Final report

1.1 Project details

Project title	SportsLED
Project identification (program abbrev. and file)	64015-059
Name of the programme which has funded the project	EUDP
Project managing company/institution (name and address)	DTU Fotonik
Project partners	NorthLed, Roskilde Kommune, Himmelev/Veddelev Boldklub, DTU Fotonik
CVR (central business register)	30 06 09 46
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1.2 Short description of project objective and results

1.3 Executive summary

1.4 Project objectives

1.5 Project results and dissemination of results

1.6 Utilization of project results

1.7 Project conclusion and perspective

Annex
Relevant links

1.2 Short description of project objective and results

English version

Apart from the very large Champions-league stadiums, almost all football fields with lights installed, use metal halide lamps. Metal halide is an energy efficient lighting technology, i.e. a large amount of light is emitted per electrical watt consumed. However, since the light point in a metal halide light bulb is relatively large (typically a few centimetres), the light emitted cannot be controlled very well by reflectors and lens optics. As a result, a significant part of the light escapes to the surroundings. Hence, in terms of lumens arriving at the pitch per watt consumed, Metal Halide is actually not the best technology.

Contrary, LEDs have small light points (few millimetres), making them ideal candidates for accurately shaping the light.

Prior to the project, DTU Fotonik had developed a lens design technology called Reshape. Here, a predefined light area can be uniformly lit by specially shaping a polymer lens that is placed right in front of an LED. The project consortium wished to use this technology to shape the light from a large array of LEDs, so that only the football field is illuminated, not the surroundings.

In particular, the technical goals were to achieve:

1. 50 % less energy consumption
2. 10 times less light pollution to surrounding areas
3. 10 times better uniformity
4. Reduced TCO on lamp light sources and maintenance by 50 %

- all relative to the existing metal halide solutions.

These goals were to be demonstrated and tested by building a full 1:1 demo lighting system at Himmelev/Veddelev Boldklubs football facility in Roskilde Kommune. The demo site would then be used as an exhibition site, by which NorthLED could attract potential customers to this new technology.

The results of the project were very good:

1. A new free-form lens was designed and an injection molding tool was manufactured to mass produce the lens in 2100 pcs.
2. A Chinese LED lamp manufacturer was identified as a supplier of six "raw" LED lamps (4500 Watts each, the largest in the world at the time!)
3. All six lamps were assembled and tested in the laboratory
4. A completely new mast installation (six masts) including electrical supplies was installed around an existing football field at Himmelev/Veddelev Boldklub.
5. The new lamps were mounted and tested:
   a. Light pollution was reduced by 90% compared to the latest metal halide installation in Roskilde Kommune
   b. A reduction in energy consumption of 48% compared with metal halide was demonstrated
   c. A reduction in TCO of 40 % was achieved
   d. Our initial goal of reaching 10 times better light uniformity was not achieved. However, the light uniformity still meets the requirements of UEFA.
6. The installation was demonstrated to 45 key persons from various Danish municipalities, football clubs, football organizations, and lighting consultants. It was very well received.

7. Another two installations have already been sold.

Danish version

Bortset fra de helt store Champions-League stadions, er næsten alle fodbold stadions i dag belyst med metal halogen lamper. Metal halogen er en energi effektiv lysteknologi, dvs der udsendes store mængder af lys per elektrisk watt, der forbruges. Lyspunktet fra metal halogener er imidlertid ret stort (nogle få centimeter), hvilket gør at lyset ikke så let kan styres og formes vha. a reflektorer og linser. Dette resulterer i, at en betydelig del af det udsendte lys rammer uden for banearealet og spildes til omgivelserne. Derfor, målt i mængden af lys, der rammer banen, per forbrugt elektrisk watt, ja så er metal halogen faktisk ikke den bedste teknologi.

Modsætningsvist, så har den nye LED teknologi et meget lille lyspunkt (få millimeter), hvilket gør LED til en meget bedre teknologi, når det kommer til at forme lyset præcist.

Før dette project gik i gang havde DTU Fotonik udviklet en linse teknologi, kaldet Reshape. Med denne teknologi kan et areal belyses helt jævnt ved at specialdesigne en plastlinse, der placeres foran LED'en. Projekt konsortiet ønskede derfor at bruge denne teknologi til at forme lyset fra store arrays af LED'ere, sådan at kun selve fodboldarealet bliver oplyst, ikke omgivelserne.

Helt specifikt var målene med projektet disse:

1. 50% mindre energiforbrug
2. 10 gange mindre lysforurening til omgivelserne
3. 10 gange bedre lysuniformitet på banen
4. reduktion af TCO for lysinstallation og vedligehold på 50%

- alt taget relativt til de eksisterende metal halogen løsninger på markedet.

Målene skulle testes ved at bygge et fuldt 1:1 demo lysanlæg på Himmelev/Veddelev Boldklubs kunstgræsbane i Roskilde Kommune. Demo installationen kunne så samtidigt benyttes som et udstillingsvindue af den nye teknologi, hvormed NorthLED kunne promovere løsningen overfor nye fremtidige kunder.

Resultaterne af projektet har været rigtigt gode:

1. Der blev designet en ny free-form linse, en sprøjtestøbe værktøj blev fremstillet og 2100 linser blev støbt
2. Der blev taget kontakt til en kinesisk LED lampe leverandør, som vi fik til at fremstille 6 demo lamper til projektet, hvori linser kunne monteres. Lamperne var på 4500 watt hver, hvilket var de kraftigste lamper i verden.
3. Alle seks lamper blev samlet og testet i laboratoriet
4. En helt ny masteinstallation blev indkøbt og opstillet omkring Himmelev/Veddelevs boldbane i Roskilde. En ny elinstallation blev etableret.
5. De seks lamper blev monteret og testet:
   a. Lysforureningen var faldet med 90% sammenlignet med den seneste metal halogen installation i Roskilde
   b. En reduktion i energiforbrug på 48% blev påvist
   c. Der er opnået en reduktion i TCO på 40%
   d. Vores mål om at nå 10 gange bedre uniformitet blev ikke nået. Dog lever lyset stadig op til UEFAs krav.
6. Den nye installation blev fremvist for 45 nøglepersoner fra forskellige danske kommuner, fodboldklubber, fodbold organisationer og belysnings konsulenter. Lysinstallationen blev meget vel modtaget.

7. Yderligere to lysanlæg er allerede blevet solgt.

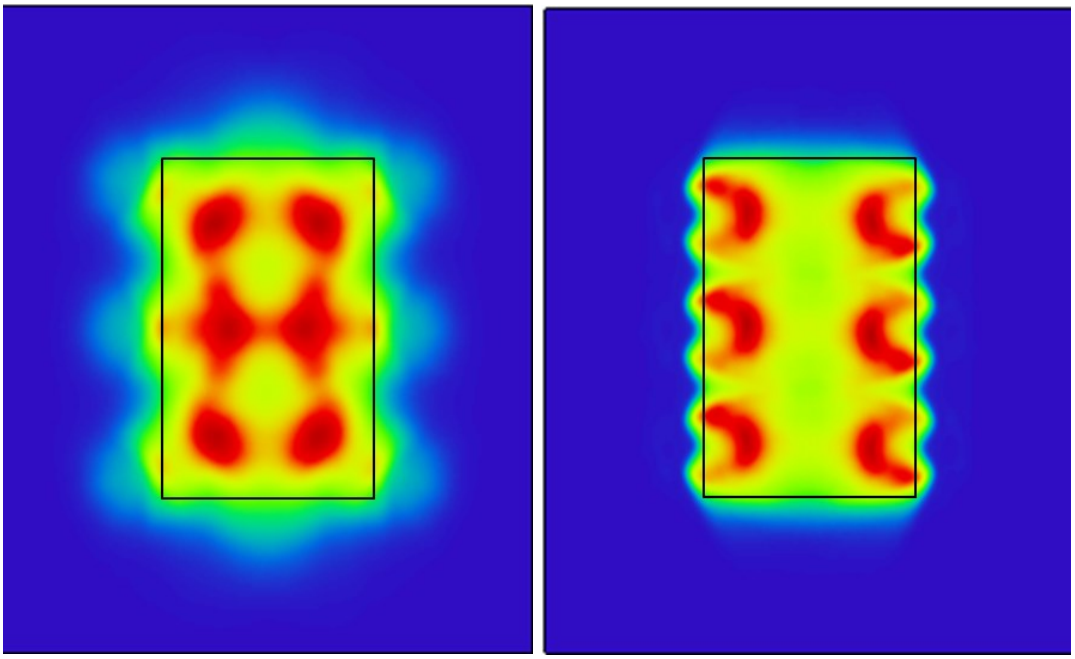
1.3 Executive summary

The aim of the project was to investigate and demonstrate a new LED lamp technology for football fields. The new technology features a 90% reduction in light pollution, 50% reduction in energy consumption, and a 40% reduction in TCO, compared with the existing metal halide technology.
A consortium consisting of Light manufacturer NorthLED, municipality Roskilde Kommune, a local football club in Himmelev/Veddelev and the Fotonik Institute at the Danish Technical University has developed this new concept. A completely new light facility has been installed at Himmelev/Veddelev Boldklub, which clearly shows the difference between the new and the old technology. The technology has been patented and is now being commercialized by NorthLED in Svogerslev, Denmark.

1.4 Project objectives

Lens design

The lens design was the first major task. Here, the job was to shape the surface of a lens to be placed in front of each LED in the lamp (one lamp comprises 350 LEDs). The lens was designed mathematically and the resulting light distribution on the football field was simulated:



On the left is shown a light distribution on a rectangular football field using traditional metal halide technology.

As is seen, the light distribution deviates from a sharp rectangle in the sense that the edges are rather fuzzy and bumpy. On the right is shown a simulation of the light distribution using our new lens technology with LEDs. The rectangle is now much sharper and much less light is lost to the surroundings.

Lens manufacturing

In order to obtain a sufficient lumen output a total of 350 LEDs and 350 lenses were necessary in each of the six lamps. We therefore needed an injection molding tool to mass produce the lenses in acrylic at a competitive price. One major risk in such a process is that the molded lens may not end up having the exact same shape as in the mathematical simulations. This would deform the light shape on the field.

However, already after the first attempt, we could measure the light distribution from a single lens and a single LED and confirm that the light distribution was as intended.
The lens shape is part of a patent application and therefore cannot be published at this time.

Constructing the rest of the lamp
Another serious task was that we needed to build a 4500W LED lamp. The most powerful LED lamp in the world at that time was 2000W. We contacted a Chinese lamp manufacturer and asked them to ramp up their largest lamp to 4500W. After several technical discussions, we succeeded in finding a suitable lamp design, which is shown here:

4500W LED lamp, first demo.

None of the project partners had been dealing with this particular supplier before. Moreover, their technical staff did not speak English, so we had to use interpreters from Chinese to English during our telephone conversations. Hence, there was a significant risk that something went wrong in the final product. For example, one small technical detail, which seemed very trivial at the time, evolved into a major two-month delay: The colour of a small plastic piece. We had ordered it to be black, but it came to us grey. We therefore had to discuss "the degree of blackness" for many weeks before reaching consensus.

Light masts
One of the main tasks in the project was to be able to do comparisons between the existing lighting installation and the new one. Hence, we needed new masts. Moreover, because the lamps are newly developed prototypes, we needed to be able to inspect the lamps regularly without having to rent a boom lift. We therefore ended up buying six foldable masts:

Each mast (18m high) was mounted in a 2 m^3 concrete block, dug into the ground.

In spite of all the risks identified during the project, we ended up following the time plan pretty well and reached our mile stones.

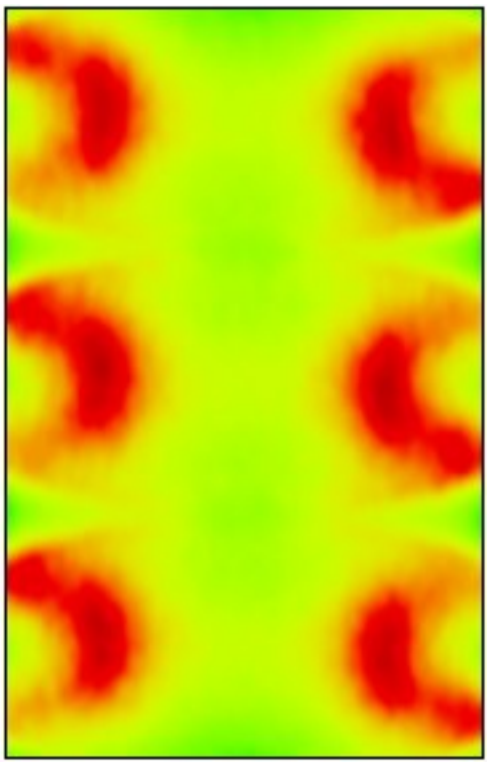
1.5 Project results and dissemination of results

The system in general
The new lighting system is up and has been running since summer 2017:

The Light installation at Himmelev/Veddelev Boldklub. The red arrow shows the new lamps mounted on new foldable 18m masts. The green arrow shows the old metal halide installation.

The illumination has been measured in a dense measurement grid showing these results:

357	362	337	283	233	198	187	191	226	271	316	350	347
411	459	491	420	334	286	265	277	327	400	467	465	434
304	396	570	503	398	336	310	325	386	481	535	405	318
321	413	566	508	402	336	311	326	390	485	544	399	311
435	484	497	429	349	293	273	287	340	417	486	458	407
356	391	365	312	263	225	211	225	261	314	360	396	373
225	307	309	279	235	205	195	212	259	299	338	338	270
372	395	375	328	266	232	222	241	275	335	384	424	393
412	451	481	431	344	297	276	292	342	426	499	483	440
297	371	516	503	410	342	315	334	398	500	547	415	336
295	367	507	493	394	331	315	339	399	500	547	407	327
404	442	465	414	343	288	273	290	341	420	479	459	401
373	406	372	317	269	229	214	225	261	311	361	392	364
266	364	356	314	258	220	196	206	237	282	317	321	245
423	464	420	358	292	248	224	230	267	324	382	412	390
447	522	558	475	376	312	286	295	345	430	505	488	447
324	420	628	555	436	353	326	338	404	509	556	402	321
341	442	613	543	427	352	322	333	402	503	550	387	304
487	507	514	438	350	292	369	282	340	414	485	456	410
332	361	335	279	233	199	183	204	239	289	334	368	362



Left: Lux values measured at 260 grid points covering the whole football field. The blue/red colors shows the illumination as a heat map (blue = low illumination, red = high illumination). Right: the simulated mathematical lux levels shown as a heat map (green = low illumination, red high illumination).

We observed that there was an excellent agreement between the measured and the simulated data.

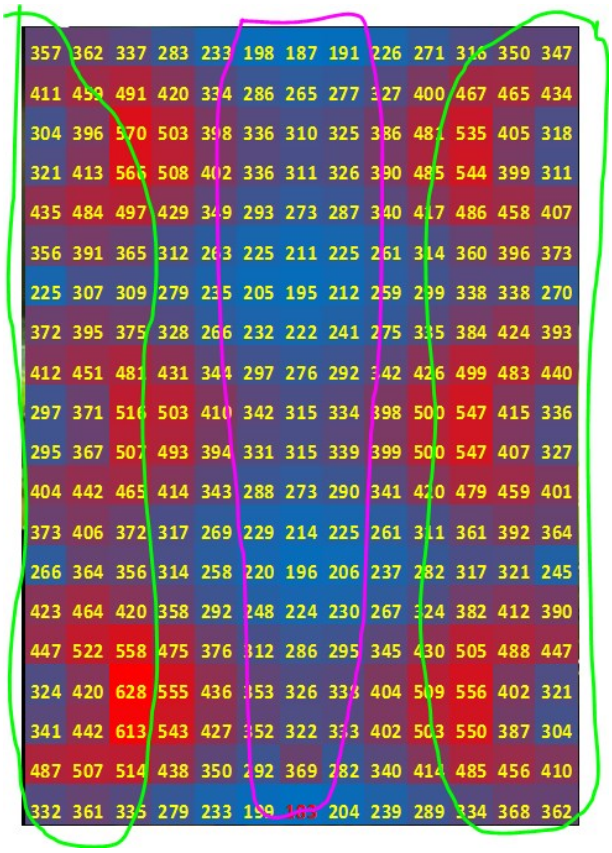
Energy savings

The average lux value was measured to be 364 lux, which is 46% more than the intended 250 Lux. It means that in future installations we can:

1. reduce the number of LEDs in each lamp from 350 to 240. This reduces the cost price accordingly, which is very important for the commercial potential of the technology
2. include the reflection from the various types of artificial turf/hybrid grass to be more precise in the actual on field (1m above field) intensity
3. reduce the number of drivers from eight to six. This also reduces the cost price.
4. reduce the weight of each lamp from 120 kg to 82 kg. This reduces the load on the mast considerably which leads to cheaper masts and cheaper concrete foundations.
5. reduce the power consumption of each lamp from 4500W to 3100W. This adds up to only 18600W for the whole field. A conventional metal halide solution comprises 18 lamps consuming 2000W each, adding up to 36000W. Hence, our solution consumes 48% less energy, which is very close to the intended 50% reduction.
6. By slightly changing a key part of the lamp (patent pending) we can further reduce the energy consumption by 10%. This will, however, be at the expense of a little higher light pollution level. At some more remote locations energy savings weigh higher than light pollution.

Light uniformity

The light uniformity (defined as the darkest spot divided by the average) was measured to 0.5. This was a little bit lower than the expected 0.57. We do believe that this is caused by the lamp heads being set at a too low angle:



The light measurements indicate that the lamp heads are pointing too much downwards causing the center of the field (magenta marking) to be slightly under exposed compared to the side areas (green markings) that are slightly over exposed.

Hence, we do believe that we can reach the expected uniformity value of 0.57 by making the final adjustment.

End user feedback
The lighting installation has been running at Himmelev/Veddelev Boldklub for six months. We have been at the facility several times talking to the players and the response has been very positive:

- "The light is awesome"
- "Much better than the old light"
- "It is much easier to see the ball"
- "The light seems whiter compared with the metal halide. It makes it easier to see the ball"
- "The ball does no longer get invisible when shooting high in the air"

- The Chairman of Himmelev/Veddelev Boldklub, Carsten Reinholdt, states:

"Jeg vil blot kvittere for et flot gennemført projekt - og jeg kan tale på hele fodboldklubbens vegne; vi er meget tilfredse med den nye belysning. Det er meget vellykket."

- The Mayor of Roskilde Kommune, Joy Mogensen, has made a formal recommendation in which she states:

"…Roskilde Kommune har skabt et ret unikt økosystem og samarbejde af erfarne erhvervsfolk, kulturcentre og uddannelsesinstitutioner. Et godt eksempel på dette, er den nyetablerede virksomhed NorthLED ApS, som udvikler miljøvenlige LED lamper til stadionbelysning. Lamperne leverer et retningsbestemt lys, der kun rammer selve grønsværen og ikke området uden for stadion. Dermed fjernes den generende lysforurening, som kendes fra traditionelle lamper, for de omkringboende borgere samt for plante og dyrelivet i området. Samtidig bruger løsningerne meget lidt strøm og er nemme at vedligeholde, hvilket gør dem både miljøvenlige og økonomiske. Himmelev-Veddelev Boldklub og Roskilde Pigefodbold i det nordlige Roskilde, er de første sportsklubber i landet, - som har fået installeret det nye belysningsanlæg, og brugerne er meget begejstrede for den nye LED lysløsning."

Total cost of ownership
The TCO calculation for a 250Lux environment will (on average) look like this:

125/250Lx Light-solution	MH HiD	LED^2
Initial Investment (technology only)	kr. 152.000,00	kr. 269.400,00
Energy consumption costs (year)	kr. 5.932,00	kr. 2.418,00
Maintenance costs (year)	kr. 11.913,00	kr. 1.112,00
TCO year 1	kr. 169.845,00	kr. 272.930,00
TCO year 5	kr. 241.225,00	kr. 287.046,00
TCO year 10	kr. 330.451,00	kr. 304.692,00

Also, when applying to and calculating a 'typical' return on investment (ROI) for replacing an existing older environment, the LED^2 solution has proven an average ROI of 6-8years (depending on the current installation and environment). Here below an example of a ROI & TCO calculation for a light system upgrade from 125Lx (MH HID) to LED^2 including environment variables (but not adding any potential

value creation of implementing a better and less polluting light system) ROI in this example is 8 years.

Kalkulationer fodboldbanebelysning		
Pris pr. KwH	kr.	1,60
Antal spilledage pr år		155
NB prisreduktion pr KwH ved energirenovering	kr.	1,04

	Type	Lyseffekt (Lux)	Armaturer (W)	Enheder	Enhedspris	MH Forkoblinger	bane effektforbrug (w)	Investering (CAPEX)	Drift (Opex) pr år
Traditionelt Anlæg nuværende	MH / HiD	125	2000	8	kr. 9.500,00	8	18400	kr. -	kr. 4.563,20
Traditionelt Anlæg opgradering	MH / HiD	250	2000	16	kr. 9.500,00	16	36800	kr. 152.000,00	kr. 5.932,16
Serviceintervaller pr år							0,76		
Gennemsnitspris pr service interval							kr. 15.675,00		kr. 11.913,00
TCO pr år									**kr. 22.408,36**
	Type	**Lyseffekt (Lux)**	**Armaturer (W)**	**Enheder**	**Enhedspris**	**MH Forkoblinger**	**bane effektforbrug (w)**	**Investering (CAPEX)**	**Drift (Opex) pr år**
LED Ligalight	LED	200	2500	6	kr. 44.900,00	0	15000	kr. 269.400,00	kr. 2.418,00
Serviceintervaller pr år							0,015		
Gennemsnitspris pr service interval							kr. 74.085,00		kr. 1.111,28
TCO pr år									**kr. 3.529,28**

Commercial outlook

The technology can relatively easily be traversed into all other outdoor sports areas, other stadiums and arenas, tennis courts, equestrian areas, golf courses, motorsports as well as city parks and playgrounds.

Other business areas, where the need for precise, performing and protective illumination will be increasingly important (for environmental financial, and local community reasons) would be obvious to address; areas like parking lots in cities and shopping areas, logistic terminals in harbours, airports and railroads. Areas that have a need for specific, concentrated and powerful light like growth and greenhouses, specific farming areas and also production facilities where light is critical (e.g. food and beverage production, healthcare and pharma as well as certian high-end electronics) There are many other areas where people, nature or other surroundings are particularly delicate or sensible, and there is a need for an increased protection from potential harm done by artificial lights; think of city-centres, old town squares and traffic points, wildlife protection stations, zoo´s, camping areas etc… the possibilities are truly many and the commercial positioning will need a careful and competent approach.

Dissemination

1. We have held four demo conferences at the Himmelev/Veddelev facility. The conferences were announced openly at Facebook and at NorthLEDs website. In total about 110 people from all parts of Denmark visited the site. These people represented different municipalities, light consultants, energy companies, electrical engineers and sports clubs.
2. Ingeniøren, 16. oktober, 2017: ” DTU-forskers linse baner vej for LED-lys på fodboldbanen” https://ing.dk/artikel/dtu-forskers-linse-baner-vej-led-lys-paa-fodboldbanen-207136
3. Ingeniøren, 16. oktober, 2017: ” DTU's LED-linse testes på fire forskellige kunstgræsbaner” https://ing.dk/artikel/dtus-led-linse-testes-paa-fire-forskellige-kunstgraesbaner-207205
4. Patent application covering the lens technology. Will be published in late 2018.
5. http://ipaper.ipapercms.dk/TEKNIQ/electra-2018/januar-2018-electra/?page=38
6. https://epaper.dk/dsf/sportsfaciliteter/9/
7. https://www.loa-fonden.dk/presse/2017/firkantet-lys-paa-vej-til-fodboldbaner-i-aarhus-silkeborg-birkeroed-og-roskilde/

1.6 Utilization of project results

A shared patent application between NorthLED and DTU has been filed in order to commercialize a product family based on the developed technology.

In the coming 1 – 2 years four to five products will be launched based on the technology:

1. LED^2 small/tiny – low cost and low pollution solution for outdoor recreational, pathways, plying ground, multifields etc
2. LED^2 cornermast – entirely new optical scope for >1000Lux environments
3. LED^2 low/low – low power/low pollution – aiming for a zero light pollution the light masts are spaced by 1/3 of the field length
4. LED^2 wide/wide – aiming for the perfect light distribution and 0,9 uniformity, masts are spaced by nearly 1/2 of the field length
5. LED^2 Band- different fixture structure and combined optics enabling a two-sided tribune-mounting for large (>1000lux) illumination

The company NorthLED ApS will pursue the productization and commercialisation of the prototypes and in that focus on promoting, maturing and further developing the technology, which - when boiled down to the very core, is about delivering 3 key-things in a combined/integrated, proven and tested solution.

1. Deliver precisely cut and concentrated illumination via brilliant new optical modulation (Prisms and Lenses)
2. Providing world class electronic elements and components, using proven technology from proven vendors with a track record of top-performance, quality, support and endurance
3. Utilizing more intelligent, user-friendly and IOT based operations and interoperability. The solution that will learn to adapt to local circumstances and conditions like e.g. the weather, the actual usage and system performance/efficiency, are all elements that will determine the best usage and operation.

With a stringent focus on these three above elements – and pushing them into the right markets; we are relatively confident that the commercialization of the prototypes and inventions will become successful.

1.7 Project conclusion and perspective

We find the project very successful. We did set high ambitions in aiming at building a full-scale lighting installation using a completely new lens technology and using LEDs instead of metal halide bulbs. Never the less, after only 1½ year the light was shining in Himmelev fulfilling nearly all the dreams we had hoped for. We think that this new development will show the way for all future football stadiums in Denmark. Not only the small 250 Lux stadiums, but also the larger stadiums, 1. Division and Superliga. Not only will lots of electrical energy be saved. Countless numbers of complaints from citizens that today are disturbed by light pollution, will cease.
Feedback from partners and clubs in the Nordics, UK and US has been interesting, and we do believe that there is a genuine and very positive interest. We have in 2018 engaged agents in Sweden, Norway, Finland, Greenland, Iceland, Ireland and the UK who in 2018 will investigate and feedback on the potentials behind this first interest. This said the larger US market will require a very different (and more comprehend and expensive) approach.

Annex

For more information see NorthLEDs homepage:
https://www.northled.biz/