectively, the luminance difference between the two parts of the field.

Correlated Colour Temperature (CCT) -The temperature of a full radiator which emits radiation having a chromaticity nearest to that of a light source being considered, eg., the colour of a full radiator at 3500 K is the nearest match to a white tubular fluorescent lamp.

Daylight -The combined effect of sunlight and skylight. In this document, the word daylight is used as a general description for natural lighting in a sports hall, and refers to the skylight.

Daylight Factor (D) -The illuminance received at a point indoors, from a sky of known or assumed luminance distribution expressed as a percentage of the horizontal illuminance outdoors from an unobstructed hemisphere of the same sky. Direct sunlight is excluded.

Daylight Factor - Externally Reflected Component (De) -The illuminance received directly at a point indoors from a sky of known or assumed illuminance distribution after reflection from an external surface.

Daylight Factor - Internally Reflected Component (Di) -The illuminance received at a point indoors from a sky of known or assumed luminance distribution after reflection within the interior.

Daylight Factor - Sky Component (Dc) - The illuminance received directly at a point indoors from a sky of known or assumed luminance distribution.
Diffuse Reflection - Reflection in which the reflected light is diffused and there is no significant specular reflection, as from a matt paint.

Diffuse Lighting - Lighting in which the luminous flux comes from many directions, none of which predominates.

Disability Glare - Glare produced directly or by reflection that impairs the vision of objects without necessarily causing discomfort.

Discharge Lamp - A lamp which produces light either directly or by the excitation of phosphors by an electric discharge through a gas, a metal vapour or a mixture of gases and vapours.

Discomfort Glare - Glare which causes visual discomfort.

Downlighter - Direct lighting luminaire from which light is emitted only within relatively small angles to the downward vertical.

Efficacy - See luminous efficacy.

Energy Management Systems (EMS) - Computer based systems for controlling the energy use of a site, a single building or a section of a building. The signals which initiate the controls may be related to time of year, month, week or day, maximum demand or power factor, daylight availability, occupancy, etc.

Glare - The discomfort or impairment of vision experienced when parts of the visual field are excessively bright in relation to the general surroundings.

Glare Index System - A system which enables the discomfort glare from lighting installations to be ranked in order of severity and the permissible limit of discomfort glare from an installation to be prescribed quantitatively. Information usually provided by manufacturers but can be calculated for pre-prepared tables for a particular luminaire.

Group Lamp Replacement - A maintenance procedure where all lamps are replaced at one time. The lumen maintenance characteristics and probability of lamp failure dictate the period after which bulk replacement, usually linked with luminaire cleaning, will take place. It has visual, electrical and financial advantages over the alternative of ‘spot replacement’.

Heliodon -A multi-axis turntable on which a building or room model is mounted. It is then adjusted, in relation to an artificial sun (bright, parallel beam spot light) or the real sun, according to the time of day, season, orientation and position on the planet that is desired, to simulate sunpaths in the model.

Illuminance - The luminous flux density at a surface, i.e. the luminous flux incident per unit area. This quantity was formerly known as the illumination value or illumination level.

Illumination - The process of lighting.

Incandescent Lamp - A lamp in which light is produced by a filament heated to incandescence by the passage of an electric current.

Indirect Lighting - Lighting in which the greater part of the flux reaches the surface (usually the working plane) only after reflection at other surfaces, usually a roof or ceiling.

Initial Illuminance - Average illuminance for a new installation when lamps, luminaires and room surfaces are clean.

Initial Light Output- The luminous flux from a new lamp. In the case of discharge lamps this is usually the output after 100 hours of operation.

Installed Efficacy - A factor which quantifies the effectiveness of a lighting installation in converting electrical power to light. Specifically, it is the product of the lamp circuit luminous efficacy and the utilisation factor. This term is now replaced by Installed Power Density.

Installed Power Density -The installed power density per 100 lux is the power needed per square metre of floor area to achieve 100 lux on a horizontal plane with general lighting.
Irradiance - The radiant flux density at a surface, i.e. the radiant flux incident per unit area of the surface.

Isolux Diagram - A diagram showing contours of equal illuminance.

Lumen -The unit of luminous flux, used to describe a quantity of light emitted by a source or received by a surface.

Luminaire - An apparatus which controls the distribution of light given by a lamp or lamps and which includes all the components necessary for fixing and protecting the lamps and for connecting them to the power supply. Colloquially a ‘lighting fitting’.

Luminaire Maintenance Factor - The proportion of the initial light output from a luminaire that occurs after a set time due to dirt deposition on and in the luminaire.

Luminance - A measure of the stimulus which produces a sensation of brightness measured by the luminous intensity of the light emitted or reflected in a given direction from a surface element, divided by the projected area of the element in the same direction.

Luminous Efficacy - The ratio of the luminous flux emitted by a lamp to the power consumed by it. When the power consumed by the control gear is taken into account this term is sometimes known as lamp circuit luminous efficacy and is expressed in lumens per circuit watt.

Luminous Intensity - The power of a source or illuminated surface to emit light in a given direction.

Lux (lux) - unit of illuminance, equal to one lumen per square metre (lm/m2).

Maintained Illuminance - The average illuminance over the reference surface at the time of replacing lamps and/or cleaning the equipment and room surfaces.

Maintenance Factor -The ratio of the illuminance provided by an installation at some stated time (eg. 100 hours of operation) to the initial illuminance. It is the product of the lamp lumen maintenance factor, the lamp survival factor, the luminaire maintenance factor and the room surface maintenance factor.

Reflectance - The ratio of the luminous flux reflected from a surface to that incident on it. Except for matt surfaces, reflectance depends on how the surface is illuminated, especially the direction and spectral distribution of the incident light. The value is always less than one.

Room Surface Maintenance Factor - The proportion of the illuminance provided by a lighting installation after a set time compared with when the room was clean. Depreciation in lumen output of lamps and the effect of dirt deposition on luminaires is not included.

Skylight - The diffuse light from the sky vault, excluding direct sunlight.

Sunlight - The direct light from the sun, after diffusion in the atmosphere.

Transmittance - The ratio of luminous flux transmitted by a material, such as a window, to the incident luminous flux.

Uplighter - Luminaires which direct most of the light upwards onto the ceiling or upper walls in order to illuminate the working plane by reflection.

Utilisation Factor - The proportion of the luminous flux emitted by a lamp which reaches the working plane.

Working Plane - The plane in which the visual task lies. If no information is available, the working plane may be considered to be horizontal and in the case of sports halls at floor level.