THE OPTIMASATION OF DAYLIGHT IN SPORTS HALLS

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ABSTRACT

Nowadays it is more desirable for daylight to be the prevalent form of lighting in most types of buildings. However, there has been concern about introducing daylight to sports halls since the design of traditional sports halls has tended to exclude natural light. If one looks at the vast majority of sports halls in the Netherlands where gymnastics is given at primary schools, the sports hall often totally relies on artificial lighting to provide a glare and shadow-free environment. This means that all the benefits of natural light have had to be eliminated. Nevertheless, it is important to see how daylight can be an integral part of the design of a sports facility, because daylight is essential for the health of human beings. This research assesses the arguments facing traditional sports hall designs, to identify whether more contemporary and creative approaches to the design of naturally lit, energy efficient, modern and safe sports hall designs can be made widely obtainable. With this inquiry alternatives are found where daylight is an integral part of the sports halls instead of using only artificial light in order to meet the technical requirements. In addition, more clarity is given on why the current regulations in the Netherlands do not specify daylight requirements for sports facilities.

KEYWORDS: *daylight, artificial light, sports hall, daylight standards, integrated daylight strategies*

I. INTRODUCTION

Making use of natural elements as primary energy sources for buildings has gained increasing interest since sustainability became widespread in the field. After a period when the use of natural light was largely devalued by artificial alternatives, in the contemporary architecture the positive contribution of natural light is being reconsidered (Brown & DeKay, 2014). It is now more adequate for daylight, when available, to be the predominant form of lighting in most types of buildings. However, when it comes to designing envelopes for indoor sports facilities it seems we are lagging behind. The design of traditional sports halls has tended to exclude natural light. Mostly due to problems such as glare, overheating and local cooling. Variations in light quality and quantity can be unmanageable and fenestration can lead to unwelcome distractions (Culley & Pascoe, 2009). However, the resulting designs are rarely compatible with attractive architecture and pleasing indoor environments. The intrinsic value of daylight is increasingly being recognized. Many studies emphasize the importance and benefits of daylight; both for health and for economic and environmental reasons (Kollman & Schulz, 2006, pp. 8-15; Sanders, 2016). If appropriately designed and integrated, it can minimize visual discomfort, improve the experiential value, reduce the environmental impact associated with artificial lighting and significantly offset the costs (D.Ander, 2016; Gaia Research, 2001). With increased concern for users and the environment daylight is often introduced to different types of buildings to reduce lighting consumption and to guarantee architectural quality. Nevertheless, if there are no specific regulations in relation to the use of natural light, it is rapidly depleted because of the additional problems, even when it is clear that this “black box”-approach does not satisfy the indoor environment and contribute to reducing energy consumption. Whilst many sports halls in the Netherlands are designed in this way, there is no clear consensus about what factor, or combination of factors, contributes to this approach. This leads to the following research question:

“*How can the relationship between daylight and sports hall designs in the Netherlands be defined compared to other European countries, when the CEN (European Committee for Normalization) remains the guideline for sports lighting at European level?”*

Besides the general acceptance that the presence of daylight in buildings has a positive effect on the health and well-being of users, in general, more than 30% of the total municipal energy use in the Netherlands is allocated to sports and recreation. As can be seen in *Figure 1*, the number of sports halls in the Netherlands has grown explosively in the last decades. Whereas in recent years growth has increased less explosively than in the 1970s and 1980s, from the nineties onward, a large number of sports halls built in the 1960s and 1970s were renovated or newly built since they no longer met the standards (NOC*NSF, 2001a, p. 8 D3.5 Lighting).

Government-driven cost control forces municipalities and managers of sports facilities to make choices. Budgets are often under pressure, which can easily lead to loss of quality. Nonetheless, with the continued growth of sports buildings and given the fact that a large part of the total energy of municipalities is consumed by sports buildings, energy-efficient lighting can also provide financial support. In addition, there are a number of other aspects that prove that sports halls are subject to major change.
Whereas in the past it was primarily municipalities and foundations that realized sports halls in the Netherlands, school communities are in recent times also becoming important (co-) parties, often financed by the relevant municipality that is responsible for the educational facilities. The school community mainly has a wide range of gym and sports hours during the day. The municipal sports club need sports facilities for the evenings and weekends. This combination of parties occurs more and more frequently and requires the joint building of a sports accommodation. It is important to think carefully about how these parties can use the same spaces, without compromising the standards and wishes of all those involved. Additionally, occupation is changing from traditional use to exercising more and more individually. This can be deduced from the increase in number of fitness clubs in the Netherlands in the recent years (Bont, Distelbrink, & Kessel, 2017, pp. 88-89). Given this change in sport, many new groups are arising and municipalities want to contribute to social participation and integration on the basis of sport by connecting sports and exercise providers with other sectors such as care, welfare, childcare and education (Breedveld, Poel, Jong, & Collard, 2011). More and more, older people are also doing sports. Given the aging of the Dutch population, the average age of athletes will probably rise even further. On the one hand, this sets higher lighting requirements, but on the other hand, and perhaps even more importantly with regard to the health and well-being of the users, is the matter of the integration of natural light. Hence, the integration of natural light is just as important as the application of energy-efficient quality lighting aimed at optimizing the use of light within sports facilities.

II. METHODS

To give an answer to the research question, the results in the paper are divided into three parts. Part 3.1 covers standards and building regulations concerning lighting at either national as European level, as well as conflicting issues of regulations in the Netherlands. Part 3.2 examines various types of sports facilities and their different types of light implementation. On the basis of case studies different systems regarding the use of (natural) light, the optimization of the orientation, values of the users will be compared to indicate whether the design will provide some acceptable level of illumination, how daylight is combined with artificial light and by which techniques or methods the light is controlled. Part 3.3 is about the integration or implementation of design strategies arising from the previous sections. The research is divided into six steps in which an overview diagram can be seen in *Figure 2*. Each step focuses on a question that is answered before going to the next step. The complete overview of the process of the detailed steps is included in the appendix *(see figure 10 – 12c).*

Figure 2. From research to design

III. RESULTS

While the intrinsic value of daylight is increasingly being recognized, the majority of sports buildings in the Netherlands are rarely compatible with pleasing indoor environments. The results try to give more clarity on the exclusion of daylight in the design of a sports hall. In relation to the results guidelines are given on how daylight can be better integrated into the design and which approach can ensure that daylight is included from the start of the design phase. In the final chapter on the results, a series of interesting design strategies is reviewed, the results of which can form both a critical tool and a design methodology for new sport-related projects.

3.1 Light and daylight standards in the Netherlands

Since there are no specific daylight requirements in the Dutch building code for sports halls, windows have become an excluded element from the design of sports halls. Windows are normally considered to be potential glare source which may cause visual discomfort for the users. The NEN-EN standard provides different requirements acquired from the European standards, where the NEN-EN 12193 describes the standards of lighting within sports-related buildings for each type of sport at three different levels, also shown in *Table 1*.

Lighting		
Tabel F3.5.4 Guidelines for lighting in most indoor sports		
	Average horizontal illuminance	**Uniformity $E_{min:Egem\ *)}$**
Level 1 - International and national top competition	Per branch of sport different, usually ≥ 750 lux	≥ 0,7
Level 2 - national and local competition	≥ 500 lux	≥ 0,7
Level 3 –training	≥ 300 lux	≥ 0,5

*) ratio between the minimum and the average illumination

*Figure 3. Guidelines for lighting in most indoor sports (NSVV, 2002, p. 9)(NOC*NSF 2001, page 8 of F3.5 Lighting).*

Consequently, for a *recreational athlete*, the requirements will be lower than for a *top-level athlete*. Nonetheless, the only term that appears is “lighting” and all the associated relevant technical light factors, although they are not further concentrated into a percentage required daylight (NOC*NSF, 2001b, 2001c).In short, no direct requirements have been drawn up in the NEN-EN for sports buildings with regard to daylight.
Since there are no requirements regarding daylight this is often the direct cause of the exclusion of windows in the design. However, regarding the users of a sports hall, is often only viewed from the perspective of a *(top)athlete*. While there are other users who also each have their own view on the use of daylight. For instance, a P.E. teacher who stands his entire working day in a gym probably has a different opinion about it.

Work-related activities must comply with the rules laid down in the Working Conditions Act (Arbo). This legislation states that for employees who are working more than two hours a day in the same workplace, a daylight area of at least five percent of the floor surface should be met (Arbo, 2009). However, this is not a requirement, there are always exceptions when rules conflict.
Nonetheless, this also applies here, given that the P.E. teacher practices a work-related activity. On the other hand, the top athlete wants to have good and reliably light so that he can practice his sport optimally. If the multidisciplinary sports accommodation is used for educational purposes, the previously mentioned, applicable health and safety legislation (Arbo) must be taken into account. This means, concerning a sport accommodation which is used for educational purposes, the same rule applies, a daylight area of at least five percent of the floor surface should be met (NSVV, 2002; Vallenduuk, 2017)

1.2


As described in the NSVV recommendation, direct daylight should be avoided. Daylight that can cause annoying reflections, light streaks or glare is not allowed in a covered multidisciplinary sports facility. Where daylight openings are used and the above cannot be met, the daylight must be completely prevented (NOC*NSF, 2001b).

3.4


Given the fact, of the previously mentioned division into levels, an equal level of illumination is not necessary (see *Table 1*). Training or recreational sports can be excellent at a lower level of lighting. Practising competition at local or national level requires more lighting. In sports halls where (inter)national top games are also played, higher levels of illumination may be desired, making it possible for things to be televised. Because of this, and to save energy, the switching and controllability of the lighting is desired.

The lighting should preferably be switchable at four lighting levels, namely: from 1/3 (cleaning)

2/3 (training and school use) and 3/3 (competition level) as shown in *Figure 2* below.

*Figure 3. Switchable four lighting levels (NOC*NSF 2001, page 8 of D3.5 Lighting).*

Sports hall de Helster in Elst is an example of how after the renovation of the lighting in 1993, they changed to a switchable lighting system. This was done on the basis of dimmable high-frequency lighting provided in mirror-optic luminaires. In principle, the level of light in the hall can be regulated between 70 and 700 lux. However, two presets are usually used: 440 lux (recreation/training) or 675 lux (top sport). The dimming control is connected to four light sensors. An advantage of this is that a constant level of light on the floor is kept intact regardless of the age of the lamps and the layout of the room. If dark mats are used in the hall or when the flexible partition wall is lowered in the hall, the amount of light is automatically adjusted. The dimmer control in the Helster sports hall shows a reduction of electricity consumption of about 33%. Incidentally, practice has taught us that the lighting should not be reduced from 675 lux to 440 lux at times when there are athletes in the hall. The lower lighting level is otherwise perceived as being too dark. (NOC*NSF, 2001b)

The observation mentioned above is very remarkable as it shows in that respect the subjectivity of light. Visibility, which is the state of being perceivable by the eye, is often thought to rely principally upon the amount of light on the object or task to be seen. However, shining more light on the object or task, will not always make it more visible. To some degree this is correct, but visibility also depends upon contrast sensitivity, in other words the ability to detect the presence of luminous, or brightness, differences (Evans, 1981, p. 7). The appearance of bright surfaces adjacent to shadowed surfaces depends not only the luminance's but also on the eye's adaption level. What all this means for the design of a sports hall is that lighting systems, whether daylight, electric light, or a combination of both, should avoid adjacent contrasting surfaces or spaces.
An important role in the design of a sports hall is therefore the contrasts between the materials used. Where there are strict requirements for floors with regard to for example anti-slip, the walls and ceilings can in that sense be determined more freely with regard to material use, however, not when we speak of reflection factors. This will be discussed in more detail in *Chapter 3.3 - on design strategies.*

3.2 Examples of lighting in other European countries

The Scandinavian countries have developed examples that resonate with both the scarce light in the winter and the long summer days. Henry Plummer, Professor Emeritus at the University of Illinois at Urbana-Champaign, has studied the various daylight phenomena in the Nordic countries in various books such as *"Nordic light: Modern Scandinavian Architecture"* and "*The Architecture of Natural Light"* (Plummer, 2009, 2012). Although the Netherlands and Scandinavia differ if we look at Denmark, it is quite similar in terms of its topography and vegetation to the Netherlands. While Denmark has more subdued light, there are many examples to be found where unique light situations are created to counterbalance the long and dark winter days.

Northern architects work with soft and reflecting daylight and its properties which create space and form. H. Plummer points out that spurred on by the modern movement's characteristics of sunlight and fresh air Scandinavian architects have sought to naturalize simple volumes by suffusing them with light which is precious in the north. For instance, the Bagsvaerd Church outside of Copenhagen (1976) designed by the Danish architect Jørn Utzon is a special example of how light is interwoven in space whereby from a concealed opening, at the very top of the space, light slowly shimmers through the "cloud ceiling" consisting of a number of arched, bowl-shaped concrete elements *(see appendix, Fig 3)*. The soft curvature of the bowls and the material effect created by the imprint of the form boards reflect light without sharp contrasts. Another example is the Nordjyllands Art Museum by Alvar Aalto and Jean-Jacques Baruel in the north of Denmark *(see appendix, Fig 4).* In the design, Alvar Aalto effectively 'manipulated the Nordic light' with the combination of strategically placed skylights and diffused lighting relying on a series of reflectors and light-coloured materials. The sunlight on the southern side is controlled by the 'two-sided, elongated skylights' with a restricted angle of 56 degrees whereas on the northern side it is completely open at a 90 degree angle.
At the same time examples can be found where daylight is integrated in sport buildings in Denmark such as *Sport and Culture House, The*

Crystal which will be discussed in more detail in the next Chapter. The conceptions mentioned above have led for choosing reference projects from Denmark. In addition, Germany and France have been chosen as well, based on similarities in topography but also with regard to similar prosperity and regulations of both countries.

Case studies

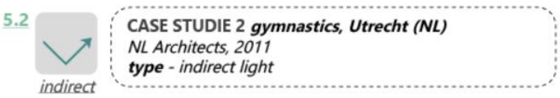
The value of the previous sections of the paper lies both in providing support design strategies and as a critical toolbox in reviewing or analysing realized buildings on the integration of daylight within the required standards of each country.

Projects have been chosen for short reviews as case studies based on their topographic similarities and period of realisation. Therefore, in this research it was decided to analyse only projects from the Netherlands, Germany and Denmark, with similar weather conditions, and other countries were left out of the consideration. For the analyses of the case studies a comprehensive yet limited set of design strategies is identified to use in the schematic part of the design process (a more extensive version is included in the appendix). The selection of the projects is based on five different lighting types: direct skylight (1), indirect skylight (2), view towards environment (3), artificial light (4), roof system (5). Each design strategy contains a main strategy, an explanation of the experience related to the strategy, a decision tool and a diagram of the strategy in an architectural application. From each case study, learning aspects are mentioned related to daylight resulting in some practical design solutions (see appendix). Finally, the six selected case studies are organised in an overview whereby is summarised to main aspect: (a) *how the light is* _optimised_ and (b) *how the light is* _controlled._

Case study 1 – Apollohal, Amsterdam (NL)

The complex is an early example of steel frame construction: large free spans through a structure of welded steel trusses and walls of light materials. This made it possible to supply large parts of the complex with glass. (a).

In order to control the light, active measures were subsequently applied – (truck) tarpaulins (b) *(see figure 14.1 in the appendix).*



Case study 2 – Gymnastics, Utrecht (NL)

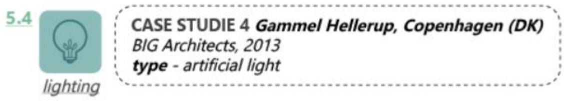
Indirect light reflects from the curved walls (a)

The carefully deformed envelop creates a mildly glowing gradient that lights up towards the top (b) *(see figure 14.2 in the appendix).*

Case study 3 – Sports hall, Berlin (DE)

A calculation of the energy balance allowed the western face of the hall to be fully glazed, so that there is a high level of daylighting. (a).

An semi-transparent acoustic soffit screen of light, glass-fibre mesh allows daylight into the building (b) (Schittich, 2012, pp. 322-327). *(see figure 14.3 in the appendix).*



Case study 4 – Gammel Hellerup, CPH (DK)

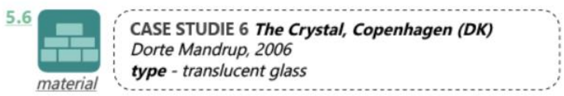
A domed roof decked with oak planking is bulging out of the previously flat school yard. The continuous roof edge consisting of wooden strips admits daylight into the sports hall (a).

The interior lighting design has only one type of lamp: Fluorescent tubes; which are carefully fixed in a way that 100% of light the tubes emit is used. The upper part of the tubes light up the wooden ceiling while the lower part gives light to the sport hall, hiding the fixtures just under their own natural way of lighting (b). *(see figure 14.4 in the appendix).*

Case study 5 – Sports hall Bon du Lait (FR)

In the roof of the sports hall are wide-spanning laminated timber elements created upon which truncated wooden pyramids evenly distribute the daylight that penetrates through the north-facing sheds throughout the room (a).

To control the light, direct light is avoided through north-facing sheds with truncated wooden pyramids and provides an evenly _distribution_ of daylight (b). *(see figure 14.5 in the appendix).*



Case study 6 – The Crystal, Copenhagen (DK)

The building´s structure is composed of steel and timber covered with opalescent polycarbonate panels with a low U-value. This translucent cover offers good daylight conditions (a).

To control the light, opalescent polycarbonate panels with a low U-value are applied (b).

(see figure 14.6 in the appendix).

3.3. Design strategies

In this chapter, the previously mentioned results are taken into account for providing design strategies related to the integration of daylight and avoiding any additional negative effects. A complete overview is included in the appendix, the results of which can be both a critical tool and a design methodology for new sports-related projects, but because of the limitation of the number of pages of the paper, a select number of important design strategies will be discussed in this chapter.

An interview with construction physicist Vincent Vallenduuk working at the building physics office Deerns indicated that in the case of multi-purpose halls, it is preferable to design the lighting to meet the requirements of badminton as it is one of the indoor sports most sensitive to appropriate lighting (Vallenduuk, 2017). Therefore, badminton is often taken as the reference when it comes to determine the regulations given that they have the highest requirements of indoor sports with regard to lighting, but as well roof structure, height, background wall and ceiling colours to aid shuttle visibility.

Sunlight is the direct light of the sun after it has been diffused by the atmosphere. Whereas sunlight is appreciated in some buildings, such as homes and intermediate spaces for pleasure and as an energy source, in sports halls it should be avoided completely, because of problems such as glare. Light from the sky, which excludes any direct sunlight, is termed skylight. The combined effect of sunlight and skylight is called daylight (Baker & Steemers, 2002; Sportscotland, 2016, p. 11). In this paper, the word *daylight* is used as a general definition for natural lighting in a sports hall. As described in NEN-EN 12193 direct daylight should be avoided in sports halls. Diffuse daylight access in the roof or façade, which does not result in annoying projection, reflection or contrast for the athletes, is permitted (Laponder, 2017; NOC*NSF, 2001b).

*NOC*NSF. (2001). Handboek Sportaccommodaties 2. Nieuwegein: Arko Uitgeverij BV. page 5 of D7.3.1 Lighting*

Passive principles

Whereas the orientation of the building has almost no effect on the quality of the interior daylight, the orientation is primarily a factor in dealing with the direct sun, also shown in figure 4.61.

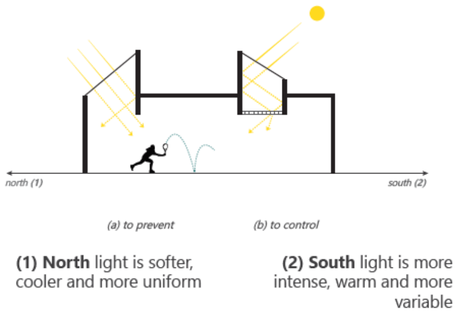
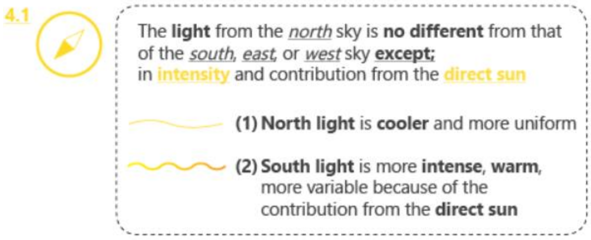


Figure 4.61 The orientation of the building is primarily a factor in dealing with the direct sun

Evans, B. H. (1981). Daylight in architecture. Page 93. United States: McGraw-Hill, Inc.

In general, there are no differences between light from the north sky and that from the south, east or west sky except in intensity and contribution from the direct sun. The same diffuse and soft daylight condition from the north sky can be achieved with any other orientation, however this requires intelligent use (e.g. expensive sun shading systems) of proper daylight control (Evans, 1981, p. 93).



In figure 4.31 a simple rectangular room is shown whereby the reduction of lighting at point **"x"** is tested due to various black-painted walls to show which surface is most effective in supporting the daylight quality of the interior. The full test with the related diagrams are attached in the appendix. The test show that the *ceiling (1)* is the most important surface in controlling the daylight coming into the room. Secondly, is the (back) *wall (2)*, and finally the *floor (3)*. Dark colours on the floor will have the least negative effect on the daylighting of tasks (Evans, 1981).

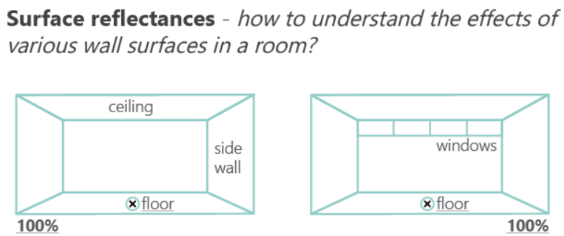


Figure 4.31. Tests on the **reduction** of lighting at point "**X**" due to various **black-painted walls** show which surfaces are **most effective** in supporting **task-level** illumination.

Evans, B. H. (1981). Daylight in architecture. Page 74-76. United States: McGraw-Hill, Inc.

From sport-technical considerations, such as sufficient contrast, requirements have been set for maximum reflection factors. As described in the NEN-EN 12193 the (colour) reflection factor of

the *ceiling* should be between 0.60 and 0.80. The colour reflection factor should be between 0.45 and 0.60 and the colour of the *wall* should be sufficiently contrasting with the players, ball or shuttle. Reflection can be prevented by placing the glass at a small angle (3-5°) in the rebate (see appendix). The (colour) reflection factor of the *floor* should be between 0.25 and 0.40 and is again compared to the other required reflection factors per wall component the lowest, which means the darkest colours at the *floor* have from a technical point of view the least effect on the lighting levels (NOC*NSF, 2001b).
Another effective strategy for avoiding excessive contrasts between exterior brightness's and the interior surfaces is the use of splayed or rounded jambs. Daylight apertures which are set flush in a ceiling or wall, tend to produce sharp contrasts. A softer, or smoother transition between the exterior and interior can be attained through the use of recessed splayed or rounded jambs *(6.5)* (Gordon, 2003, p. 52).

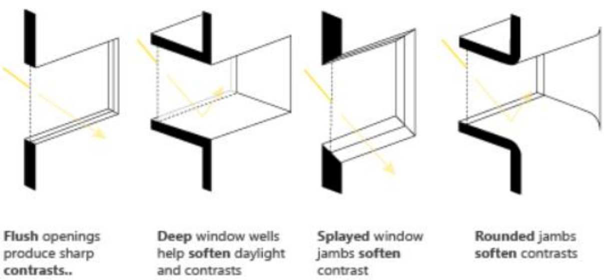


Figure 3. Various window elements in softening brightness contrasts (Gordon, 2003, p. 52)

In order to prevent reflection in the application of glass, sloped glass can be used as a technique for eliminating viewable reflections. Vertical glass frequently reflects appearances of brightly lighted objects across for example the street, from behind the observer, which hinder vision through the glass when the illumination in the interior is less than the outside.

3.3

Colour reflection of the ceiling	0.60-0.80
Reflection can be prevented by placing glass at a small angle	3-5°
Colour reflection of the wall	0.45-0.60
Colour reflection of the floor	0.25-0.40

Glass which is set back at the bottom (sloping from top to bottom - see *Figure 4.32*) will tend to reflect to the eye of the observer an appearance of the flat sidewalk which is relatively uniform in brightness and texture and which is more shielded from sun and skylight by an overhang.

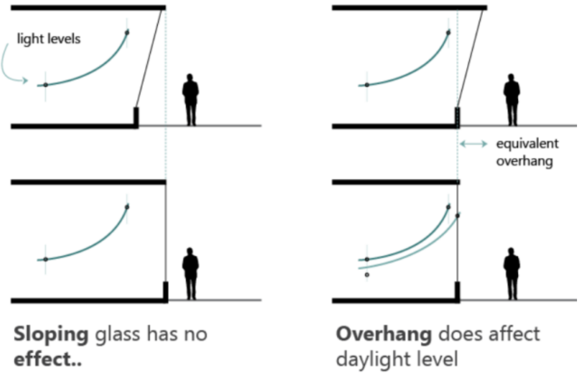


Figure 4.32. Sloped-glass windows do not affect **task-level** illuminiation, but the "**overhang**" does.

Evans, B. H. (1981). Daylight in architecture. Page 74-76. United States: McGraw-Hill, Inc.

One would think that sloped glass has a negative effect on the level of illumination. Nevertheless, inwardly sloped glass has no effect on levels of daylighting reaching the interior. Conversely, an overhang does affect the daylight level *(6.2)*.
As discussed before reflection can be prevented by placing glass at a small angle and if placed inwards this has no negative effects on the daylight (Evans, 1981; NOC*NSF, 2001b)

6.2 **Inwardly sloped glass has no effect on levels of daylight reaching the interior; An overhang has effect on levels of daylight**

In multifunctional sports halls, however, it is not only about the flexibility of the use, but also the layout of space. Often it should be divided into smaller parts so that various sports can make use of the hall at the same time. If a sports hall is divided into separate spaces by means of partition walls, the illuminance in these spaces will be lower than in the entire sports hall without partition walls. If a sports hall is divided in several parts, an average illumination of at least 300 lux must be achieved per division thus must be taken into account in the design *(3.1)*.

3.1 **Per division of a sports hall the average illumination must be at least 300 lux**

IV. CONCLUSIONS

The set of issues identified and examined in this paper can be used both as a tool for critical evaluation of sports buildings and as part of a design methodology for new projects. In the paper is looked at the conflicting issues of regulations and recommendations that are partly the cause of the exclusion of windows in the design of a sports building. To give an answer to the research question: "*How can the relationship between daylight and sports hall designs in the Netherlands be defined compared to other European countries, when the CEN remains the guideline for sports lighting at European level?"* there is looked at which factors play a role in this regard. Based on identified problems, requirements and recommendations, a method has been drawn up that can be used in which daylight is integrated into the design of a sports hall.

For instance, the prevention of daylight if it can cause reflections or glare while opposite stated the fulfillment of daylight concerning a sports accommodation with educational purposes. As previously defined in this paper a daylight area of at least 5% of the floor surface should be met in in case the sports accommodation is used for educational purposes *(1.2)*. When daylight can be applied, direct daylight should be avoided in sports halls. Diffuse daylight access in the roof or façade, is permitted *(3.4)*.

On the basis of the literature study it can be concluded that northern light is no different from that of the south, east, or west sky expect in intensity and contribution from the direct sun *(4.1)*. To control light from the south more expensive sun shading systems are required for proper daylight control. An example of such an *active system* is the Sports hall in Berlin designed by Ludloff+Ludloff Architekten *(5.3)*.

The materialisation of the sports hall also has an influence on the daylight level of the hall. This is demonstrated in the study of B.H. Evans wherein dark colours on the floor will have the least negative effect on the daylight quality of the interior. The second study coming from the building regulations of the Netherlands shows the requirement of the reflection factors of both the ceiling, walls and the floor. As previously mentioned the reflection factors per wall component, it can be concluded that the floor can have the darkest colours given the fact the colour reflection is the lowest of all *(3.3)*. The two studies both implies to the design: *keep the ceiling and walls as light in colour as possible and use deep colours for the floor surface (6.1).*

In the Crystal designed by Dorte Mandrup this can be seen from the brightly coloured application of the floor and light materials for walls and ceilings *(5.6)*. In relation to the requirement *(3.1.)* about the amount of illumination that must be achieved per division or sport hall if it has to be divided, actually requires windows on each side, or at least two sides. Then with regard to the orientation of the building, there cannot be chosen for only north-oriented light. So in order to meet this requirement, one is forced to bring in light from another side, which will be the south. In that case, you have to choose to control this on the basis of technical systems. Another option is instead of opting for windows in the walls, only allow light in the space from north orientated sheds in the roof. In this way it meets the requirement of achieving an average illumination of at least 300 lux per division of the sports hall, but also only light is obtained from the north. To fulfil the requirement concerning the division of a sports hall it can be concluded that a north oriented roof system is the best option. The Sports hall in Bon du Lait designed by Dietrich and Untertrifaller demonstrates this strategy in the use of north facing sheds *(5.5)*.

As outlined before a softer transition between exterior brightness's and the interior surfaces can be reached through the use of *(1) recessed windows* and *(2) rounded* or *splayed jambs.* NL Architects used this concept in the design of the gymnastics Nieuw Welgelegen *(5.2)* to create a similar effect from walls which are slanted toward the window openings in the roof.

In conclusion, this paper is intended to be a guide for the design of sports halls and intentified whether more contemporary and creative approaches to the design of naturally lit and energy efficient sports hall designs can be made widely obtainable. There are wide ranging issues associated with daylighting which need consideration, although the discussed strategies shows ways to provide useful and controllable daylight and shows alternatives for inceasing the daylight in sports halls (Mensink, Harsta, Boon, & Boeijenga, 2006).

References

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ILLUSTRATIONS

Appendix

Research paper:

Light and sports

Playing with light – The relationship between daylight and sports hall designs in the Netherlands

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As part of:
The Architectural Engineering
Graduation Studio 19

Master of Architecture, Urbanism and Building Sciences:
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December 19th, 2017

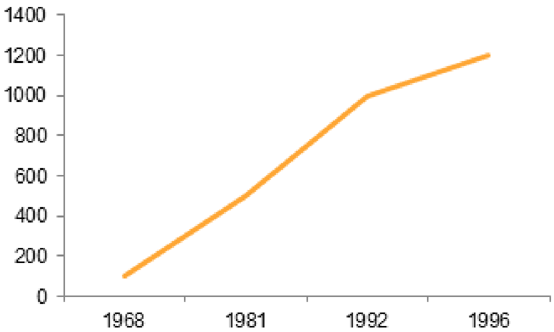


Figure 1. *Number of sports halls being built in the Netherlands (NOC*NSF (2001) page 8 of D3.5 Lighting).*

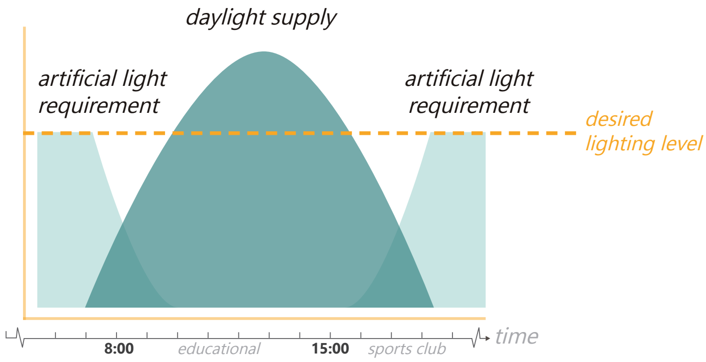


Figure 2. *Daylight supply in relation with artificial lighting requirement (own image, 2017)*

Lighting		
Tabel F3.5.4 Guidelines for lighting in most indoor sports		
	Average horizontal illuminance	Uniformity $E_{min:Egem}$ *)
Level I - International and national top competition	Per branch of sport different, usually ≥ 750 lux	≥ 0,7
Level II - national and local competition	≥ 500 lux	≥ 0,7
Level III - training, recreation	≥ 300 lux	≥ 0,5

*) ratio between the minimum and the average illumination

Figure 3. *Guidelines for lighting in most indoor sports (NOC*NSF (2001) page 8 of F3.5 Lighting).*

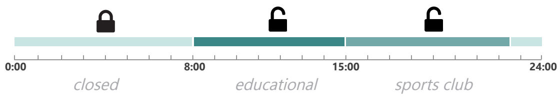


Figure 4. *Occupancy rate sports building (own image, 2017)*

Typical reflectance factors	
Tabel x.x Internal Materials	
	Reflection factor
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

*) Sportscotland. (2016). Understanding Daylighting of Sports Halls.

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.

Recommended reflectance factors	
Tabel x.x Per wall component	
	Reflection factor
Walls	0.3 - 0.5
Back wall, screens, etc.	0.2
Ceilings	0.6 - 0.9
Floors	0.2 - 0.4

*) Sportscotland. (2016). Understanding Daylighting of Sports Halls.

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

Figure 5. *Typical reflectance factors (Sportscotland, 2016).*

Figure 6. *Recommended reflectance factors (Sportscotland, 2016)*

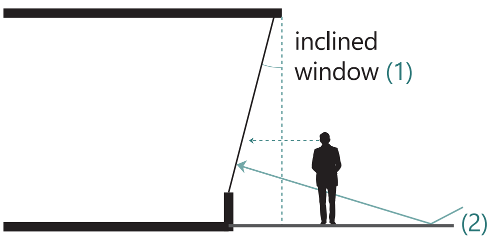


Figure 7. *Principle of inclined window (Evans, 1981).*

Lighting

1.6 Lighting criteria

- Flatten away, obstacle-free and ball-proof
- Strength: for movement education NEN-EN 12193, NN 351005 'Lighting' class 3 will be handled. This standard indicates the value-use. The new value is approximately 1.25 higher.
- The average horizontal illuminance is ¡Ý 300 lux
- The evenness is ¡Ý0.5
- The colour rendering is ¡Ý20 Ra

Positioning: not above centre line. Light strips in the longitudinal direction of the ceiling are very disrupting for volleyball and badminton. Preferably several TL luminaires at the corner on the side ceiling.
NB. If gym is used for exams or i.d. 350 Lux at floor level is recommended.

Figure 8. *Lighting criteria ((Zandstra, Burgerhout, Koudijs, & Blok, 2005)*

Figure 7.
Sport hall for the Helsinki University of Technology, Espoo,
Alvar Aalto, 1949-1952.

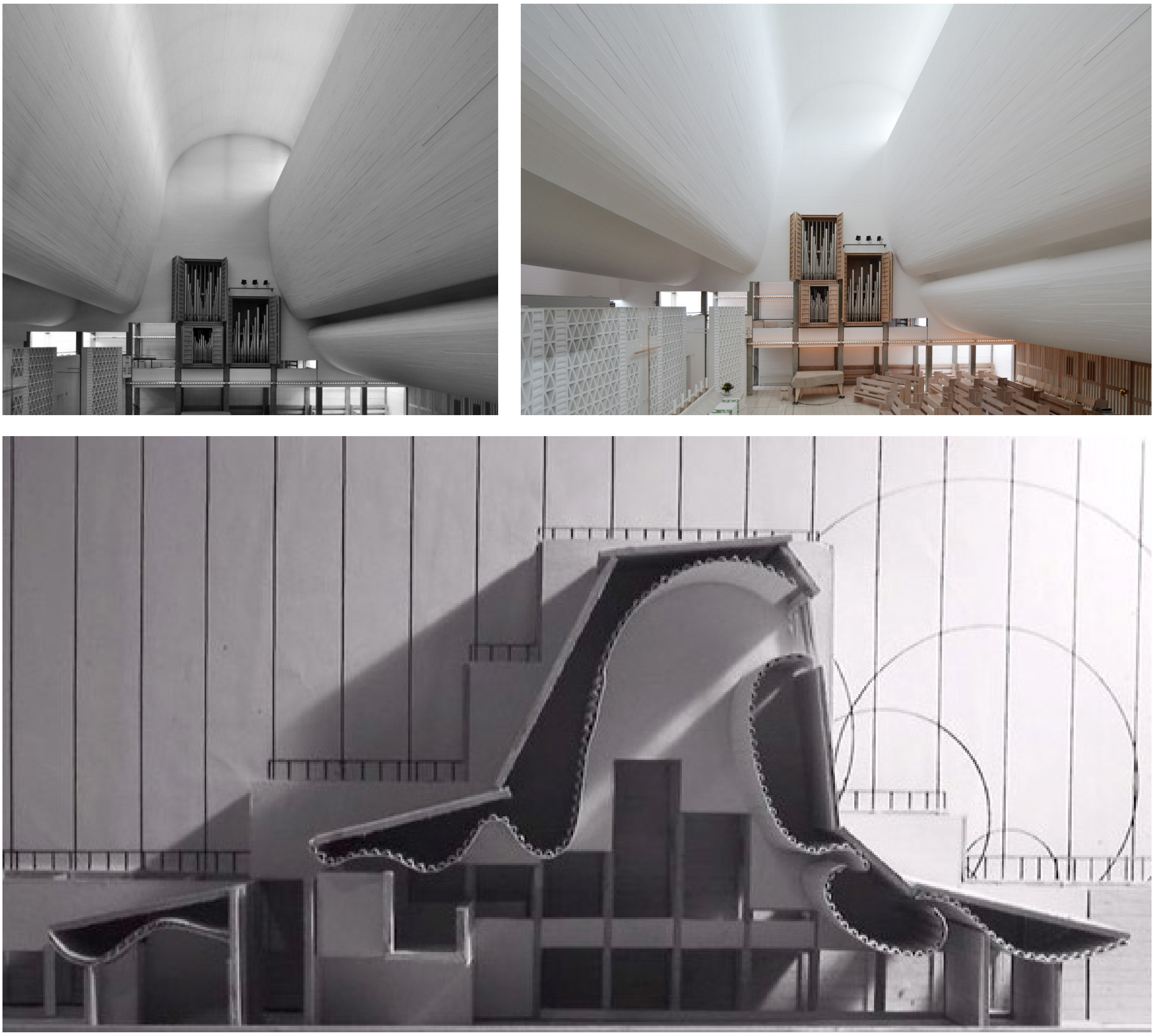


Figure 8.
Bagsværd Church, Copenhagen,
Jørn Utzon, 1968-1976

Figure 9.
Nordjyllands Art Museum, Aalborg,
Alvar Aalto,1958-1972

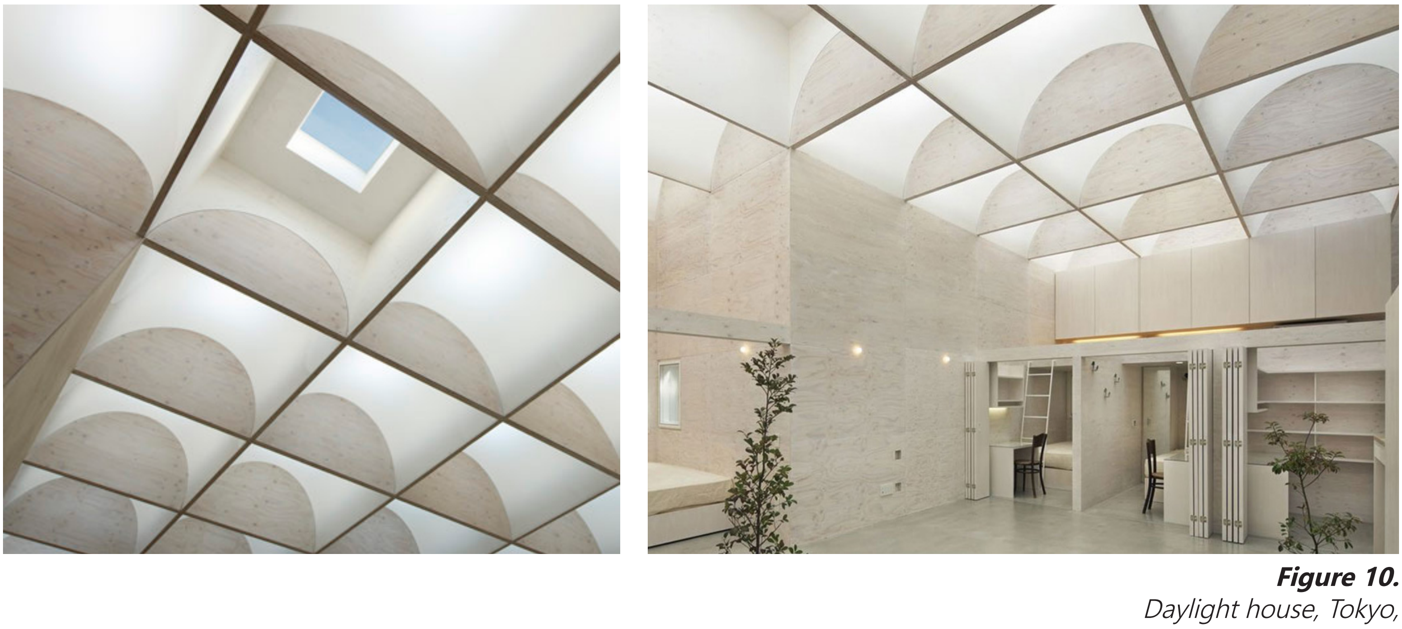


Figure 10.
Daylight house, Tokyo,
Takeshi Hosaka Architects, 1968-1976

APROACH

From research to design

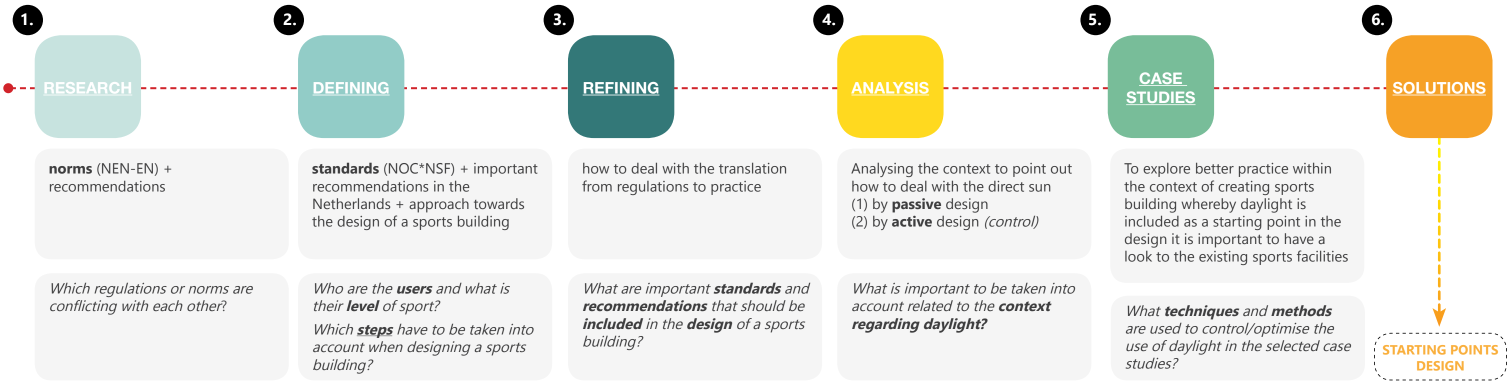


Figure 10. *Approach towards the design of a sports complex (own image, 2017)*

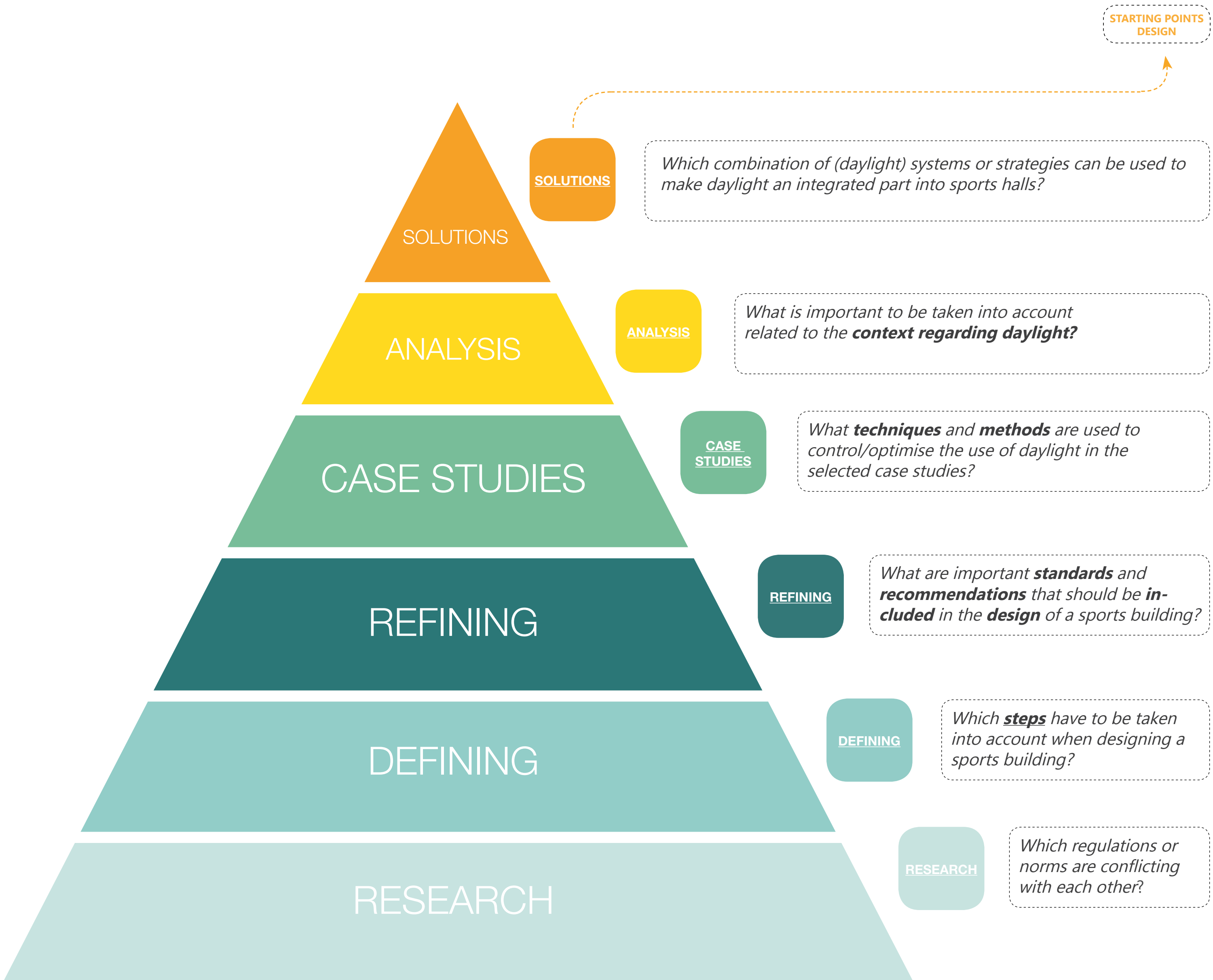


Figure 11. *Approach from research towards the design of a sports complex (own image, 2017)*

APROACH

From research to design

1. RESEARCH — norms (NEN-EN) + recommendations — *Which regulations or norms are conflicting with each other?*

2. DEFINING — **standards** (NOC*NSF) + important recommendations in the Netherlands + approach towards the design of a sports building — *Who are the **users** and what is their **level** of sport? Which **steps** have to be taken into account when designing a sports building?*

3. REFINING — how to deal with the translation from regulations to practice — *What are important **standards** and **recommendations** that should be **included** in the **design** of a sports building?*

4. ANALYSIS — Analysing the context to point out how to deal with the direct sun (1) by **passive** design (2) by **active** design *(control)* — *What is important to be taken into account related to the **context regarding daylight?***

5. CASE STUDIES — To explore better practice within the context of creating sports building whereby daylight is included as a starting point in the design it is important to have a look to the existing sports facilities — *What **techniques** and **methods** are used to control/optimise the use of daylight in the selected case studies?*

6. SOLUTIONS → STARTING POINTS DESIGN

1. RESEARCH

norm

1.1 The Dutch-European Norm for Sport lighting
NEN-EN 12193
NN 351005 'Lighting'
Handbook Sports Accommodations (NOC*NSF)

recommendation

NSVV
Lighting for sport accommodations - indoor sports
Lighting for sport accommodations - indoor sports

1.2 **Concerning a sport accommodation which is used for educational purposes, a daylight area of at least 5% of the floor surface should be met.**

1.3 **The daylight surface must be composed in a way that teachers and students can have a look out at the weather**

1.4 If gym is used for exams **350 Lux** at floor level is recommended.

2. DEFINING

defining (1)

2.1 **standards** (NOC*NSF) + important recommendations in the Netherlands and data from other sports buildings
- ***What is the level of sport for the design?***

2.2
- **Level I** .... **≥750 lux**
- **Level II** .... **≥500 lux**
- **level III** .... **≥300 lux**

2.3 **occupancy** rate + who are the **users**?
- ***Is the multidisciplinary sports accommodation used for educational purposes?***

controlling (2)

2.4 Take a closer look at the desired **switching** and **controllability** of the **lighting** in the various spaces **(2.3)**
Analyze which **lighting system** meets the best the lighting requirements, but also match the best the chosen zoning and the requirements in terms of **controllability, ambiance and comfort**

optimizing (3)

2.5 Optimize daylight entry through façade and/or roof, considering the heat load in the summer.
Choose for such lightweight interior, but consider the **reflection factors** on the principles and guidelines of the NOC*NSF **(3.2)**
Make a selection of lamps based on function, colour views and **colour** impression + select the highest lamp system efficiency **(3.2)**

optimizing control (4)

2.6 (1+1=2) **Switch/rule** on the **presence** of **daylight**: aim for hardly noticeable changes of daylight and artificial light
Presence of people - application of a **dimming** arrangement, which allows the lighting level to be used or the wishes can be adjusted

3. REFINING

3.1 **Per division of a sports hall the average illumination must be at least 300 lux**

3.2 **Take in account the aging and pollution during the lifetime of lighting. This aging factor averages 1.25 to 1.3**

3.3
- **Colour reflection of the ceiling** **0.60-0.80**
- **Reflection can be prevented by placing glass at a small angle** .... **3-5°**
- **Colour reflection of the wall** **0.45-0.60**
- **Colour reflection of the floor** **0.25-0.40**

3.4
- ✗ **No direct daylight in the sports hall**
- ✓ **Diffuse daylight access in the roof or façade**

3.5 **switchable lighting levels to adapt to suitable level (see 1.1.) + presence detection**

3.6 **keep the walls and ceiling as light in colour as possible and use the floor surface for deep colours or character-giving patterns;**

3.7 **the minimum required light values vary per function, per branch of sport and per level**
300 -750 lux

recommendation

3.8 Use lamps with a **color rendering index Ra** of at least **80** and a color temperature of approx. 3000K

4. ANALYSIS

4.1 The **light** from the *north* sky is **no different** from that of the *south, east,* or *west* sky **except;** in **intensity** and contribution from the **direct sun**
- **(1) North light** is **cooler** and more uniform
- **(2) South light** is more **intense**, **warm**, more variable because of the contribution from the **direct sun**

4.2 **By using northern daylight, you avoid the disadvantages of the 'direct' light that with its intensity often has to be controlled by *(technical) systems***

4.3 **Solatube daylight system filters the negative effects of daylight and can control the diffuse daylight;**
hereby the system is suitable for both top athletes and educational institutions

5. CASE STUDIES

5.1 *direct* — **CASE STUDIE 1 *apollohal, Amsterdam (NL)***
J. van Stigt, 2005
type *- direct light*

5.2 *indirect* — **CASE STUDIE 2 *gymnastics, Utrecht (NL)***
NL Architects, 2011
type *- indirect light*

5.3 *view* — **CASE STUDIE 3 *sports hall, Berlin (DE)***
Ludloff + Ludloff architects, 2011
type *- view towards environment*

5.4 *lighting* — **CASE STUDIE 4 *Gammel Hellerup, Copenhagen (DK)***
BIG Architects, 2013
type *- artificial light*

5.5 *roof* — **CASE STUDIE 5 *Sports hall Klaus, Klaus (DE)***
Dietrich and Untrifaller, 2013
type *- roof system*

5.6 *material* — **CASE STUDIE 6 *The Crystal, Copenhagen (DK)***
Dorte Mandrup, 2006
type *- translucent glass*

6. SOLUTIONS → STARTING POINTS DESIGN

6.1 **keep the walls and ceiling as light in colour as possible and use the floor surface for deep colours or character-giving patterns;**

6.2 **Inwardly sloped glass has no effect on levels of daylight reaching the interior;**
An overhang has effect on levels of daylight

6.3 **Reflection can be prevented by placing glass at a small angle** .... **3-5°**

passive

6.4 **By using northern daylight, you avoid the disadvantages of the 'direct' light that with its intensity often has to be controlled by *(technical) systems***

6.5 **Recessed splayed or/and rounded jambs help in softening brightness contrasts.**

active

6.6 **Solatube daylight system filters the negative effects of daylight and can control the diffuse daylight**

Figure 12a. *Overview and explanation approach towards the design of a sports complex (own image, 2017)*

1. research input — 2. defining — 3. refining

1. REGULATIONS AND PARTIES

1.1 REGULATIONS

what are the requirements of light in a design of a sport hall

international level

CEN (European Committee for Normalization)

The European Committee for Standardization is a public standards organization whose mission is to foster the economy of the European Union (EU) to interested parties for the development, maintenance and distribution of coherent sets of standards and specifications.

national level

NEN (Nederlands Normalisatie-instituut)

supports within the Netherlands the standardization process and application at both national and international level.

1. **NEN-EN 12193**
2. **NN 351005 'Verlichting'**

De Nederlands-Europese Norm voor Sportverlichting
NEN-EN 12193

ARBO

- **Daylighting in gyms and sports halls with educational use is necessary**
- The daylight surface must be composed and situation so that teacher and students can have a look out at the weather
- Annoying daylight and direct sunlight must be prevented (at the exterior, to control from the inside)
- The daylight area of the gym is at least 5% of the floor surface. For example, at 308m2 this is minimum 15.40m2

Concerning a sport accommodation which is used for educational purposes, a daylight area of at least 5% of the floor surface should be met.

1.2 PARTIES

which parties are involved who give input and make guidelines for the requirements of light in a design of a sport hall?

international level

NOC*NSF

Netherlands Olympic Committee * Netherlands Sports Confederation

ISA

Institute for Sport Accommodations

KIWA

national level

NSVV

Nederlandse Stichting voor Verlichtingskunde

Lighting

1.6 Lighting criteria

- Flatten away, obstacle-free and ball-proof
- Strength: for movement education NEN-EN 12193, NN 351005 'Lighting' class 3 will be handled. This standard indicates the value-use. The new value is approximately 1.25 higher.
- The average horizontal illuminance is ¡Ý 300 lux
- The evenness is ¡Ý0.5
- The colour rendering is ¡Ý20 Ra

Positioning: not above centre line. Light strips in the longitudinal direction of the ceiling are very disrupting for volleyball and badminton. Preferably several TL luminaires at the corner on the side ceiling.
NB. If gym is used for exams or i.d. 350 Lux at floor level is recommended.

2. APPROACH TOWARDS DESIGNING

1. Step 1 – PROJECT DEFINITION

Draft lighting concept

- Describe the **function of lighting** in view of the **use** and spatial concept of the building; pay attention to the energy performance deterioration **(1.1)**.
- Select the architectural light, light technical and ergonomic criteria based on experiences, **standards** (NOC*NSF) in the Netherlands and data from other sports buildings
- Write lighting systems with durable light sources, low installed power and **good controllability**
- *What is the level of sport for the design?*

1.1 Level of indoor sport

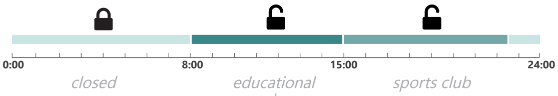
Lighting

Tabel F3.5.4 Guidelines for lighting in most indoor sports

	Average horizontal illuminance	Uniformity $E_{min:Egem}$ *)
Level I - International and national top competition	Per branch of sport different, usually ≥ 750 lux	≥ 0,7
Level II - national and local competition	≥ 500 lux	≥ 0,7
Level III - training, recreation	≥ 300 lux	≥ 0,5

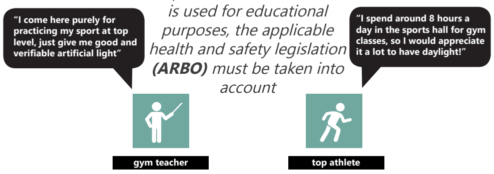
*) ratio between the minimum and the average illumination

1.2 Municipal sports club vs. educational sports



Occupancy rate

*If the multidisciplinary sports accommodation is used for educational purposes, the applicable health and safety legislation **(ARBO)** must be taken into account*



contrasted issues as the gym teacher is required from the ARBO to have a workplace with daylight (from > 2 hours stay) but on the other hand, the top athlete wants to have good and reliably light so that he can practise his sport optimal

2. Step 2 – STRUCTURAL PLAN

Draft lighting concept

- **Determine the extent to which daylight can be used** as light source in corridors, changing rooms, canteens, office and storage areas. Even though daylight is mostly avoided within gyms, daylight attendance can also be attractive in gyms. When calculating the percentage of glass in the façade or roof, keep in mind a possible heat shed during the summer **(2.1)**.
- Analyze the extent to which the building can be classified into **zones** with different **lighting levels**. Also consider situations where only a part of the building and/or the hall is used **(2.2)**.
- Take a closer look at the desired **switching** and **controllability** of the **lighting** in the various spaces **(2.3)**.
- Analyze which **lighting system** meets the best the lighting requirements, but also match the best the chosen zoning and the requirements in terms of **controllability, ambiance and comfort**

3. Step 3 – SKETCH DESIGN

Optimization lighting design

- Optimize daylight entry through façade and/or roof, considering the heat load in the summer.
- Choose for such lightweight interior, but consider the **reflection factors** on the principles and guidelines of the NOC*NSF **(3.1)**.
- Create a pre-selection of lamps based on function, colour views and colour impression, then select the lamp with the highest lamp system efficiency (preferably select high-frequency mirror optic illumination)
- Select arrays open base of light distribution, anti-glare shield and desired ambience, then choose the luminaire with the highest illumination efficiency **(3.2)**.

4. Step 4 – FINAL DESIGN

Optimal control of the lighting

- Turn on the presence of people: no one present, then the lighting off.
- **Switch/rule on the presence of daylight**: aim for hardly noticeable changes of daylight and artificial light
- Strive for the application of a **dimming arrangement**, which allows the lighting level to be used or the wishes can be adjusted
- Test the design by calculations and/or test setup on (operating) costs, light quality, controllability and ambiance (DIVA - MSc3)
- Make a plan for energy management, measurement (and allocation of usage costs)

3. CONCLUSIONS

Types of sports

various indoor sports

badminton is seen as a starting point since this indoor sport has the **strictest requirements** with regard to light

Layout sports hall

If a sports hall is **divided** into **separate spaces** by means of partition walls, the illuminance in these spaces will be lower than in the entire sports hall without partition walls. This must be taken into account in the design of the installation. In a sports hall divided in several parts, an **average illumination of at least 300 lux** must be achieved per division.

NSVV. (2002). Verlichting voor sportaccommodaties, binnensporten. Pag. 17. 5.4 Sports halls. Veenendaal: GVO grafisch bedrijf BV.

3.1 **Per division of a sports hall the average illumination must be at least 300 lux**

Finishing floors, walls and ceilings

The colour of the wall should be sufficiently contrasting with the players, ball or shuttle. The colour **reflection** factor should be between **0.45** and **0.60**.
Reflection can be prevented by placing anti-reflective glass of the glass at a **small angle (3-5°)** in the rebate.

The ceiling must be made of ball-resistant material. The (colour) reflection factor of the ceiling should be between **0.60** and **0.80**.

*NOC*NSF. (2001). Handboek Sportaccommodaties 2. Nieuwegein: Arko Uitgeverij BV. page 4-5 of D7.3.1 Lighting*

3.2
Colour reflection of the wall .... **0.45 - 0.60**
Reflection can be prevented by placing glass at a small angle .... **3-5°**
Colour reflection of the ceiling **0.60-0.80**

No direct daylight should enter the competition room. Diffuse daylight access in the roof or façade, which does not result in annoying projection, reflection or contrast for the athletes, is permitted.

*NOC*NSF. (2001). Handboek Sportaccommodaties 2. Nieuwegein: Arko Uitgeverij BV. page 5 of D7.3.1 Lighting*

3.3
✗ **No direct daylight in the sports hall**
✓ **Diffuse daylight access in the roof or façade**

Artificial light

recommendation

Use lamps with a **color rendering index Ra** of at least **80** and a color temperature of approx. 3000K (warm white). If daylight can be combined, a color temperature of 4000K is possible.

3.4


The lighting should preferably be switchable in four lighting levels, namely: from **1/3** (cleaning) **2/3** (training and school use) and **3/3** (competition level). Switching through **presence detection** is also recommended in the sports hall.

*NOC*NSF. (2001). Handboek Sportaccommodaties 2. Nieuwegein: Arko Uitgeverij BV. page 6 of D7.3.1 Lighting*

3.5 **switchable lighting levels to adapt to suitable level + presence detection**

A reflective floor has less effect on the light intensity than reflective walls and ceiling

Evans, B. H. (1981). Daylight in architecture. Page 74-76. United States: McGraw-Hill, Inc.
Sanders, F. (2016). PV as Art. Part 1. Page 53. Delft: TU Delft.

3.6 **keep the walls and ceiling as light in colour as possible and use the floor surface for deep colours or character-giving patterns;**

3.7

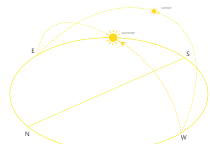

the minimum required light values vary per function, per branch of sport and per level (see

Figure 12b. *Overview and explanation approach towards the design of a sports complex (own image, 2017)*

4. ANALYSIS

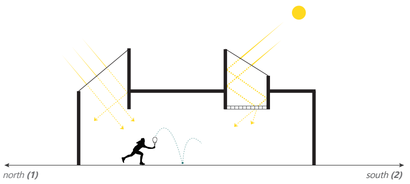
Context based
(a) to prevent

sun



sun diagram

orientation



(1) North light is softer, cooler and more uniform

(2) South light is more intense, warm and more variable

Figure 4.61 The orientation of the building is primarily a factor in dealing with the direct sun

Evans, B. H. (1981). Daylight in architecture. Page 93. United States: McGraw-Hill, Inc.

Whereas the **orientation** of the building has almost **no effect** on the quality of the interior **daylight**, the **orientation** is primarily a factor in **dealing with the direct sun**. The same diffuse and soft daylight condition from the north sky can be achieved with any other orientation, however this requires intelligent use *(e.g. expensive sunshading systems)* of proper **daylight control..**

4.1

The **light** from the *north* sky is **no different** from that of the *south*, *east*, or *west* sky **except;**
in **intensity** and contribution from the **direct sun**

(1) North light is **cooler** and more uniform

(2) South light is more **intense**, **warm**, more variable because of the contribution from the **direct sun**

Design solution

4.2

By using northern daylight, you avoid the disadvantages of the 'direct' light that with its intensity often has to be controlled by *(technical)*

Technical based
(b) to control

A variety of daylight **controlling** systems/materials will be discussed which can be meaningful in getting the daylight to where it is needed and for **eliminating** excessively **bright areas** from view *(dynamic controls are not included due to the costs in this analysis).*

(a) systems

- reflecting blinds, louvers, and shelves
- skylight and roof reflectors
- mirrors and polished reflectors
- drapes and fine screens

(b) (glazing) materials

- tinted glasses
- translucent
- directional transmitting

Technical based
(c) to optimise

A recently developed system is the **Solatube daylight** system. The solatube recently obtained using statement Kiwa ISA Sport will now diffuse daylight anywhere in the gym that demonstrably voldoent all standards of the NOC * NSF. The sports halls are therefore **suitable for both top athletes and educational institutions.**

The daylight systems **filter** the **negative effects** of daylight and bring **diffuse daylight** to any place under the roof in a controlled manner. The tubes capture the outside light with a dome and transport the daylight into the sports hall via a reflective tube.

4.3

Solatube daylight system filters the negative effects of daylight and can control the diffuse daylight;
hereby the system is suitable for both top athletes and educational institutions

5. CASE STUDIES

5.1 *direct*

CASE STUDIE 1 *apollohal, Amsterdam (NL)*
J. van Stigt, 2005
***type** - direct light*

DESIGN SOLUTIONS

A The complex is an early example of steel frame construction: large free spans through a structure of welded steel trusses and walls of light materials. This made it possible to supply large parts of the complex with glass. (a).

B In order to control the light, active measures were subsequently applied – (truck) tarpaulins (b)

5.2 *indirect*

CASE STUDIE 2 *gymnastics, Utrecht (NL)*
NL Architects, 2011
***type** - indirect light*

DESIGN SOLUTIONS

A Indirect light reflects from the curved walls (a).

B The carefully deformed envelop creates a mildly glowing gradient that lights up towards the top (b).

5.3 *view*

CASE STUDIE 3 *sports hall, Berlin (DE)*
Ludloff + Ludloff architects, 2011
***type** - view towards environment*

DESIGN SOLUTIONS

A A calculation of the energy balance allowed the western face of the hall to be fully glazed, so that there is a high level of daylighting (a).

B An semi-transparent acoustic soffit screen of light, glass-fibre mesh allows daylight into the building (b).

5.4 *lighting*

CASE STUDIE 4 *Gammel Hellerup, DK*
BIG Architects, 2013
***type** - artificial light*

DESIGN SOLUTIONS

A The continuous roof edge consisting of wooden strips admits daylight into the sports hall (a).

B The upper part of the tubes light up the wooden ceiling while the lower part gives light to the sport hall, hiding the fixtures just under their own natural way of lighting (b).

5.5 *roof*

CASE STUDIE 5 *Sports hall Klaus, Klaus (DE)*
Dietrich and Untrifaller, 2013
***type** - roof system*

DESIGN SOLUTIONS

A Truncated wooden pyramids evenly distribute the daylight that penetrates through the north-facing sheds throughout the room (a).

B To control the light, direct light is avoided through north-facing sheds with truncated wooden pyramids and provides an evenly distribution of daylight (b).

5.6 *material*

CASE STUDIE 6 *The Crystal, Cph (DK)*
Dorte Mandrup, 2006
***type** - translucent glass*

DESIGN SOLUTIONS

A The building´s structure is composed of steel and timber covered with opalescent polycarbonate panels with a low U-value. This translucent cover offers good daylight conditions (a).

B To control the light, opalescent polycarbonate panels with a low U-value are applied (b).

6. DESIGN SOLUTIONS

Surface reflectances - *how to understand the effects of various wall surfaces in a room?*

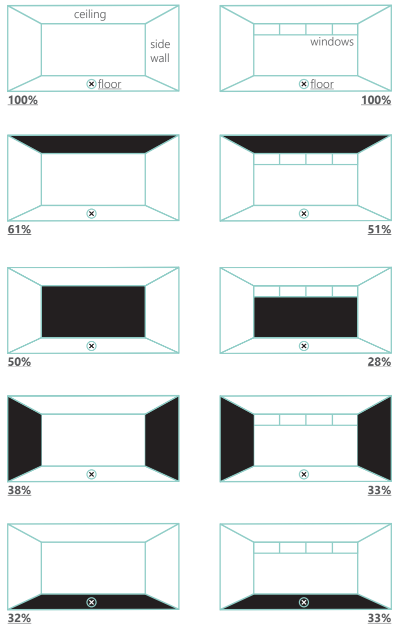


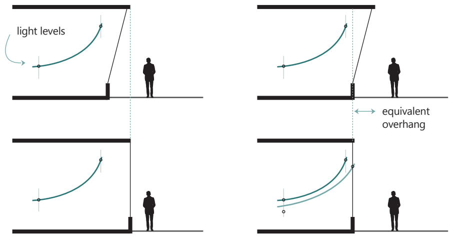
Figure 4.31. Tests on the **reduction** of lighting at point "**X**" due to various **black-painted walls** show which surfaces are **most effective** in supporting **task-level** illumination.

Evans, B. H. (1981). Daylight in architecture. Page 74-76. United States: McGraw-Hill, Inc.

The figures above show that the *ceiling (1)* is the most important surface in controlling the daylight coming into the room. Secondly, is the *back wall (2)*, and finally the *floor (3)*. Dark colours on the will have the least negative effect on the daylighting of tasks. This implies to the design:

6.1

keep the walls and ceiling as light in colour as possible and use the floor surface for deep colours or character-giving patterns;



Sloping glass has no **effect..**

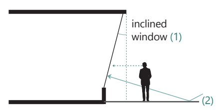
Overhang does affect daylight level

Figure 4.32. Sloped-glass windows do not affect **task-level** illumination, but the "**overhang**" does.

Evans, B. H. (1981). Daylight in architecture. Page 74-76. United States: McGraw-Hill, Inc.

6.2

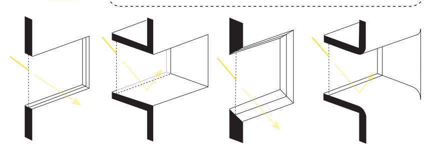
Inwardly sloped glass has no effect on levels of daylight reaching the interior;
An overhang has effect on levels of daylight



***Sloped glass* can be used as a technique for eliminating viewable reflections on the glass (1).**
Glass which is set back at the bottom *(sloping from top to bottom - see figure 4.32)* will tend to reflect to the eye of the observer an appareance of the flat sidewalk which is relatively uniform in brightness and texture (2) and which is more shielded from sun and skylight by an overhang.

6.3

Reflection can be prevented by placing glass at a small angle 3-5°



Flush openings produce sharp **contrasts..**

Deep window wells help **soften** daylight and contrasts

Splayed window jambs **soften** contrast

Rounded jambs **soften** contrasts

Figure 3. Various window elements in softening brightness contrasts (Gordon, 2003, p. 52)

6.5

Recessed splayed or/and rounded jambs help in softening brightness contrasts.

Figure 12c. *Overview and explanation approach towards the design of a sports complex (own image, 2017)*

Project database

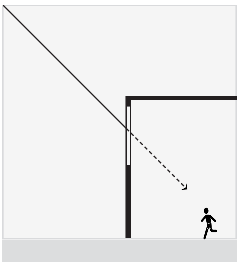
Case studies + case visits

Information

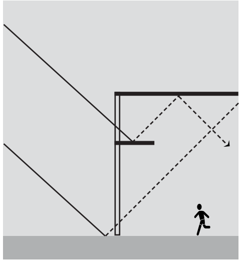
case visit / case study

To explore better practice within the context of creating attractive, healthy and manageable sports facilities that are environemtally responsible in relation to users, I think it is important to have a look to the existing sports facilities. Therefore, to compile more knowledge in the field of public buildings and sports facilities I will do every once in the two weeks a **case visit** of a project related to sports within the Netherlands.

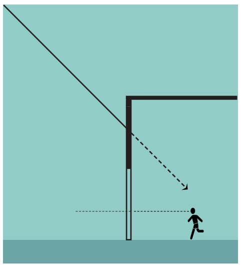
The other week I will do a **case study** whereby I choose a reference project outside the Netherlands to investigate. I will have a look in which way daylight plays a role within the design. Furthermore, I will try to point out some **learning aspects** and **design solutions**.



direct light
examples of sports hall with the use of direct light

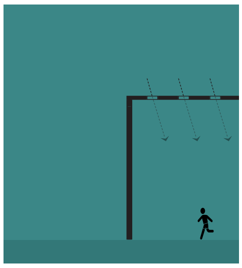


indirect light
use of indirect light is more preferable then direct light, examples have been found whereby strategies are used to create indirect light in the hall



view towards environment
it can give occupants a sense of well-being, of time, and orientation, but it must be used with discretion or it is likely to cause poor seeing conditions or add excessive heat to a space

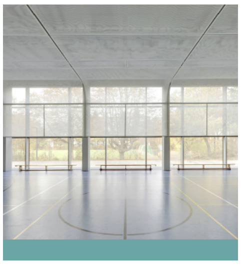
artificial light
examples whereby artificial light is used in a nice or interesting way to supplement the lighting level



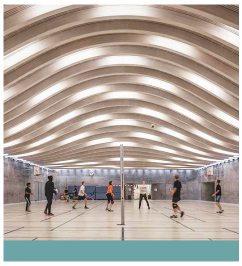
daylight systems roof | 1
Different daylight roof systems such as square skylights to allow natural light into the hall

apollohal, Amsterdam
J. van Stigt, 2005

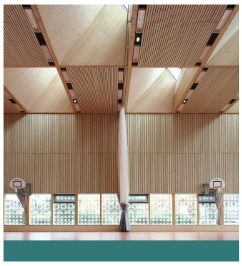
gymnastics Utrecht
NL Architects, 2016



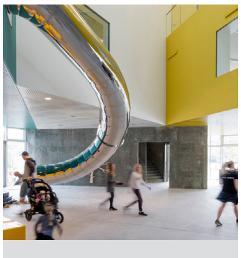
sports hall Berlin
Ludloff + Ludloff architects, 2011



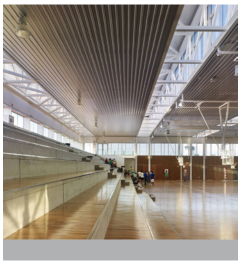
Gammel Hellerup School, DK
BIG, 2013



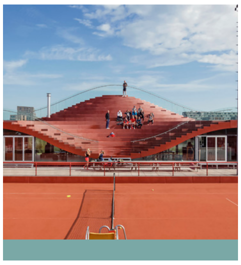
Gymnasium du Bon Lait, Lyon
Dietrich Untertrifaller, 2016



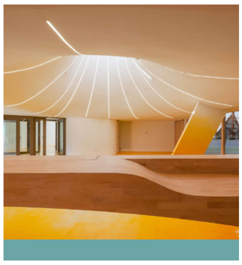
Ku.Be Copenhagen
MVRDV + ADEPT, 2016



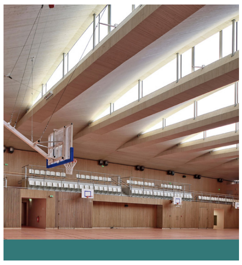
Arteixo Sport Center, Spain
Jose Ramon Garitaonaindia de Vera, 2011



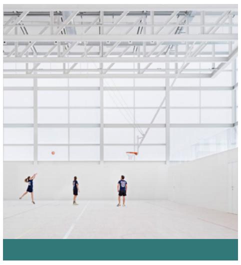
Tennisclub IJburg, Amsterdam
MVRDV, 2015



Tennisclub, Strasbourg
Paul le Quernec, 2017



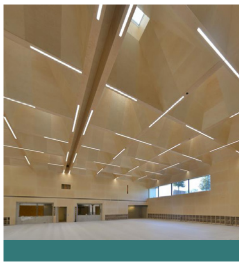
Pajol Sports Centre, Paris
Brisac Gonzalez, 2012



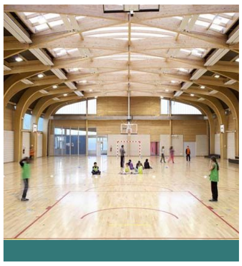
Multi-Sport Pavilion, Spain
Alberto Campo Baeza, 2016

Sporthal de Geuselt, Maastricht
Slangen+Koenis Architects, 2017

Monconseil Sports Hall, France
Explorations Architecture, 2014

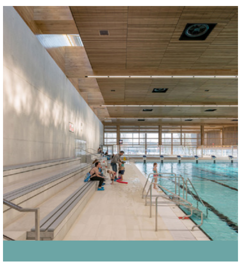


Sports hall, Klaus
Dietrich Untertrifaller, 2014

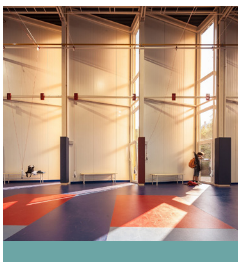


Gymnasium Régis, Drancy
Alexandre Dreyssé, 2011

Drieburcht multisport Tilburg
VenhoevenCS, 2013

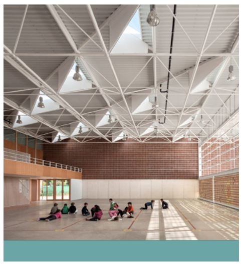


De Steur Aquatic Centre
VenhoevenCS, 2015

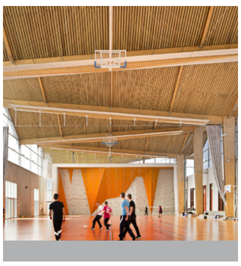


The Vasas Sportclub, Hungary
A4 Studio, 2013

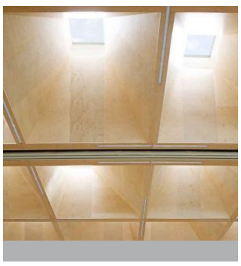
Penrhos College, Australia
Solatube, 2015



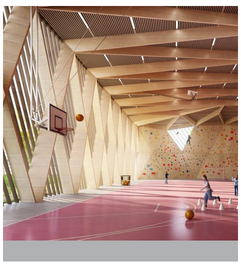
The Educational Hall, Picanya
Carmen Martínez Gregori, 2016



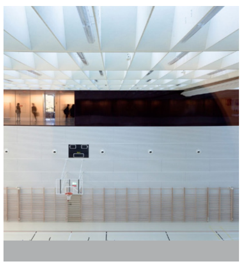
Louise Michel High Schools FR
archi5, 2015



Sports hall, Klaus
Dietrich Untertrifaller, 2014



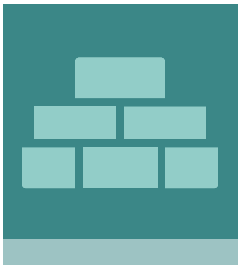
Sports Centre de Loisirs, Rouen
Tank Architectes, 2011



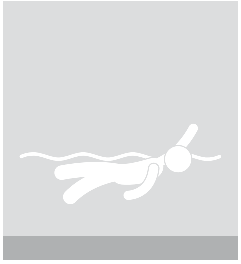
School Sports Hall, Vouvry
Berrel Berrel Kräutler, 2013

Pabellón deportivo en Almería
Ferrer Architects

Figure 13. *Project database; case studies + case visits (own image, 2017)*



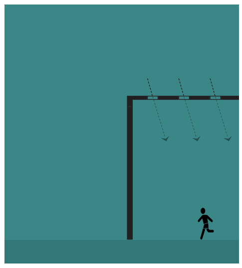
material
examples of materials with properties that avoid strong light-dark contrasts in the interior.



swimming pool
examples of swimming pools

yoga / pilates
Introverted and quiet spaces, with dim and changing light, spaces are related to the architecture of temples.

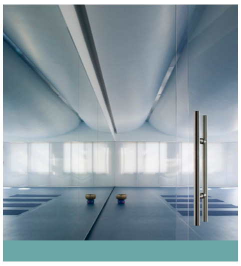
climbing
examples of climbing and bouldering centres



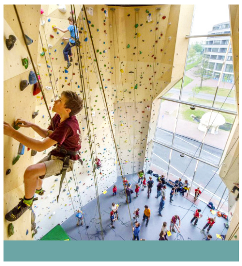
daylight systems roof | 2
Different daylight roof systems such as square skylights to allow natural light into the hall

The Crystal, Copenhagen
Dorte Mandrup, 2006

Swimming pool, Surrey
Hawkins \ Browns, 2016



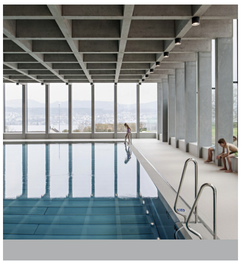
Yoga Deva, USA
Blank Studio, 2008



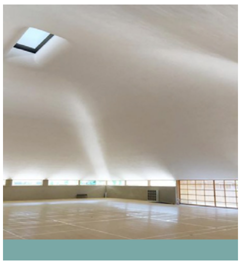
Sports Hall, Dordrecht
NL Architects, 2014

Sports Centre, Musholm, DK
AART architects, 2016

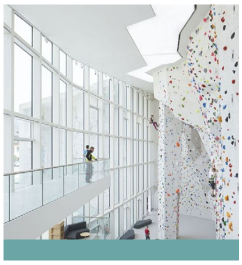
Sports hall Parkloods, Antwerp
Verdickt & Verdickt, 2007



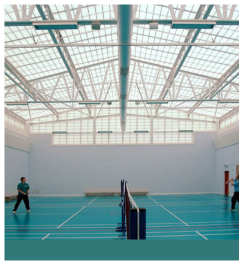
Swimming Pool Allmendli, Switz.
Illiz Architektur, 2016



Community centre, Naoshima
Hiroshi Sambuichi, 2017



School Bouldering Centre, Italy
Stifter + Bachmann, 2010

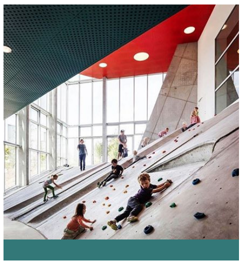


Jock Stein Centre, Hamilton
South Lanarkshire, 2012

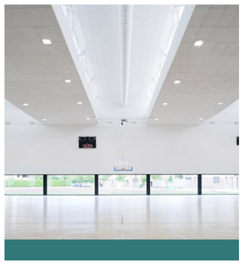
the Arena do Morro, Brasil
Herzog & de Meuron, 2014

Swimming Pool, Maastricht
Slangen + Koenis, 2013

Yoga House, Chile
DX Arquitectos, 2014

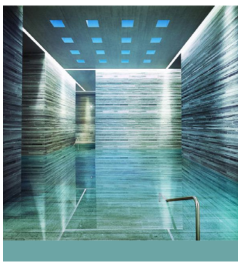


Ku.Be Copenhagen
MVRDV + ADEPT, 2016



Sports hall, Girona, Spain
BCQ Architects, 2015

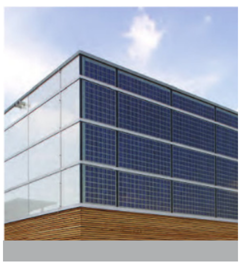
Sports Centre, Kiel
UR Architects, 2014



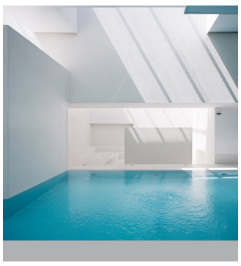
The Therme Vals, Switzerland
Zumthor, 1996

Yoga House, Chile
WMR Arquitectos, 2014

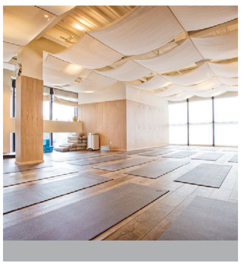
Siloo o, Amsterdam
NL Architects, 2011



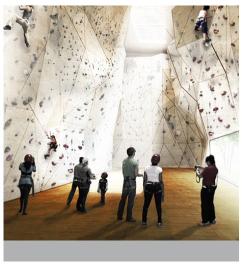
Sports hall, Regensburg
Tobias Ruf, 2004



Les Bains des Docks, France
Jean Nouvel, 2008



Y+ Yoga, Shanghai
Red Design Consultants, 2013



Collider Activity Center, Sofia
INDEX, 2013

Figure 13. *Project database; case studies + case visits (own image, 2017)*

apollohal, Amsterdam
J. van Stigt, 2005

5.1 *direct*

CASE STUDIE 1 *apollohal, Amsterdam (NL)*
J. van Stigt, 2005
***type** - direct light*

case visit

DESIGN SOLUTIONS

A The complex is an early example of steel frame construction: large free spans through a structure of welded steel trusses and walls of light materials. This made it possible to supply large parts of the complex with glass. (a).

B In order to control the light, active measures were subsequently applied – (truck) tarpaulins (b)

gymnastics Utrecht
NL Architects, 2016

5.2 *indirect*

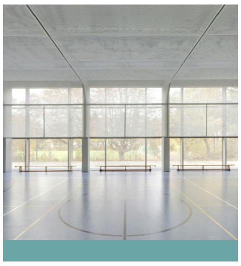
CASE STUDIE 2 *gymnastics, Utrecht (NL)*
NL Architects, 2011
***type** - indirect light*

case visit

DESIGN SOLUTIONS

A Indirect light reflects from the curved walls (a).

B The carefully deformed envelop creates a mildly glowing gradient that lights up towards the top (b).



sports hall Berlin
Ludloff + Ludloff architects, 2011

5.3 *view*

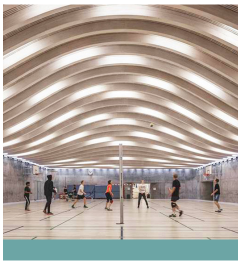
CASE STUDIE 3 *sports hall, Berlin (DE)*
Ludloff + Ludloff architects, 2011
***type** - view towards environment*

case study

DESIGN SOLUTIONS

A A calculation of the energy balance allowed the western face of the hall to be fully glazed, so that there is a high level of daylighting (a).

B An semi-transparent acoustic soffit screen of light, glass-fibre mesh allows daylight into the building (b).



Sporthal de Geuselt, Maastricht
Slangen + Koenis Architects

5.4 *lighting*

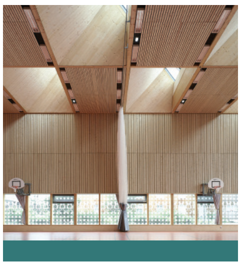
CASE STUDIE 4 *Gammel Hellerup, Copenhagen (DK)*
BIG Architects, 2013
***type** - artificial light*

case study

DESIGN SOLUTIONS

A The continuous roof edge consisting of wooden strips admits daylight into the sports hall (a).

B The upper part of the tubes light up the wooden ceiling while the lower part gives light to the sport hall, hiding the fixtures just under their own natural way of lighting (b).



Pajol Sports Centre, Paris
Brisac Gonzalez, 2012

5.5 *roof*

CASE STUDIE 5 *Sports hall Klaus, Klaus (DE)*
Dietrich and Untrifaller, 2013
***type** - roof system*

case study

DESIGN SOLUTIONS

A Truncated wooden pyramids evenly distribute the daylight that penetrates through the north-facing sheds throughout the room (a).

B To control the light, direct light is avoided through north-facing sheds with truncated wooden pyramids and provides an evenly distribution of daylight (b).

apollohal, Amsterdam
J. van Stigt, 2005

5.6 *material*

CASE STUDIE 6 *The Crystal, Copenhagen (DK)*
Dorte Mandrup, 2006
***type** - translucent glass*

case study

DESIGN SOLUTIONS

A The building´s structure is composed of steel and timber covered with opalescent polycarbonate panels with a low U-value. This translucent cover offers good daylight conditions (a).

B To control the light, opalescent polycarbonate panels with a low U-value are applied (b).

Figure 14. *Selected case studies + case visitis (own image, 2017)*

*
A *how the light is optimised (a)*
B *how the light is controlled (b)*

Apollohal Amsterdam
J. van Stigt

Sports hall

This **indoor sports hall** is located in an area where the northern and southern Amstel canal come together, in the middle of the expansion of plan South of H.P. Berlage. The building, designed by A. Boeken (1934) in the style of 'het Nieuwe Bouwen' has functioned for decades as tennis and exhibition space. Over the years the building had lost her vanity. In 1954 the backside of the hall was rebuilt for Cinema du Midi; but after an intensive renovation (2005), was connected again to the hall, and now has two gyms for schools in the area. The Apollo hall regained its multifunctionality and pride.

OVERALL ← → DETAIL

To learn

- **The complex is an early example of steel frame construction: large free spans through a structure of welded steel trusses and walls made from light materials.**
- **This made it possible to supply large parts of the complex with glass.**

Design solutions

- The complex is an early example of steel frame construction: large free spans through a structure of welded steel trusses and walls of light materials. This made it possible to supply large parts of the complex with glass. (a).
- In order to control the light, active measures were subsequently applied – (truck) tarpaulins (b)

source: http://www.burovanstigt.nl/product/apollohal/

Figure 14.1 *Case visit: Apollohal, Amsterdam, J. van Stigt (own image, 2017)*

Turnzaal Nieuw Welgelegen

NL Architects - 2011

Gymnastics

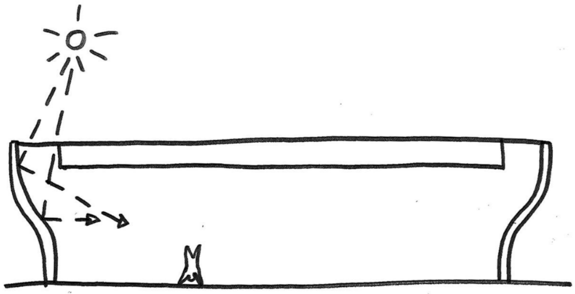
Design a gym without windows. That was the assignment of NL Architects. Turnaccomodatie Nieuw Welgelegen is a sports hall dedicated to **gymnastics** in Utrecht. The gym was completed at the end of 2011.

Exclusion of windows

No windows, but some daylight in the room was nice. To realize that, NL Architects has reversed the facade on the top as it were, the "**skin**" of the building has been slightly peeled off the top. Due to the slight curvature an opening between the edges and walls has emerged. This entails light entering the hall. On the outside the building has been given a sculptural view through the corrugation.

A two story service block with dressing rooms, storage paces, technical installations is placed along the side in such a way that the facade remains 'free'.
The traditional material to clad large halls - **corrugated steel plate** - has been deployed in a blissful way.

Luuk Kramer (buiten)



indirect light reflects from the curved walls

OVERALL ◄──────────────► DETAIL

own pictures

To learn

- Daylight is required, but for serious training and competitions windows will cause undesired effects: **too much contrast and too much distraction** -> Windows at eye level are not a good idea
- The **vulnerability** that comes with **glass** is an issue Especially in this particular area: not long ago the streets around here used to be paved with shattered glass from cars that had been broken in to
- Another problem of windows is their **transparency** due to privacy issues

- As a consequence gymnastics halls often tend to be gloomy -

Design solutions

- Indirect light reflects from the curved walls (a).
- The carefully deformed envelop creates a mildly glowing gradient that lights up towards the top (b).

source: webpage NL Architects

Figure 14.2 *Case visit: Gymnastics, Nieuw Welgelegen, NL Architects (own image, 2017)*

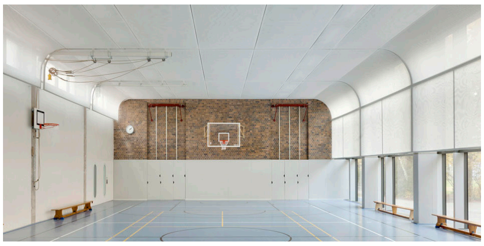
Sports Hall, Berlin (2011)
Ludloff + Ludloff Architekten

Sport Center

The sports hall had suffered from the numerous changes made to its form and function over the years. As well as **improving** the **energy situation**, they sought to reinterpret the original design quality in an up-to-date manner.

The finely dimensioned concrete structure was freed of all extraneous elements, and the floor and roof were newly insulated. A **calculation** of the **energy balance** allowed the **western face** of the hall to be **fully glazed**, so that there is a **high level of daylighting**. Their lively surfaces stand in bold contrast to the smooth, pale-blue, resilient flooring and the **semi-transparent acoustic soffit screen**, which determines the spatial character of the hall. With its **light, glass-fibre mesh**, the **screen** imposes a minimal load on the structure and at the same time **protects** the **light fittings** and **acoustic elements** from balls flying around in the hall below. Drawn in a curve down the upper part of the facade, it also protects against insulation. By carefully **removing certain elements** and **achieving a succesful interplay of light, colour and materials**, the architects have created a hall in which sport is fun again.

OVERALL ← → DETAIL



To learn

- through an **semi-transparent acoustic soffit screen** with its **light, glass-fibre mesh** a **great interplay of light** is achieved
- moreover, the screen imposes a **minimal load on the structure**
- and at the same time **protects the light fittings and acoustic elements from balls flying around**
- the screen is curved down, hereby **the upper part of the facade is insulated**

Design solutions

- an semi-transparent acoustic soffit screen of light, glass-fibre mesh (metogla sportacoustex, kogelbestendige textieldeken) allows daylight into the building but also offers more advantages, such as minimal load on structure, protection of acoustic installations and ceiling lighting and partly insulation of the facade

source: https://www.competitionline.com/de/projekte/48468
http://metogla.de/system/textile-akustikdecke/
DETAIL Serie 2012.04 Innenraum + Asubau, Interiors + Finishings

Figure 14.3 *Case study: Sports Hall, Berlin, Ludloff + Ludloff Architekten (own image, 2017)*

Gammel Hellerup School
BIG - 2013

School

A domed roof decked with oak planking is bulging out of the previously flat school yard – the continuous roof edge consisting of wooden strips admits daylight into the sports hall

The use of daylight an artificial light in Gammel Helerup gymnasium allows the space to be used also for other activities. The interior lighting design has only one type of lamp: Fluorescent tubes; which are carefully fixed in a way that 100% of light the tubes emit is used. The upper part of the tubes light up the wooden ceiling while the lower part gives light to the sport hall, hiding the fixtures just under their own natural way of lighting.

xxx

OVERALL ◄——————————————————► DETAIL

To learn

- A domed roof decked with oak planking is bulging out of the previously flat school yard. The continuous roof edge consisting of wooden strips admits daylight into the sports hall.
- The interior lighting design has only one type of lamp: Fluorescent tubes; which are carefully fixed in a way that 100% of light the tubes emit is used. The upper part of the tubes light up the wooden ceiling while the lower part gives light to the sport hall, hiding the fixtures just under their own natural way of lighting.

Design solutions

- The continuous roof edge consisting of wooden strips admits daylight into the sports hall (a).
- The upper part of the tubes light up the wooden ceiling while the lower part gives light to the sport hall, hiding the fixtures just under their own natural way of lighting (b).

https://www.archdaily.com/412908/gammel-hellerup-gymnasium-big

Figure 14.4 *Case study: Gammel Hellerup School, Hellerup, BIG (own image, 2017)*

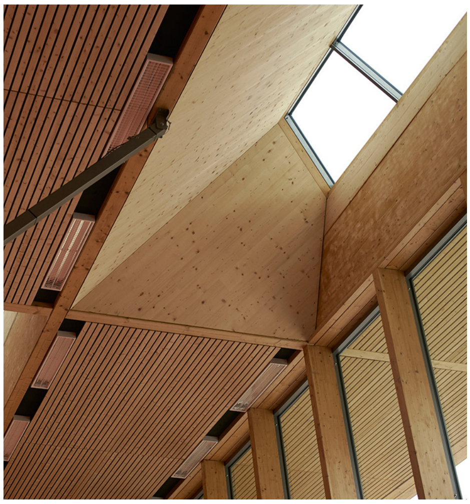
Gymnasium du Bon Lait
Dietrich Untertrifaller - 2016

Sport Center

The **multi-functional sports hall** is timber-frame constructed with straw insulation and forms a neighborhood hub in the heart of Bon Lait, an urban development area in the Lyonnais district of Gerland. The allocation plan consists of a **triple gym for various ball sports** and a **training hall** for martial arts, dance and gymnastics.

With a homogeneous shell of pre-grayed larch wood battens and **generous glazing**, the sports hall stands out boldly from the environment. Through its simplicity, it also emphasizes its function as a low-threshold, available-to-all communal infrastructure. Inside the 9-meter-high hall with its 45 x 24-meter-wide playing field, the ceiling is characterized by **wide-spanning laminated timber elements** upon which **truncated wooden pyramids** evenly distribute the daylight that penetrates through the sheds. The wall cladding made of wooden slats ensures good acoustics. It is well-supplied with **daylight via a window strip** and an air space with a skylight.

OVERALL ← → DETAIL



To learn

- wide-spanning laminated timber elements upon which truncated wooden pyramids **evenly distribute the daylight** that penetrates through the **north-facing sheds** throughout the room
- wall cladding made of **wooden slats** ensures good **acoustics**
- well-supplied with daylight via a **window strip** and an **air space with a skylight**
- **renewable resources** such as **wood** and **straw.**

Design solutions

- Evenly distribution of daylight through north-facing sheds with truncated wooden pyramids

source: http://www.archdaily.com/876509/bon-lait-sports-hall-dietrich-un-tertrifaller-architekten
http://www.dietrich.untertrifaller.com/en/projekt/sportzentrum-bon-lait

Figure 14.5 *Case study: Gymnasium Bon du Lait, Dietrich Untertrifaller (own image, 2017)*

The Crystal, Copenhagen
Dorte Mandrup - 2006

Sports hall

The building´s structure is composed of steel and timber covered with opalescent polycarbonate panels with a low U-value. This translucent cover offers excellent daylight conditions and at night the structure appears as a glowing crystal. The building will be used for a variety of daily sport and cultural activities such as concerts and theatre performances. The dynamic landscape inside allows for various activities to take place on different levels in visual contact with each other.

OVERALL ◄——► DETAIL

To learn

- The building will be used for a variety of daily sport and cultural activities such as concerts and theatre performances. The dynamic landscape inside allows for various activities to take place on different levels in visual contact with each other.
- This translucent cover offers excellent daylight conditions and at night the structure appears as a glowing crystal.

Design solutions

- The building´s structure is composed of steel and timber covered with opalescent polycarbonate panels with a low U-value. This translucent cover offers good daylight conditions (a).
- To control the light, opalescent polycarbonate panels with a low U-value are applied (b).

source: webpage Dorte Mandrup

Figure 14.6 *Case study: The Crystal, Copenhagen, Dorte Mandrup (own image, 2017)*

an optimal daylight design
in 24 steps

Stichting Living Daylights

1. Take into account the orientation (north / east / south / west) of the building plot. And use this knowledge during the first sketches of the building form.

2. Make an inventory of the surrounding buildings and vegetation. These can influence the daylighting of the building to be developed.

3. Check the zoning plan for future construction projects that can influence the daylighting of the building to be developed.

4. Take into account the location and the climatic conditions that exist there with regard to the lighting design and the application of daylight systems. Many daylight systems mainly function with direct solar radiation. Direct sunlight only occurs in the Netherlands for only 30-35% of the time.

5. Prepare a daylight ambition for the building to be realized. This will reflect on the role of daylight in the future building at an early stage

6. Use light-coloured outdoor materials for horizontal parts that can provide extra daylight entry into the building through reflection. For example by applying water, white gravel, light-coloured roofing materials.

7. Expose the building to daylight. By making use of atria, incisions and e.g., more façade area is obtained, which allows more daylight access. However this must match the thermal energy-efficient character that prescribes a compact form in an ideal situation.

8. Use profiling of the cross-section of the building mass for daylighting and shadowing. A terrace shape offers opportunities for a lot of daylighting; overhangs provide shading on the façade surface.

9. Get inspiration from old buildings where daylight was the main source of illumination and remember that most interventions, solutions and methods are still very applicable

10. Perform at least 35-40% of the façade surface as a light opening. A higher glass percentage (and therefore a lot of light openings) is not necessarily better. Make a distinction between quantity and quality of daylight.

11. At high glass percentages (from 40 to 100%), multiple, individually adjustable sun and light regulation are essential in work environments. Too high solar irradiation can cause climatic problems (overheating) and visual discomfort. Separate systems for daylight and sun protection are preferred.

12. Match the location of the various functions in the building to the daylight requirements, for example, functions that require more daylight to place closer to the façade.

13. High spaces with high windows give a lot of light. Design rooms with a high ceiling and high-placed light openings for daylight penetration deep into the room. The depth of the room must be adjusted to the height of the façade with the light opening. A rule of thumb for this is; the departure depth is approx. 1.5 to 2 times the departure height (where the departure height is measured from floor to top of the window).

14. Use roof lights wherever possible. Compared to a sidelight, a roof light has a higher daylight efficiency

15. If possible, apply light openings on both sides of a room. This achieves good daylight penetration and more uniform light distribution in the room.

16. Adjust the number and size of the light apertures in a façade to the specific characteristics of the solar position associated with the different façade orientations:
    North façade: uniform light incidence, no sun regulation necessary, light regulation is
    South façade: plenty of natural light possible by direct sunlight, sun regulation relatively easy due to steep sun exposure.
    West and East façade: difficult sun regulation due to low solar radiation.

17. Use horizontal light openings for facade windows. These have a better efficiency with respect to daylight output and provide less contrast. A vertical window, on the other hand, offers more possibilities for a good view.

18. Sufficient view is of great importance to the user. This requirement can conflict with measures that are necessary for optimizing the daylight climate. Especially in terms of positioning the window. The use of visible and light windows can resolve inconsistencies.

19. Pay attention to the design and detailing of the light openings both inside and outside. Den in the shape of the daily edges, the materialization, the color but also the type of filling. Annoying contrasts are thus prevented and the distribution of the incident daylight can be considerably improved.

20. Choose light colors for the interior to get light-reflecting surfaces. The colors and materials of the interior can be adjusted to the required reflection: ceiling - high reflection, wall - medium reflection, floor - low reflection

21. Take the artificial light plan early in the development of the design in order to achieve a good balance between natural light and artificial light. Zoning of artificial light and a daylight-dependent circuit are measures that can be part of this.

22. Key in the design. Create a simple daylight model of the design using simulation software or a scale model.

23. Learn from previous projects. Visit and assess completed projects after they have been taken into use. How did the interventions work out. What are the experiences of users? Take that knowledge with you in new designs or assignments.

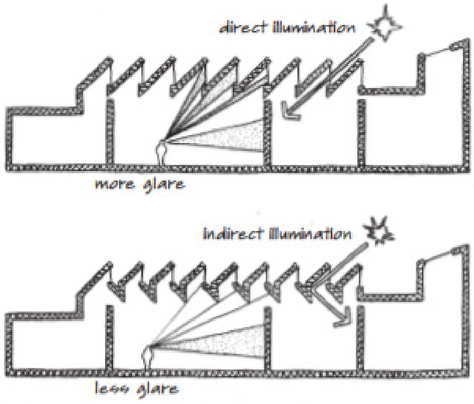
24. The main strength and also its most unique selling point is the dynamics of daylight. Use that dynamic! Daylight makes architecture alive.

Figure 15 *List of points for optimal daylight design from Living Daylight 01*

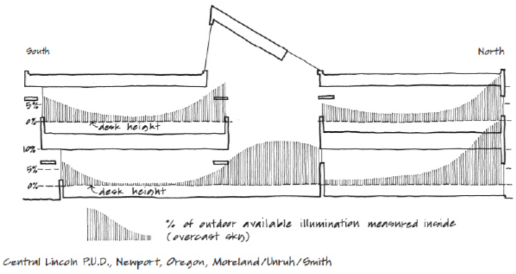
Integrated daylight strategies
ways of introducing daylight

Examples

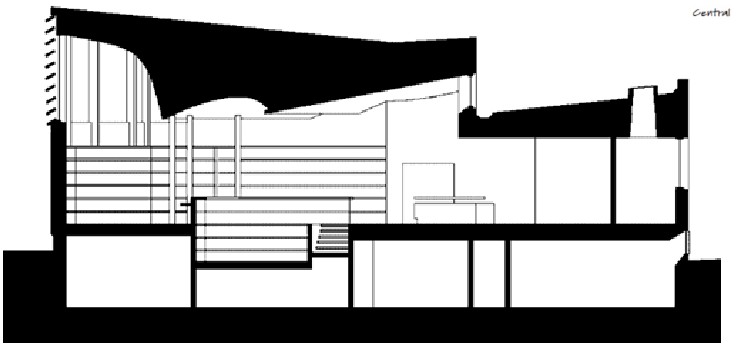
Strategies of **how to introduce daylight** into spaces. There are many important daylight **redirection systems** for windows openings. Thereafter, I would like to choose maximum four **relative systems to investigate** further on.
In general there are mainly two categories of daylighting openings: **side light (1)** and **top light openings (2)**. The key difference of them is that side light opening introduces daylight from the perimeter walls of building while top light opening introduces daylight through the top of the building.



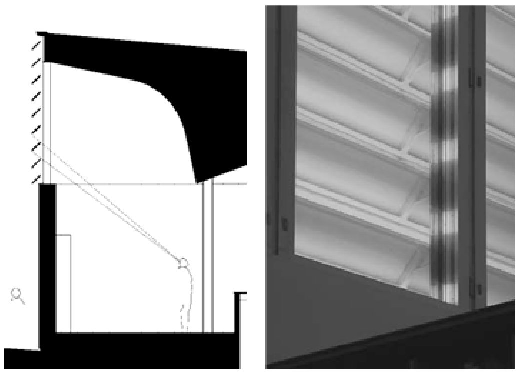
16.1
Studies of Daylight for the 20th Century Rooms, Muséé d'Intéret National, Grenoble, France, Antoine Félix-Faure, Group 6, Architect



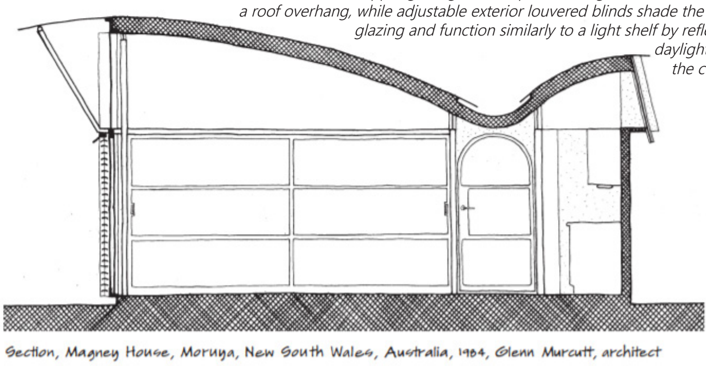
16.2
Whether dayilghting is used to meet task lighting conditions or for ambient lighting within the daylit zone, there is a decrease in illumination as one moves away from the opening.

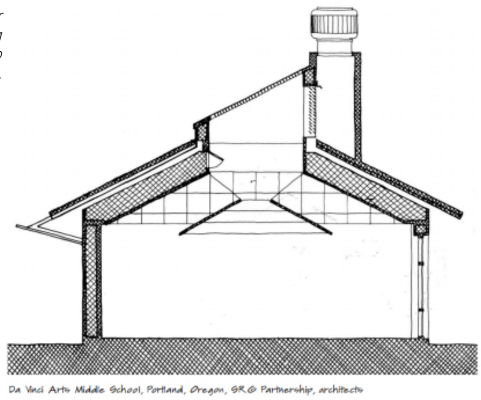


16.7
Glenn Murcutt combined a tall window wall with a curved and sloping ceiling in the Magney House in Moruya, Australia (Bachman, 2003). The high head height admits light deep into the relatively shallow room. The upper glazing in the equator-facing facade is shaded by a roof overhang, while adjustable exterior louvered blinds shade the lower glazing and function similarly to a light shelf by reflecting daylight onto the ceiling.



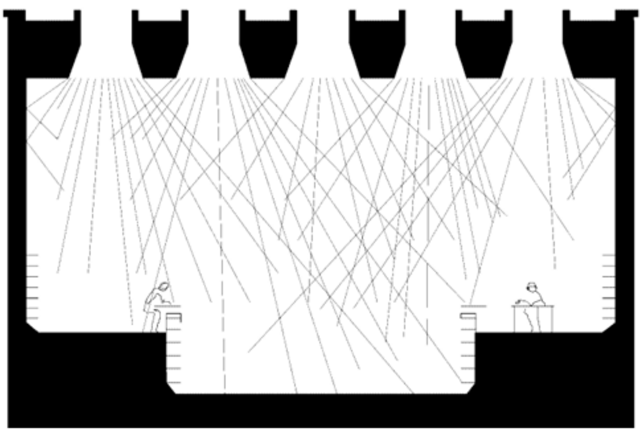
16.3
Humanizing architecture: a veiled light-scoop formed from southern clerestory and curved ceiling provides good diffuse daylight to bookstacks below while mitigating glare of overcast sky for browsers, as this diagram, after a 1964 drawing by Aalto, indicates.

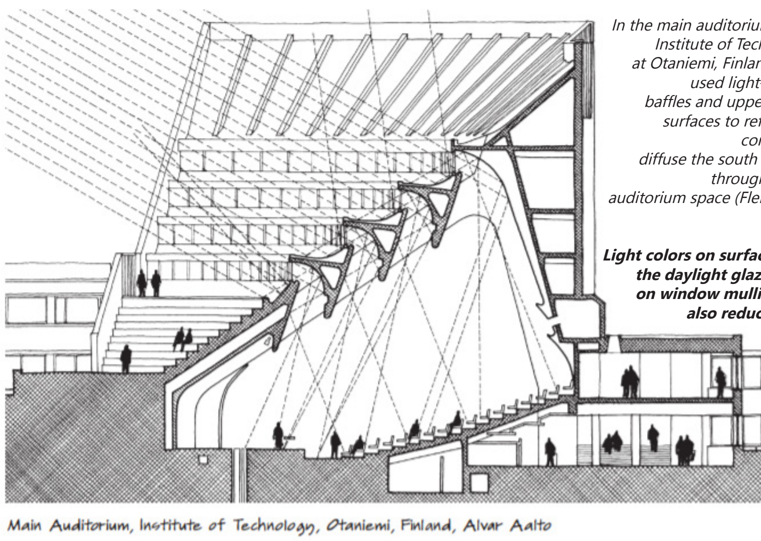




16.4
Create glare-free rooms by using interior daylight reflection strategies and obscuring the sources of light.

16.6
Rational reading light.
The conical roof-lights at Viipuri Library that produce even, shadowless light for focused reading, after a sketch by Aalto.

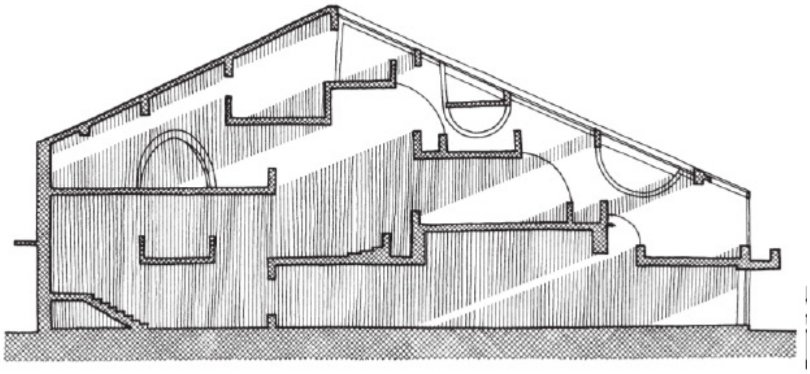




16.5
In the main auditorium at the Institute of Technology, at Otaniemi, Finland, Aalto used light-colored baffles and upper ceiling surfaces to reflect and completely diffuse the south sunlight throughout the auditorium space (Fleig, 1975, p. 88).

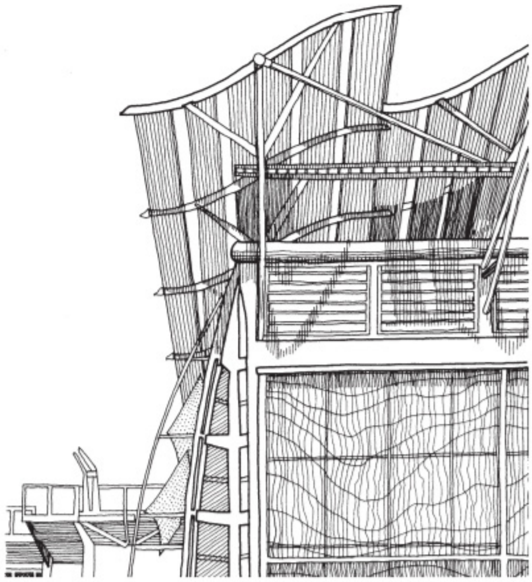
Light colors on surfaces near the daylight glazing and on window mullions can also reduce glare.

Figure 16. *Overview integrated daylight strategies (Brown, G. Z., & DeKay, M., 2014)*



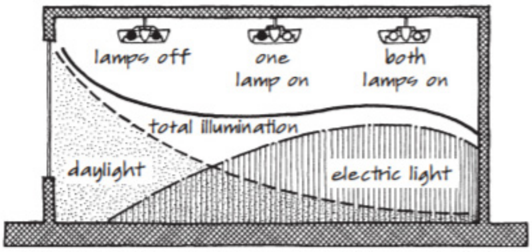
Primary School, Tournai, Belgium, Jean Wilfart, North-South Section

16.8
The roof then can be terraced, providing solar gain opportunity through south-facing monitors, or may be sloped to create a continuous ceiling over a series of semi-open floors, such as in the Primary School in Tournai, Belgium, by Jean Wilfart. An unconditioned central, south-facing atrium with a sloped glazed roof penetrates deep into the building, with openings to each level of the building. The north side library is heated only by the sunspace and by gains from the adjacent heated spaces (Buckley et al., 1991, Chapter 15; Hildon & Seager, 1989, pp. 17–22).



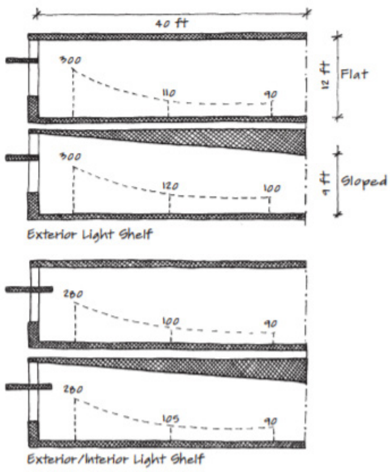
UK Pavillion, Expo '92, Seville, Spain, Nicholas Grimschaw & Partners, 1992

16.10
Photovoltaics can perform a second function as architectural shading. PVs mounted on frames above the roof were used by Nicholas Grimshaw & Partners to power the lighting and evaporative wall water pumps while shading the roof and skylights of the U. K. Pavilion at Expo 92 in Seville, Spain (Davies, 1992; Haryott, 1992).



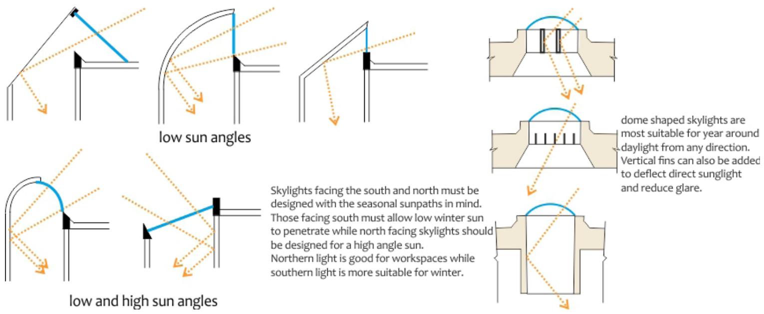
Maintaining Design Illuminance With Electric Light Switching in Layered Zones

16.9
Occupancy controls turn lights off when a zone is unoccupied, while lumen maintenance controls dim lights when lamps are new and turn them up as their light output falls off with age. A schematic section of lighting zones parallel to a sidelight window wall is shown in Maintaining Design Illuminance with Electric Light Switching in Layered Zones.



Effect of Ceiling Slope with Light Shelves

16.12
When combined with light shelf, a sloped ceiling can increase daylight by 10-15% in the middle and back of sidelighted rooms (Innovative Design, 2004; Fardeheb, 1986). The diagrams of Effect of Ceiling Slope with Light Shelves are the results of scale model studies (Fardeheb, 1986). The study was done under clear skies at 34º N latitude with windows facing north and no direct sun on the apertures.



16.11
Principles of skylights

/ sport and daylight /

What is important for sport is not enough light from the right direction, so sharp shadows are created, but the distribution of light so that no glare occurs. It implies that the relationship of the athlete to the light, the activity and the room is important, and that good conditions for sports are a matter of spatial geometry and sufficient lighting.

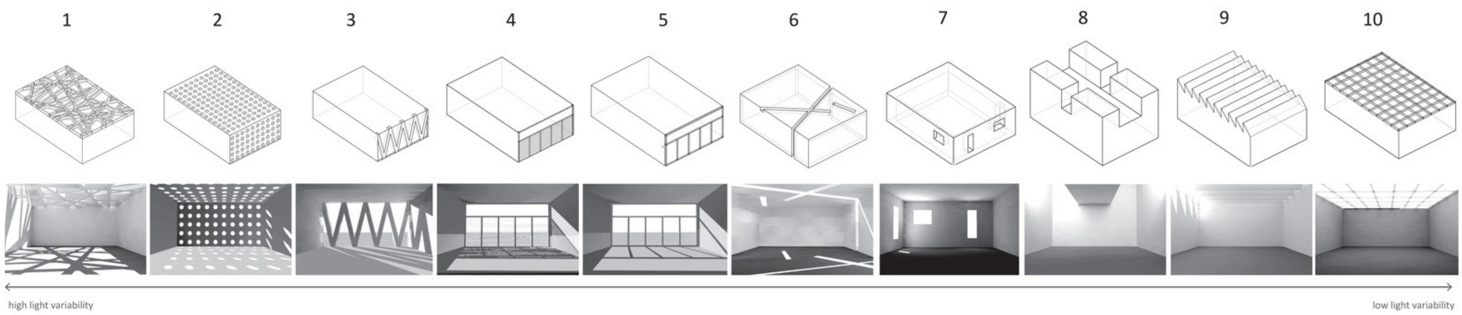


Figure 16. *Overview integrated daylight strategies (Brown, G. Z., & DeKay, M., 2014)*

Playing with light

Research paper:

Light and sports

Playing with light – The relationship between daylight and sports hall designs in the Netherlands compared to other European countries, whereby the European Committee for Normalization is the guideline for sports lighting at European Level

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