Instructions for Ice Hall Illumination

Finnish Ice Hockey Association
Finnish Hockey League
Ministry of Education and Culture
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FOREWORD

This publication serves as a guidance document in evaluating the technical requirements for illuminating ice halls and ice rinks and designing the ice hall lighting. The technical requirements of TV-recordings have especially taken into consideration when building up the instructions.

This guide handles only the rink area of an ice hall. The rink area consist of game area - enclosed by the side boards - plus the team bench and penalty boxes. The hall's general lighting, outdoor lighting, safety lighting, event lighting and the lighting of the outside rinks must be carried out according to specific instructions.

This guide has been built up according to the assignment of the Finnish Ice Hockey Association by the following group :

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The aim of the work group has been to build up a clear and manufacturer-independent guide to be used by decision makers, authorities, hall operators and designers. The work has been attended by a representative of Ministry of Education and Culture

The development in the lighting technology has been rapid, and thus representatives of the lighting fixtures manufacturers have participated in the work.

The work group enhances, that the guide as the result of the work is not as such a promissory document to any party. The guide is, however, constructed so that it can be - if suitable - used as a quality requirements document in projects including design and building of ice halls.

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1. NEED FOR ILLUMINATION

1.1 Ice hall activities and purposes of use

An ice hall is an indoor hall, which has an iced game area. The game area consists mostly of artificial ice. The main purpose of an ice hall is ice sports; ice hockey, figure skating, floor ball, ringette etc. The biggest ice halls are multi-function halls and many other sports can be played there e.g. basketball, volley ball etc. Moreover it is possible to arrange different events e.g. fairs and concerts. In an ice hall the inner climate, temperature and air humidity are controllable, which is not the case in roofed artificial ice rinks.

Table 1 demonstrates the basic ice hall types with their activities and capacities.

Table 1. Ice hall types.

Ice hall type	Activity	Grandstand seats
Large arena	Multi-function hall, ice sports, international events, TV-ready	> 6000
Competition hall	Multi-function hall, ice sports, national events, TV-ready	1500 – 6000
Small competition hall	Ice sports, local multi-use, local matches	300 – 1500
Training hall	Ice sports, local training- and junior matches	100 – 300 standing seats
Roofed artificial ice rink	Ice sports, local hobby- and junior matches	100 – 300 standing seats

1.2. Ice hall illumination

The ice hall illumination contains the following partial areas of lighting:

— **General lighting** containing the lighting of public spaces, grandstand areas, locker rooms, corridors and other smaller places. The lighting of these areas should be designed according to the standard EN 12464-1 ”Lighting of indoor work places”.
— **Outdoor lighting**, which includes the outer spaces of the hall area e.g. walking passages, parking lots, and other technical areas in the immediate vicinity of the hall. The lighting of these areas should be designed according to the standard EN 12464-2 ”Lighting of outdoor work places”.
— **Security lighting**, situated in the inner parts of the hall contains the exit- and backup-lighting. The security lighting should be designed according to standards EN 50171, EN 50172, EN 1838 and SFS 6000-5-56 . The lighting fixtures must fulfil the requirements of the standard EN 60598-2-22.
— **The rink area lighting**, which includes the ice hall's rink area lighting and the needed backup lighting. The rink area consist of game area - enclosed by the side boards - plus the team bench and penalty boxes.
— **Event lighting**

All of the above sectors must be taken into account when designing ice hall lightings.

This guide handles only the lighting technology requirements and designing instructions of the rink area.

1.3 Purpose of illumination

The main purpose of ice hall illumination is:

- sufficient lighting for the activities so that users can carry out the required visual procedures and perceive the space and environment plus the needed entities,
- to guarantee sufficient visual comfort so that the lighting does not disturb the user and
- to ensure a sufficient safety level and produce a proper atmosphere.

The most important factors concerning visual comfort and those main purposes mentioned above are:

- luminance distribution,
- luminous flux,
- glare,
- direction of light,
- light color and light's color rendering characteristics
- the color and reflection factor of the ice , see also section 3.4.

2. LIGHTING TECHNOLOGY REQUIREMENTS

2.1 Common criteria

The lighting technology requirements introduced in this chapter comply with the EN 1219 standard. Also the additional requirements concerning TV-recordings are taken into account.

2.2 Lighting technology quantities

Illuminance E

The density of light incident on a surface is called luminous flux (also luminous power) The unit of the luminous power is lm/m^2 i.e. lux (lx). The illuminance to the horizontal surface is E_h and respectively to the vertical surface E_v.

The average illuminance is E_m

The average illuminance E_m (lx) is the arithmetic mean of the luminous powers calculated on the observation area's surface level. Increasing the average illuminance improves detection, reaction speed, perception of the space and environment plus the evaluation of movements in the sports area. Additionally the level of illumination affects the common feeling of safety and visual comfort.

The general uniformity of illuminance U.

General uniformity U affects the visual performance and it describes how evenly the light distributes on the area of observation.

General uniformity U_o is calculated as the quotient of the smallest E_{min} and the average illuminance E_m.

General uniformity U_d is calculated as the quotient of the smallest E_{min} and the largest illuminance $E_{max.}$

Glare GR

To describe the areal lighting glare magnitude, a specific classifying quantity GR is used. The GR quantity depends on the veiling luminance caused by the lighting fixtures and surroundings. Table 2 demonstrates glare values and their evaluation.

Table 2. Glare classification of a area lighting.

GR	Glare
90	Intolerable
70	disturbing
50	roughly acceptable
30	detectable
10	unobtrusive

The amount of glare depends on the light distribution of the lighting fixtures, their amount and mounting heights plus the environment luminance.

Color rendering index R_a

Color rendering index indicates how well and correctly the light source reproduces colors. Color rendering index R_a is an arithmetic mean of eight recommended color specimen special indices having a maximum value of 100. Table 3 indicates color rendering properties and the respective R_a-indices.

It is important for the visual efficiency and comfort, that the color of the environment and its objects in addition to human skin tones are reproduced natural and correct.

Table 3. Color rendering properties and the respective color rendering indices.

R_a	Color rendering properties
> 90	excellent
$70 < R_a \leq 90$	good
$50 < R_a \leq 70$	satisfactory
$20 \leq R_a \leq 50$	poor
< 20	non-existent

Color temperature

To define the color of the light source, color temperature is used, indicated in kelvins (K). The color temperature is defined as the absolute temperature of a so-called blackbody object so that the blackbody's and the observed light source's light color qualities correspond to each other.

Table 4. Color temperatures and their corresponding color impressions.

Color temperature K	Color impression
< 3300	warm white
$3300 \leq T_{CP} \leq 5300$	white
> 5300	cool white

2.3 Lighting classes and choosing them

The lighting class is chosen according to ice hall type and the matches played in it from table 5.

Table 5. Lighting classes according to different ice hall types.

Ice hall type	**Matches played**	**Lighting class**
Large arena Competition hall	Ice hockey main series Finnish Championship league	J1
Competition hall Small competition hall	2nd level league (Junior Finnish Championship league)	J2
Small competition hall	2nd division and lower ice hockey series, Junior league	J3
Training hall Roofed artifiall ice rink	Practice and training	J4

J-classes are meant for different events of the ice hall rink surroundings. The lighting technology requirements are drew up taken into account the TV/video recording activities taking place in the ice halls, see section 2.6. The average illuminance values indicated in table 6 are maintenance values, under which the average illuminance values on a specified area may not reach before the maintenance of the lighting is performed.

Table 6. J- lighting classes for the rink areas of the ice halls.

Lighting class	**Horizontal illuminance.**			**Vertical illuminance.**			**Glare**	**Light color properties**	
	E_{hm} lx, min	U_{ho} min	U_{hd} min	E_{vm} lx, min	U_{vo} min	U_{vd} min	GR max	Color temperature K	R_a min
J1	1200	0,80	0,60	800	0,70 **	0,50 **	45	5000 - 6500	80
J2	800	0,70	0,50	500	0,60	0,40	45	4000 - 6000	70
J3	500	0,70	0,50	300	0,40	0,20	no req.	3000 - 5000	70
J4 rehearsal	250	0,60	0,40	no req.	no req.	no req.	no req.	3000 - 5000	60

* *The vertical illuminances are calculated and measured orthogonally towards the longwise level of the field (following the main camera directions) to both directions , see section 3.4.*

** For halls belonging to J1 lighting class the vertical illuminance must be calculated to all four main directions. *The general smoothness strengths towards the end side auditoria (perpendicularly to the width level) are $U_{vo} \geq 0,50$ and $U_{vd} \geq 0,30$, see section 3.4.*

The vertical illuminance difference between the adjacent calculation points must be at maximum 20 % in the lighting classes J1 and J2.

The lighting requirements for the team bench and penalty-boxes are defined according to the lighting class of the ice hall's rink area, table 7.

Table 7. The lighting technology requirements for the team bench and penalty-boxes

Lighting class	Horizontal level illuminance	
	E_{hm} lx, min	U_{ho} min
J1	1000	0,80
J2	750	0,70
J3	300	0,60
J4 rehearsal	150	0,40

During the maintenance the horizontal illuminance must be ≥ 100 lx in the rink area and in the team bench and penalty-boxes ≥ 60 lx . The horizontal general illumination uniformity U_{ho} should be ≥ 0,30.

The lighting technology simulations must be done with a software fulfilling the requirements of standard EN 12193, see also section 3.4.

Big variance in illuminance in the rink area and it's immediate vicinity may cause visual weariness and uncomfortable feelings and thus should be avoided.

Big changes in color temperatures must be avoided in the rink area and its immediate vicinity. Event illumination makes an exception.

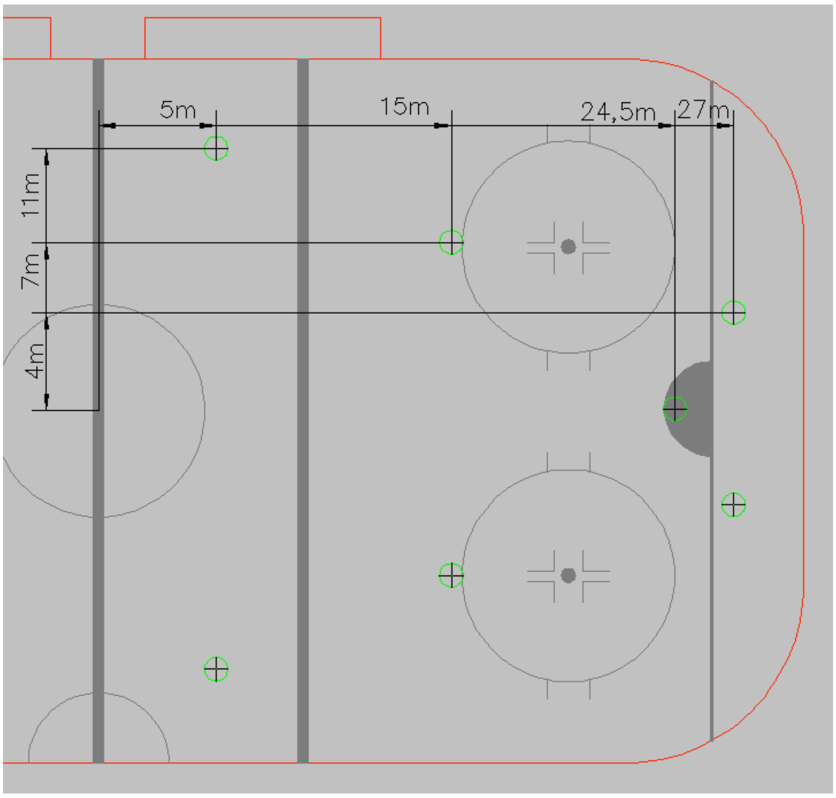
Flicker hinders the ability to concentrate and may cause physiological symptoms like headache. Flicker may also decrease the quality of a TV-recording. The lighting systems must be planned so, that no remarkable flicker or stroboscope effect occurs.

The lighting classes of the outdoor rinks are defined in the standard EN 12193.

2.4 Glare

The GR-method is used in evaluation of glare because of the large size of the hall, pale color of the ice and dark wall and ceiling surfaces. The lighting calculations must be done by defining the positions of the observers seen in figure 1 and glare values must be calculated for them. The observer is positioned at the height of 1.5 m and his/her visual direction is 2 degrees downwards from the horizontal level. The glare values are calculated for every observer in 15 degrees intervals throughout the whole axis, altogether 24 calculated values. The glare value and direction needs to be reported to every observer. The greatest value is used as the limiting value.

Additionally it must be taken into account the positions of the main cameras and the glare influence to the TV-recording.



Observer	X (m)	Y (m)
P1	5	11
P2	15	7
P3	27	4
P4	0	24,5
P5	27	- 4
P6	15	- 7
P7	5	- 11

FIgure 1. Calculation points of the glare values (observer positions) The origin is situated in the faceoff spot in the center of the rink.

Glare can be restricted by following means:

- Taking into account in the lighting design the position of players, main cameras and the spectators. The lighting fixtures should be positioned and directed so, that the players can accomplish their normal procedures according to the activity when the glare is detectable at most.
- Choosing the light distribution of the fixtures so that there occurs no disturbing glare. Lighting fixtures, which reflect a great amount of light to big C- γ-angles (> 70°) should be avoided.
- Avoiding big tilting angles of the spots.
- Using other constructions as glare shields thus preventing players' and spectators' straight visual contact to the light sources.
- By making the intensities of the light sources proportional to the mounting height of the lighting fixtures i.e. limiting the luminance of the low-mounted fixtures.

Reflection of the ice needs to be taken into account in lighting designs.

Additional instructions for restricting glare have been introduced in the CIE publication CIE 112-1994 ”Glare Evaluation System for Use within Outdoor and Area Lighting”.

In other sectors of the hall and in situations, which correspond the working conditions specified in the standard EN 12464-1, the glare values should be calculated using the UGR-method. The glare requirements for different spaces and areas have been defined in the illumination requirement tables of the standard EN 12464-1.

2.5 Definition of the lumen maintenance factor

To prevent the illuminance to fall below the lighting requirements prior to maintenance procedures, a lumen maintenance factor is used in lighting calculations. The lumen maintenance factor is defined by specific lighting fixtures and mounting environment. The illumination level must remain steady throughout the whole life-cycle of the lighting, taken into consideration the maintenance procedures.

The lighting fixture can get dirty depending of e.g. its structure, mounting height, lighting properties and the uncleanness of the surroundings. It is advisable to define the right lumen maintenance factors as project by project and determine all the above mentioned factors, especially the effect of the lighting fixture properties. The lumen maintenance factor has to be mentioned in the lighting information included in the construction plan and in the project-specific quality requirements. If the influences of all factors are for some reason unknown, the basic value indicated in table 8 should be used.

Table 8. Lumen maintenance factors ≤ 400 W light sources for different enclosure classes.

Light source	**Group change interval**	**Enclosure class IP 4X**	**Enclosure class IP 5X**	**Enclosure class IP 6X**
Metal halide, quartz glass ≤ 400 W	10 000 h	0,55	0,60	0,65
Metal halide, ceramic ≤ 250 W	12 000 h	0,60	0,65	0,70
Fluorescent tube T8 /T5, cold-air fluorescent tube	48 000 h	0,60	0,65	0,70
LED*	**	0,60	0,65	0,70

* *For values $L_{80}F_{10}$, in temperature t_a = 25 °C.*

** *A LED-luminaire producing white light has an approximate life span of 50 000 - 80 000 h. The values vary greatly depending on the luminaire type and application used.*

The life spans of the luminaries and the lumen maintenance factors should be defined case by case according to the information provided by the manufacturer.

What comes to the lighting fixtures, the constant luminous flux control can be used, so that the lighting level over-ratings during the startup-phase , caused by the use of lumen maintenance factor, can be minimized.

As for the lumen maintenance factor of the LED lighting fixtures, one must also take into consideration the dirt gathering to the fixtures during their life cycle.

2.6 Additional requirements concerning TV-recordings

The essential lighting technology concerning TV-recordings are the vertical illumination strength and its uniformity. The required level of the illuminance depends on the speed of movements on the field, size of the game medium, recording distance and angle.

Additionally the following factors must especially be taken into account when designing ice hall lighting:

— the general uniformity of lighting,
— color rendering index,
— color temperature,
— glare and notification of the critical lighting fixtures concerning the main cameras (switching off or using glare shields if necessary),
— flicker and
— brightening and dimming properties of the lighting.

The additional requirements of TV-recording have been taken into consideration in the lighting requirements in table 6, especially in the case of lighting class J1. Table 6 indicates requirements to lighting classes concerning the average vertical illuminance, general lighting uniformity, color rendering and color temperatures.

The requirements in table 6 applies to average vertical illuminance for maximum recording distance of 25 m. When the recording distance of the main cameras is longer, the average vertical illumination strength requirement must respectively be bigger according to the standard EN 12193 figure 3.

The vertical illumination strengths for J1 lighting class must be calculated for all four main directions because of the positioning of the main cameras and multi-functionality of the halls, see section 3.4.

In ice hockey, many activities take place in the immediate vicinity of the boards. Thus it is essential, what comes to TV-recording, that the vertical illuminance alongside the boards fulfill the requirements in table 6 and that the boards do not throw shadows on the ice.

In Europe the frequency of the TV-cameras is usually 50 Hz (25 frames per second). Use of high-frequency cameras is, however, becoming more common and when using them, the frequency and flicker of light may have a great influence to the recording quality. To prevent flicker transferring the control of lighting from lighting class J1 to class J2 is recommended to be carried out by partial light switch-off instead of dimming. Dimming can be used, if it can be guaranteed that the lighting fixtures, when dimmed, do not cause flicker disturbing the recording. Flicker can be restricted by the choices concerning attached equipment.

The most essential parts concerning a TV-recording's lighting control are the starting and dimming properties of the light sources. It is recommended to use light sources, which after switching on gain rapidly the full luminous flux and the right color temperature.

The remarkable reflection of light from ice and its consequences to the TV-recording must be taken into consideration in the positioning of lighting fixtures and choosing the light distribution properties. Big luminances on the ice surface can easily cause over-exposing. The designer has to check the positions of the main cameras from the orderer before beginning the design process.

The luminances of the ice hall's lighted ads must always be made proportional to the lighting technology requirements of the rink area. Lighted ads and info screens shall not cause such flicker that could disturb TV-recordings.

The so-called moire-effect of lighted ads and info screens can be resticted by increasing the resolution of the ads and screens.

2.7 Safety lighting

Safety lighting consists of two entities: backup lighting and exit lighting. The safety lighting must be designed and implemented according to national laws and commandments in force plus following the standards EN 50171, EN 50172, EN 1838 ja SFS 6000-5-56. The lighting fixtures must comply with the requirements in the standard EN 60598-2-22.

The rink backup lighting of ice halls must at least fulfill the following regulations:

- the illumination strength must be at least 5 % of the required lighting class,
- the backup lighting must function for at least 30 seconds and
- the backup lighting must stay on (or start immediately) in case of a failure in the field lighting, e.g. during a power failure.

It is recommended to build the backup lighting as a fixed part of the rink lighting, e.g. by connecting some of the rink lighting fixtures after a UPS device The purpose of a rink area backup lighting is to ensure safe interruption of a sports event in case of failure.

3. DESIGN

3.1 Principles of illumination

The lighting fixtures are chosen and positioned so, that the 20 year cumulative life cycle cost of the building and maintenance stays as small as possible and that the requirements of the chosen lighting class and other requirements concerning functionality, safety and durability are fulfilled.

The illumination design process is started according to following phases:

1. The needs of hall illumination are defined. The lighting class is chosen according to the ice hall's type and need of use avoiding under- and over sizing, see sections 1.1 and 2.3.
2. By using lighting calculations (see section 3.4), equivalent alternatives are created, which fulfill all the lighting technology requirements.
3. Comparison of the alternatives. A comprehensive economical evaluation is made to the alternatives, by calculating the present value of the life-cycle costs, cost-benefit ratio or the returns of the first year. When making life-cycle calculations one must take into account also the maintenance costs caused by the lighting itself. An example of cost calculation is presented in appendix 1. Alternate lighting installations must always fulfil all the lighting technology requirements, only after that the final choice can be made on the basis of energy efficiency.
4. The final choice. The lighting principles must be made by taking into consideration all the constructions and it must be based on overall economic evaluations.
5. The lighting principles must then be approved by the orderer, after which the implementation of the plans can start, including the lighting fixture fittings to the hall structures and after that he electrical systems and supporting structures are designed.

3.2 Light sources

The choice of light type must be based on overall economic evaluations, see section 3.1.

The most important properties of the light sources considering the lighting are:

— luminous flux,
— light efficiency (lm/W including the drivers),
— luminaire lifetime (h),
— failure rate,
— lumen maintenance factor,
— light color, light temperature, and color rendering index,
— dimming properties,
— light directivity and
— price.

The technical data of the LED-luminaires, performance and life span must be presented according to standard IEC 62722 and that of the LED-modules respectively according to standard IEC 62717. For the time being, until the above mentioned standards are published, the life span of LED-luminaires is estimated using the IEC's PAS pre-standard IEC/PAS 62722 related to performance requirements and standard IES LM-80-08 together with standard IES TM-21-11. More instructions for evaluating the properties of LED-luminaires are found in the guide "This is how you compare the LED-luminaires":

Other properties to take into consideration are the connected load (nominal load + the power losses of the driver, starting and restarting time, properties of the plane glass and lenses, properties of the reflectors etc.

The most commonly used light sources in ice halls are metal halide lamps and LEDs because of their big illumination strength. The properties of metal halide lamps, fluorescent tubes and LEDs are presented in table 9.

Low power and luminous flux lead to high number of lighting fixtures, which increases building and maintenance costs. High luminance–and long burning time and small lumen maintenace factor decrease costs, but the big efficiency and small amount of lighting fixtures may lead to worse general uniformity of the lighting.

The color rendering and color temperature requirements are presented in table 6. Too high color temperatures should be avoided if the project do not necessarily require them.

The color coordinates of LED luminaires light should remain throughout the life span inside the 7-stage MacAdams ellipsis.

The requirements for ecological design of energy consuming products are represented in the directive 2009/125/EC. The energy efficiency requirements of light sources and attached equipment are presented in Commission commandment (EC) No 245/2009. Additionally the Changing Commandment (EU) No 347/2010 has to be taken into account.

Table 9. The properties of metal halide lamps, fluorescent tubes and LEDs.

Metal halide lamp	**Fluorescent tube**	**LED**
Good color rendering capabilities Dimming Ease of service Good light efficiency Short burning lifetime Starts slowly The light efficiency and color quality of a ceramic emission tube are better than those of a quartz glass tube.	Long burning lifetime Simple and cheap to service Tricky in light distribution control, which in ice halls usually lead to poor energy efficiency. The production of light depends on the surrounding temperature Starts rapidly Glare easily controlled Best suited for low mounting heights	Very good dimming capabilities Small sized and very bright Heat production properties differ from traditional light sources Long life span Life span greatly dependable on semi-conductor temperature Good illumination strength. Easily modifiable light distribution Starts rapidly vibration resistant

3.3 Lighting fixtures

The choice of lighting fixtures must be based on lighting technology requirements, overall economic evaluations and choose of light type, see sections 3.1 and 3.2.

Additionally the choosing of lighting fixtures is dependable on:

- their positioning possibilities in relation to the lighted area ,
- the mounting heights of the lighting fixtures and
- the influence of other structures to light distribution.

The lighting fixture should direct the light with good efficiency ratio to the rink area and it's nearby surroundings and protect the light source and reflectors from different kind of stress and dirt.

The whole lighting fixture power, the lumen output and efficacy must be indicated for the LED-fixtures.

The lighting fixtures must fulfill the low-voltage directive 2006/95/EC safety requirements according to the standards mentioned below.

—	EN 60598	section 2 chapter 1: Fixed general purpose luminaires and the section 2 chapter 5: Spot lights used together in section 1: General requirements and tests.
—	EN 61347	section 2 chapter 13: Particular requirements for d.c. or a.c. supplied electronic control gear for LED modules to be used together with section 1: General and safety requirements for attached equipment.
—	EN 62031	LED modules for general lighting - Safety specifications
—	EN 62493	Assessment of lighting equipment related to human exposure to electromagnetic fields

The lighting fixtures must fulfil the EMC-requirements mentioned in the directive 2004/108/EC concerning the electromagnetic compatibility according the standards mentioned below.

—	EN 55015	The limiting values and measuring methods of radio disturbances of lighting fixtures and devices alike.
—	EN 61000	section 3 chapter 2: Limits - Limits for harmonic current emissions (equipment input current ≤ 16 A per phase)
—	EN 61000	section 3 chapter 3: Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤16 A per phase and not subject to conditional connection
—	EN 61547	Equipment for general lighting purposes - EMC immunity requirements

The fulfilling of the requirements have to be indicated by a requirement compliance guarantee and its technical documents combined to the CE-sign or by test results according to the commandment 2008/765/EC run by a requirement compliance evaluation institute.

Also directive 2011/65/EU " Restriction of the use of certain hazardous substances in electrical and electronic devices" applies to lighting fixtures.

The lighting fixtures must also go through a photo biological radiation measurement according to the standard EN 62471. The measurement standard applies to every photo biological radiation measurement concerning light sources and lighting fixtures. LED-luminaires and -lamps have to be tested and evaluated. The requirement concerning other lamp types is under preparing process. A CE-marking demands that the level of the photo biological radiation is confirmed.

The lighting fixtures must have an enclosure classification of at least IP43.

If the protection shield of the lighting fixture is made of glass, it must be hardened and laminated.

The lighting fixtures must have markings following the standard EN 60598-1.

The metal lamp holder of a discharge lamp must be so rigid that the lamp will always stay in the position in which the light distribution properties have been measured. Other requirements concerning the lamp holder are indicated in the standard EN 60238.

There must exist light distribution measurement results run by a commandment 2008/765/EC approved requirement compliance evaluation institute in the C - γ -system according to the standard EN 13032-1.

3.4 Lighting technology calculations

Calculations shall be made according to EN 12193 standard.

Rink lighting calculations will be performed using a calculation point net, composed of 17 calculation points lengthwise and 9 points across the width, see Figure 2. Lengthwise and across the width the outer points are placed 1 m away from the rink boards. Other points are equally spaced out on a straight line through the outer points.

Calculation point net corner points that are either outside the rink or too close to the rink boards (< 1 m) can be ignored when evaluating compliance with lighting requirements.

Horizontal illuminance is calculated at the surface of the rink. Vertical illuminance is calculated from the same points at the height of 1 m height field perpendicular to the rinks longitudinal plane (towards the main cameras) in both directions. The smallest E_{vm}, U_{vo} and U_{vd} values are used for sizing. Vertical illuminance can be calculated in only one direction if there is no audience or a main camera on one side or if the hall lighting is symmetrical. For J1 lighting-class halls vertical illuminance should be calculated for all four main directions due to the location of the main cameras and the multifunctional nature of the halls.

Due to the multifunctional nature of the halls, the rink borders are not taken into account in the lighting calculations. However, light sources must be positioned so that the rink boards do not cause shadows on the playing area, because in ice hockey many actions takes place in the vicinity of the sides. See also section 2.6 .

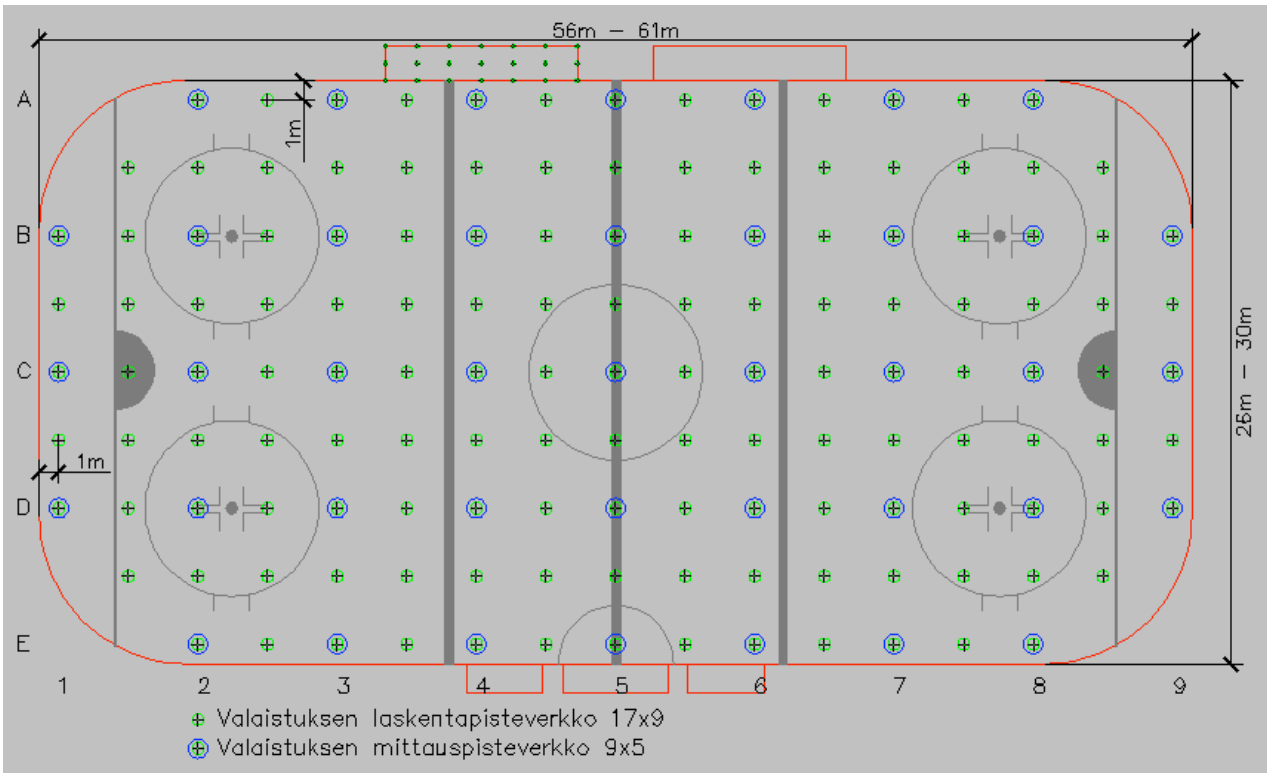


Figure 2. Rink calculation point net.

Lighting calculations for the team benches and the penalty box must be performed with separate calculation point net. These will have 3 crosswise points and 7 lengthwise points (7 x 3 net), see Figure 3. Horizontal illuminance is calculated at 1 m height. The dimensions and locations of team benches and penalty boxes will vary on a project by project basis and need to be clarified with the customer before you can start planning.

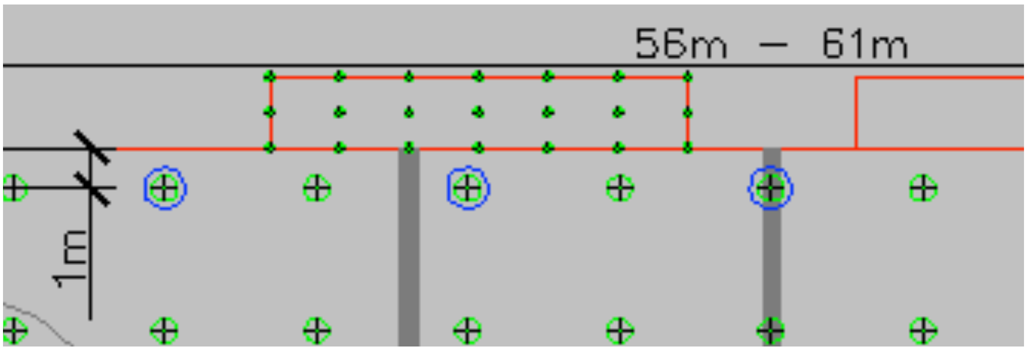


Figure 3. Team bench and penalty box calculation point net.

In lighting calculations RAL 9010 is used as the ice's color shade. The value used for the ice's reflection coefficient is 0.70. If a large number of dark advertisements are painted on the ice the coefficient value should be lowered to 0.60 . For the roof and walls a reflection coefficient of 0.10 is used. If other reflection coefficients are used in a project, they must be approved by the customer and documented in the construction plan's lighting information and the project quality requirements.

Lighting should be designed using a lumen maintenance factor (LLMF) that matches the lighting equipment, the environmental aspects of the space and a defined maintenance plan, see Points 2.5 and 5.

Lighting calculations should take into account the location of the media cube and the information displays and their effects on the lighting outcome.

3.5 Electrical Systems

3.5.1 The grid

Electricity system design is to be done according to:

- standard SFS 6000 Low Voltage electrical installations
- standard SFS 3209 Distribution center and teletechnical spaces and cable channels ,
- house technics RYL 2002 (part 2, points H and J),
- ST manual 34 Good installation practice in electrical and teletechnical works
- ST-card ST 51.13 Cable trays, -ladders and lighting fixture rails.

The sizing of the electrical grid must be taken into account when sizing the lighting grid. In an ice hall cables can be very long and that must be taken into consideration in sizing the electrical grid. The high power and ignition current of the lamps need to be taken into account. Group front fuses should be scaled to withstand the ignition current of the lamps.

3.5.2 Electrical devices

Cable conduits are planned according to luminaire locations. Symmetrical placement of the luminaire facilitates cable conduit optimization. Standard SFS 3209 Electrical switch board and teletechnical spaces and cable channels " gives instructions on sizing of the spaces required by cable conduits.

When designing cable conduits comply with manufacturer instructions. All angles, intersections, an joints should be designed using standard parts for the cable conduit system that are of the same series with the rack.

When designing the cable conduits the requirements of audio and other technical equipment need to be taken into account.

Supporting structures for cable conduits should be scaled taking into account the entire load of the luminaires, cables and cable runs. In addition you should determine what other cables and devices (Audio and low voltage cables) will be connected to the cable conduits.

Cable conduit suspension intervals must comply with the manufacturers type-specific load-curves. In addition, the designer must determine whether shared supports with HVAC systems should be used.

3.6 Lighting control

A simple and effective control can be used to achieve significant energy savings.

Need for lighting control is determined by the function and purpose of the hall and the lighting class of the hall. Lighting control must take into account the multifunctionality of the hall e.g. various sports.

The lighting of a large arena hall, competition hall and a small competition hall should be controllable to at least three lighting levels (Competition, training, maintenance). Control can be implemented through lighting classes, table 10, changing between the lighting class depending on the requirements.

Lighting control is recommended to be implemented through dimming. In this way the general uniformity of illuminance will be retained. With an exception when going from lighting class J1 to J2, see Section 2.6 .

If the lamps cannot be dimmed partial-off controls should be used. Usually a partial-off solution weakens the general uniformity. Partial-off control should take into account operational hours by using a rotation to ensure equal operational periods for all lamps.

Table 10. Lighting control through lighting classes.

Ice hall type	Lighting class	Variable lighting
Large arena hall Competition hall	J1	J1 – J2 – J3 – J4 – Service – J4 – J3 – J2 – J1
Competition hall Small competition hall	J2	J2 – J3 – J4 – Service – J4 – J3 – J2
Small competition hall	J3	J3 – J4 – Service – J4 – J3
Training hall Roofed artificial ice rink	J4	J4 – Service – J4

Event lighting can be connected to the controls Event lighting usually requires switching off the lights bringing the lighting down to very low levels. When designing controls the ignition speed of the light sources used should be taken into account. For example, discharge lamps do not turn on immediately but require a certain amount of time in order to achieve full lumen level. In lighting class J1 halls the control must be compatible with the event lighting.

In lighting class J1 ice halls you should use light sources that reach full lumen level and the correct color temperature quickly. Alternatively, lamellas or other covering structures can be used with discharge lamps to limit the lamp luminance as needed without switching off the lamps.

Excessive switching on/off of discharge lamps should be avoided due to the life span of the lights decreasing with each switching on.

Lighting control unit should be centrally and accessibly located for the staff. It is easy to add rink lighting controls to a building automation system. The need for possible additional control points for event lighting should be determined.

4. LIGHTING DESIGN AND PLANS

All design documents must be drafted in such a way that they contain no room for interpretation and that they contain all of the design-data required for the project. When making the designs the designer must make sure of the following.

- lighting class and lighting requirements match the hall type and the activities performed in the hall.
- lighting principles have been chosen taking into account all structures and they are based on the overall financial evaluation.
- lighting technical calculations take into account the effect of the media cube, informational displays and other structures to the lighting outcome
- Luminaires are placed in such a way that they do not cause shadows within the playing area,
- All lighting requirements are met using proper LLMF and reflection coefficient as pertains to the rink, the team benches and the penalty box,
- the rink area lighting design takes into account the multifunctionality of the halls e.g. different sports
- Lamp positioning and light distribution takes glare into account
- additional requirements of TV-recording have been taken into account (main camera locations, vertical illuminance main directions),
- rink area lighting is adapted to the hall's general, safety, and event lighting
- the rink area lighting is designed in such a way that it will not interfere with cctv systems
- rink area lighting control is implemented according to the hall's functions and purpose (e.g. lighting classes depending on the event) and the requirements of TV-recording
- designs are feasible and do not conflict with the designs for other aspects and technology areas.

The designer must carry out an internal audit of the designs that ensures their applicability and conformity to regulations.

In the list below are the documents to be produced in the ice hall lighting build plans:

- blueprint list,
- job specific quality requirements.
- cabling, placement and plan drawings 1:100 or 1:50
- luminaire alignment drawings,
- list of lighting fixtures,
- list of equipment,
- structural drawings for special solutions and dimensional drawings for fastening of equipment
- lighting technical calculations with a defined light lumen maintenance factor, the calculations shall be archived in a quality-binder
- lighting calculations with a 1.00 lumen maintenance factor
- main diagrams
- group specific load capacity diagrams
- voltage drop and short circuit calculations
- control diagram
- quantity list and
- cost estimate

The final extent of the document list is always determined on a project by project basis.

In addition to the documents listed above the designer should define a thorough maintenance plan, which details group replacement intervals, requirements for single replacements, the lamp cleaning intervals and procedures, and other lighting service procedures see Item 5.

After the customer approves the designs, the designer provides the finalized designs and files to the customer. If approved plans are altered after this point, the alterations are marked with alteration signifiers.

5. LIGHTING MAINTENANCE

5.1. Lighting System Maintenance

The goal of lighting system maintenance is to maintain proper working condition of the lighting and extend the lifecycle of the structures and devices as long as possible with properly timed and high-quality maintenance. Lighting maintenance ensures the fulfilment of lighting requirements throughout lighting's life cycle.

For rink area lighting the tasks include group- and single replacement, fuse- and group cable repairs, audit of the condition of cabling conduits and necessary repairs, and examination of the functionality of the controls and recording the hour-meter readings.

Lighting group- and single replacement includes replacing light sources, replacing LED lights or LED modules, replacing ballasts and other electrical components, cleaning the lights, replacing broken components and checking orientation.

It is recommended that lighting maintenance is performed simultaneously with other maintenance of the ice hall.

Lights that are equipped with long life light sources (e.g. Fluorescent or LED), should be cleaned every 4 years between group replacements .

5.2 Light source group replacement

Light source group replacement shall be handled at the intervals presented in table 11 in accordance with the interval specific to the light source. Replacement shall be carried out according to group specific hour readings.

If the control system or center isn't equipped with hour meters a yearly estimate is used. In this case the annual burning time of the lighting must be determined.

In the case of metal halide lamps group replacement may have to be carried in advance of the interval presented in table 11 if the lamps color reproduction qualities degrade significantly.

Group specific fuse replacement and/or the testing of the cable protection-automat and the repair of faulty protective glass, ballasts, starters, capacitors and other electrical devices is carried out during group replacements. In addition the condition of fastenings is checked during group replacements.

Table 11. Group replacement intervals for different light sources.

Light source	Group replacement-Interval	Annual estimate
Metal halide, quartz glass ≥ 1000 W	4 000 h	2 v
Metal halide, quartz glass < 1000 W	10 000 h	2,5 v
Metal halide, Ceramic	12 000 h	3 v
Fluorescent T8 /T5, Cold-air tube	48 000 h	12 v
LED*	*50 000 - 80 000 h**	12,5 – 20 v*

* *Lifespan of white-light LED-lights is around 50 000 - 80 000 h values $L_{80}F_{10}$, temperature t_a = 25 °C. Values vary greatly depending on light type and usage. Project specific values must always be checked with the manufacturer.*

Lights are cleaned during group replacements. Cleaning shall follow the manufacturer's instructions (e.g. detergents). No strongly acidic or alkaline substances are to be used. Use of other chemicals should also be avoided. Lights are cleaned e.g. by washing protective glasses, lens surfaces and reflectors.

Light source group replacement times are recorded in a database. Maintained groups have their hour meters zeroed.

5.3 Light source single replacement

In ice halls light source replacement must be primarily done through group replacement. It may be necessary to carry out single replacement of light sources if ≥5 % of the rink area lights are blacked out. In this case light source single replacement should be carried together with other maintenance when possible.

Repair of faulty protective glass, ballasts, starters, capacitors and other electrical devices is carried out during single replacements. In addition the condition of fastenings is checked during group replacements.

Lights that have their light sources replaced are cleaned, see section 5.2.

Data of lamps that have undergone single replacement, are saved to the database.

5.4 Quality Assurance and Lighting Technical Measurements

To ensure the requirement compliance of the implemented rink lighting, the quality control has to make sure that

— lighting technical calculations fulfil all quality requirements
— light installation is in compliance with lighting design

Quality assurance is based on a two-stage approach that are performed in the following sequence

— site lighting design review and
— lighting technical measurements

Lighting design documents are required as the basis for quality assurance (final drawings)

If the original lighting designs have been altered in respect to procured lights the lighting technical calculations must be checked carefully.

If the original lighting calculations are deficient or conflict with the actualised installation, the fulfilment of lighting technical requirements must be checked with new calculations. If the lighting requirements are not met the installation must be corrected. If necessary, the possible faults of the installation can be checked with lighting measurements.

When the lighting calculations have been checked to match the requirements the lighting technical measurements are performed on site. The measurements verify whether lighting has been implemented according to the designs.

A suitable high-quality CIE standard light A calibrated vertical- and horizontal luminance measuring tool with a separate light sensor should be used when making the measurements. The tool must be calibrated to < ± 4 % accuracy. The tool must take into account cos correction and eye spectrum sensitivity curve.

Lighting is measured at full power. If necessary, separate measurements are made for dimmed lighting to investigate illumination control functionality. A separate report for each measurement must be made and must contain the following information:

— measurement site information
— name of the person conducting the measurements
— measurement time and conditions (date, time, temperature),
— dimensions of the ice hockey rink, player benches and the penalty box
— main directions if vertical luminance is measured
— types of lights and light sources and
— the condition and dirtiness of the measured lighting

Measuring point net and measuring points are defined in section 3.4 , figures 2 and 3.

Measurements should disclose the following:

— measuring point vertical- and horizontal luminance E_h ja E_v,
— average horizontal luminance E_{hm} (calculated as the average of all measurement points),
— average vertical luminance E_{hm} (calculated as the average luminance of all measurement points) In the main directions, smallest value is dimensioning/design value
— minimum luminance E_{hmin} ja E_{vmin} (the lowest measured horizontal and vertical luminance),
— maximum luminance E_{hmax} ja E_{vmax} (the highest measured horizontal and vertical luminance)
— general smoothness of illuminance U_{ho}, U_{hd}, U_{vo} ja U_{vd} (U_{vo} ja U_{vd} smallest value the design value/dimensioning) and
— largest percentual differences in adjacent measuring point vertical illuminances.

When luminances have been measured in the measurement points indicated by the measuring point net, the luminance values for those same points are checked from lighting calculations. Because the measured lighting is usually new the light lumen maintenance factor should be 1. If the lights are not new, a project specific light lumen maintenance factor that represent reality as well as possible and has been agreed upon with the customer should be used.

If the measured and simulated illuminance levels match each other well enough (average illuminance at most -5% general uniformity) U_o at most -15 % and general uniformity of illuminance U_d at most -30 %), the lighting installation can be declared to be in accordance with the designs and with lighting requirements. If the measurements differ from the simulation, one should determine the reason for the difference and decide on further action on a case by case basis.

The difference in vertical illuminance between adjacent measurement points in J1 and J2 lighting classes can be at most 40%

APPENDIX 1 LIGHTING LIFE CYCLE COSTS

The investment and maintenance costs shall be taken into account in the life cycle calculations. Ice hall lighting life cycle is usually 20 years.

Investment cost estimates need to take into account the installation of various lighting solutions and cable conduit and cable amounts for lighting and lighting control. Maintenance costs must take into account the need for single replacements and repairs for lighting equipment in addition to normal group replacements. Energy costs must be determined according to a burn time that matches reality as well as possible.

Table 12 shows the life cycle costs for lights from six different manufacturers. Cost estimates are for a small competition hall with a lighting class of J3. Lighting technical calculations have been performed as detailed in this guideline. Ice hockey rink dimensions are 61 m x 30 m. Lighting equipment mounting height is 6 m.

Table 12. Life cycle calculations for different light sources and lights. Information of the lighting equipment acquired 1/2014.

	T5	HID	LED_A	LED_B	LED_C	LED_D	LED_E	T5
Valaisimia [kpl]	196	44	120	70	120	150	70	108
Valaisin rivejä [kpl]	7	4	6	5	6	6	5	5
Teho [kW]	33,7	24,6	15,0	18,7	15,6	15,9	17,2	37,2
Huoltoväli [h]	50000	12000	60000	60000	60000	50000	60000	50000
Investointi	59 100 €	24 800 €	78 000 €	64 300 €	81 000 €	89 700 €	64 300 €	45 400 €
Ryhmävaihto	12 800 €	38 700 €	53 403 €	11 000 €	56 500 €	75 400 €	11 000 €	15 000 €
Kunnossapito (yksittäis vaihdot lamppu+Valaisin)	11 000 €	3 700 €	18 100 €	10 000 €	22 800 €	21 800 €	10 000 €	10 100 €
Hoitokulut yhteensä	**23 800 €**	**42 400 €**	**71 503 €**	**21 000 €**	**79 300 €**	**97 200 €**	**21 000 €**	**25 100 €**
Energiakustannukset	134 500 €	92 750 €	60 500 €	75 400 €	63 000 €	64 200 €	69 266 €	148 000 €
Elinkaaren aikaiset käyttökustannukset 20 vuotta	**158 300 €**	**135 150 €**	**132 003 €**	**96 400 €**	**142 300 €**	**161 400 €**	**90 266 €**	**173 100 €**
Elinkaarikustannus (investointi + käyttö) 20 vuotta	**217 400 €**	**159 950 €**	**210 003 €**	**160 700 €**	**223 300 €**	**251 100 €**	**154 566 €**	**218 500 €**

The assumed basis for the calculations are the following values:

- The annual burn time, 100% power, 1200 h/A
- The annual burn time, 50% power, 3000 h/A
- Energy price 0.10 EUR/kWh
- Group replacement costs 28 EUR/Light
- Single replacement costs 56 EUR/Light
- Ballast faults 1 % a year
- Relative amount of yearly single replacements 0.5 %
- Light channel installed 35 EUR/m
- Cabling including work 5 EUR/m

Group replacement intervals for Metal halide and fluorescent lights as defined in Table 11. In addition, it is assumed that 1% of the lights fail per year (ballast replacement) and individual light source malfunctions at a rate of 0.5 % a year (single replacements). Ballasts have been calculated to be replaced once during the life cycle during a group replacement.

LED luminaires have been calculated to have one luminaire group replacement or LED module or driver group replacement during the life cycle. In addition, it is assumed that 1% of the lights fail per year (drivers replacement) and individual light source malfunctions happen at a rate of 0.5 % a year (light or LED module replacement).

The effect of lighting fixture heat loads to maintenance costs must be taken into account in the life cycle cost calculations of the ice hall.