LEDs in the exterior lighting (LED-ek a kültéri világításban)

Budapest, 4 – 5 February 2014

Dionyz GASPAROVSKY

1) Introduction

2) Market overview

3) LED luminaires for roadlighting: optical performance

4) LED luminaires for roadlighting: electrical parameters

5) LED installations

6) Roadlighting calculation

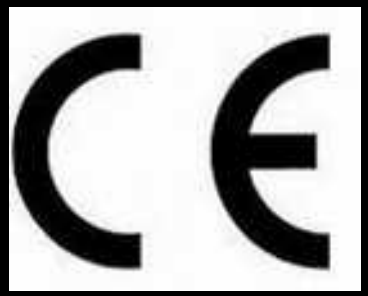
7) Conclusions

- LED technology is rapidly penetrating to the field of public lighting
- Modern LED luminaires caught the attention of many mayors and municipal decision makers and are therefore preferred against classical sodium based technologies also despite their significantly higher price
- The presentation aims to summarize the status, problems and experience with the LED lighting outdoors, with focus to road lighting

01 Introduction

- Market with the LED luminaires and systems is overhlemed by various sorts of products:
  - certain number of sophisticated high-tech luminaires
  - vast bulk of cheaper and thus technically much less advanced luminaires
- Because the market's offer highly prevails over demand, it is in question, what types of luminaires are installed in real instalations

Conformité Européenne



02 Market overview:

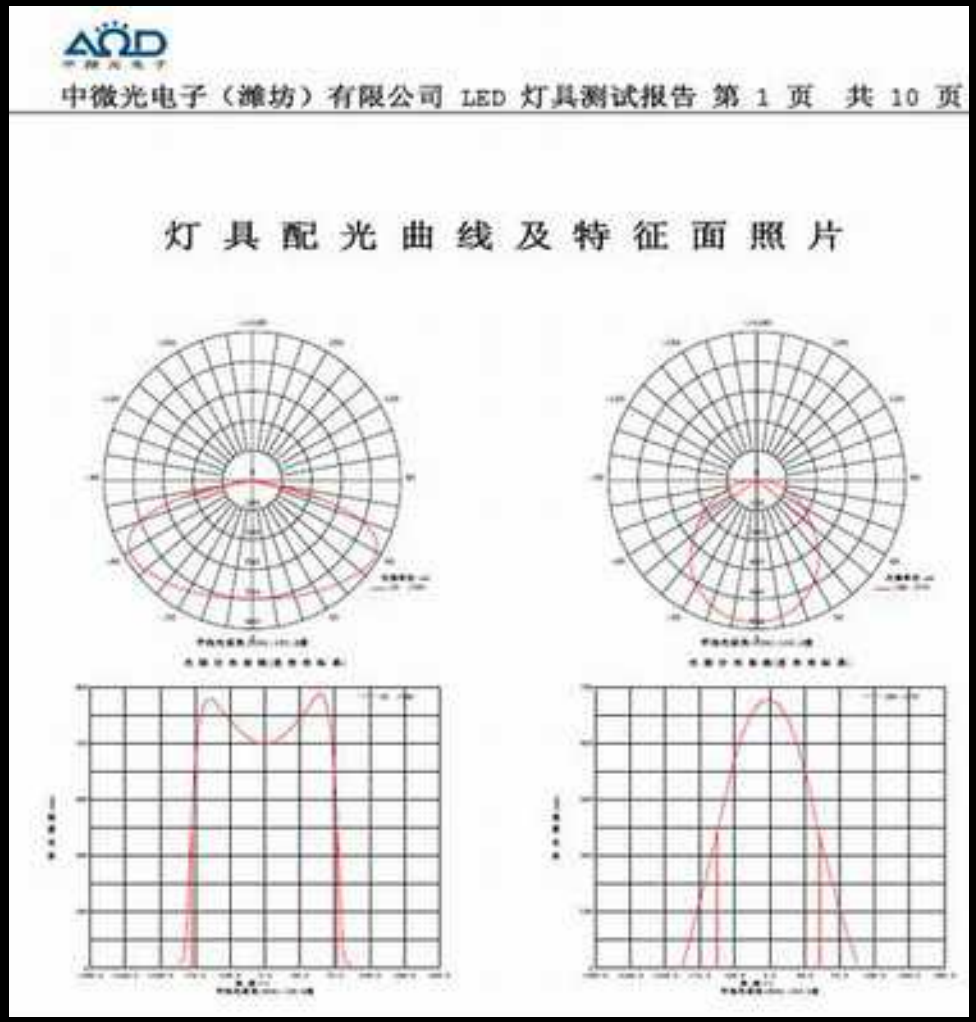
Conformité Européenne or China export?

versus

02 Market overview:

- Made in P.R.C. = Made in China
- Made in R.O.C. = Made in Taiwan
- Brand mark products are mostly also made in China
- Countless types of „new brands" or nonames
- Prejudice over chinese products should be avoided
- Dangerous raise of local importers who offer expertise and complex services without knowledge and skills
- Made in EU: new local manufacturers without professional background
- The fundamental problem: Quality versus Costs

02 Market overview:



中微光电子（潍坊）有限公司 LED 灯具测试报告 第 1 页 共 10 页

灯 具 配 光 曲 线 及 特 征 面 照 片

道 路 灯 具 光 度 数 据

实测参数：U:221.4V I:0.1895A P:39.08W PF:0.9316 实检光通:2683x1 lm			
灯具名称：AL-303		灯具类型：	灯具重量：
外型尺寸：		灯具规格：	测试编号:B100518074000
制造厂商：AGD		发光口面：	保护角：

光 源 数 据		光 度 数 据 光效：68.64 lm/W			
型 号	AL-303	峰值光强(cd)	883.0	n路边向上(%)	0.0
标称功率(W)	40	灯具效率(%)	100.0	n路边向下(%)	51.3
额定电源电压(V)	222	灯具总光通量(lm)	2683	n屋边向上(%)	0.0
额定光通量(lm)	2683.0	峰值光强位置(C,γ)	175°,54.5°	n屋边向下(%)	48.7
灯具内光源数(只)	1	上射光通比(%)	0.0	76°闪亮面积(m2)	0.0500
实测电源电压(V)	221.4	下射光通比(%)	100.0	不舒适眩光 SLI	21.046

- Translations to national language are of very low quality with inappropriate terminology

02 Market overview :

02 Market overview :

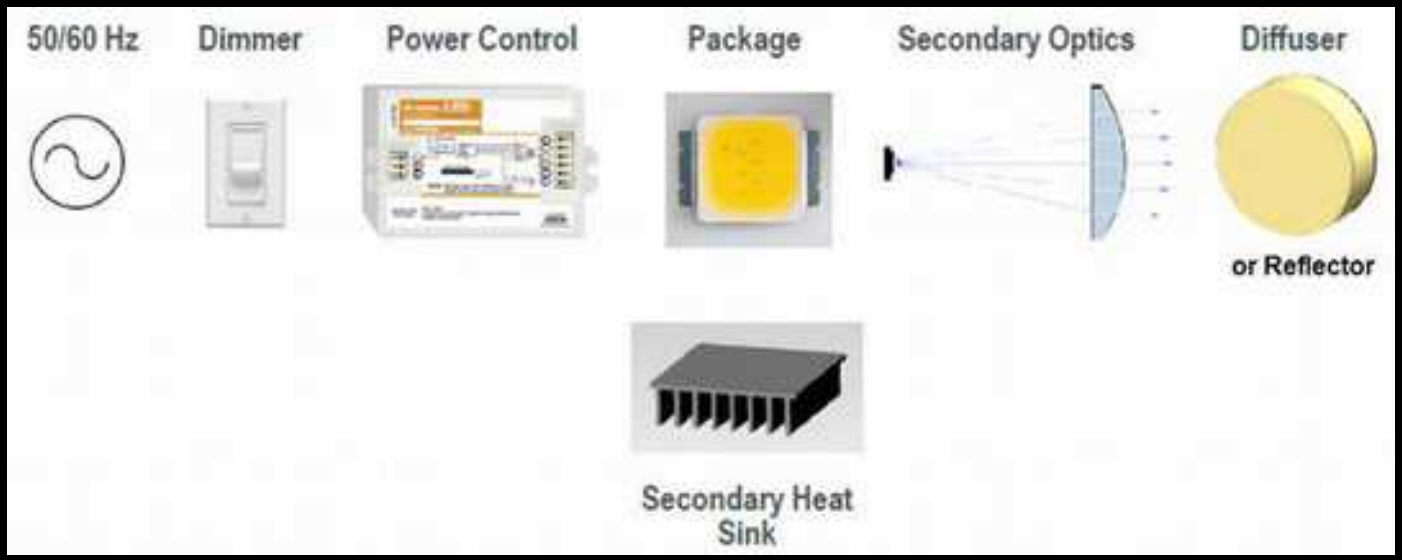
Luminous efficacy:

- Many LED luminaire suppliers proclaim unreal or even miraclous luminous efficacy of 150 to over 200 lm/W
- Investors do not even doubt about such numbers
- Comparison of technologies should account for luminous efficacy of luminaires, not lamps (for HID lamps: efficacy x L.O.R.)

03 LED luminaires for roadlighting:

Luminous efficacy:

- LED luminaire is a system of many components
- Every component not only adds function (and cost), but affects the performance of the other components, and can be a factor in determining lifetime



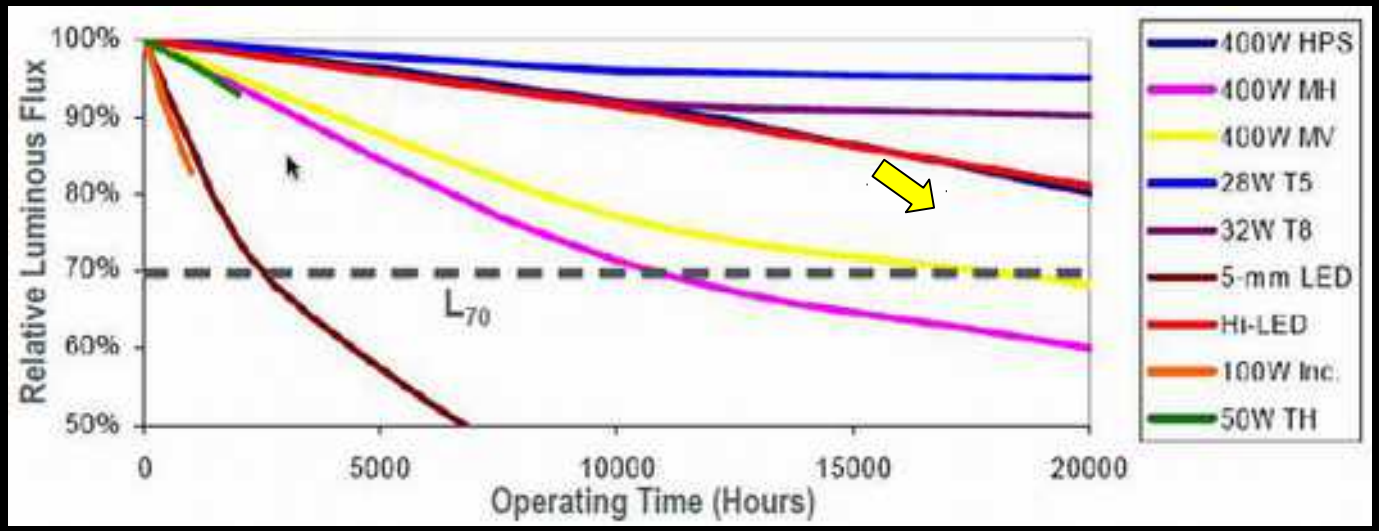
03 LED luminaires for roadlighting:

Lamp Luminous Flux Maintenance Factor (LLMF):

- Life expectacy is seldom related to LLMF curves
- High lifetime of LEDs is proclaimed: 50 000 to 100 000 hours (i.e. 12 to 25 years in roadlighting)
- The corresponding value of f_{LLM} is very low – significantly lower than those for HID lamps
- This fact is often omitted in lighting desing
- Comparison of technologies should account on lower LLMF (i.e. combination of luminous efficacy and LLMF)
- Constant luminous flux over time can be achieved by gradual increase of the bias current to the LEDs

Lamp Luminous Flux Maintenance Factor (LLMF):

- L70: Reduction to the level of 70 % (or by 30 %) initial luminous flux
- LLMF of 0,7 leads to very low overall MF
- Comparison of costs: 12 to 25 years time span of LEDs corresponds to 3 to 8 relampings of HPS (relamping costs = lamps + labour)



03 LED luminaires for roadlighting:

Lamp Survival Factor (LSF):

- For LED luminaires for roadlighting cannot be neglected
- Unlike in the case of HID lamps, LED luminaire consist of certain number of LEDs which are self-standing lamps
- LSF should account for the failure rate of the LEDs
- If this is neglected, luminous flux and thus the illuminance/luminance will not be maintained

Open optics vs cover glass:

- Lenses attached to LED chips must be protected by smooth surface cover
- If such cover is absent, dust and dirt deposits in narrow drains of lenses cannot be removed by cleaning and contribute to constant increase of luminous flux losses

Open optics vs cover glass:

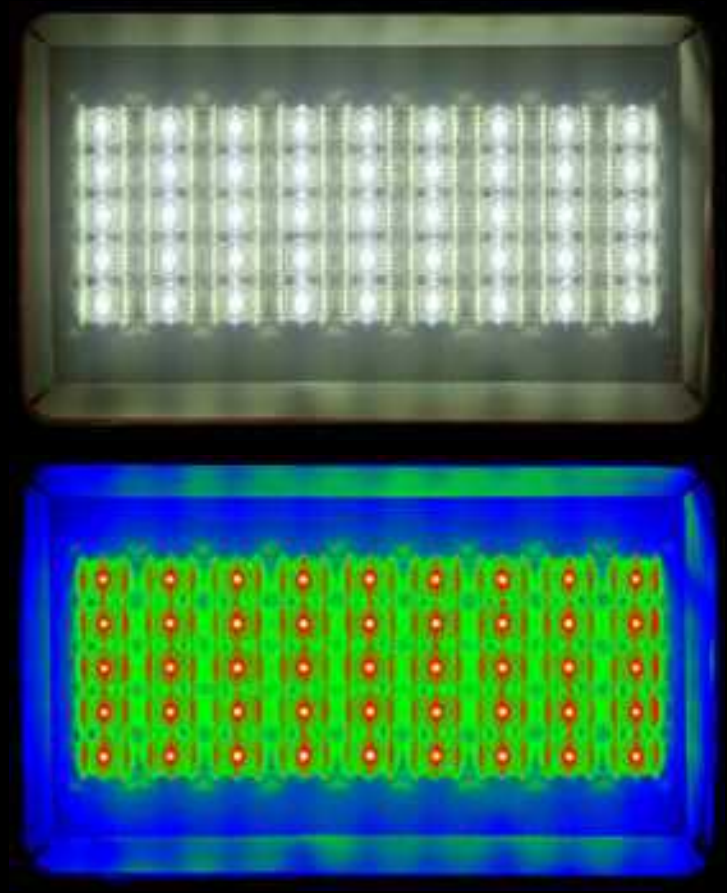
03 LED luminaires for roadlighting:

Number of LEDs in a luminaire:

- Luminaires are available with less or more LEDs of different wattage
- The more LEDS:
  - The better composition of LIDC
  - The more and smaller or less intensive point light sources causing glare
  - The better LSF due to failure
  - The more expensive

03 LED luminaires for roadlighting:

Number of LEDs in a luminaire:

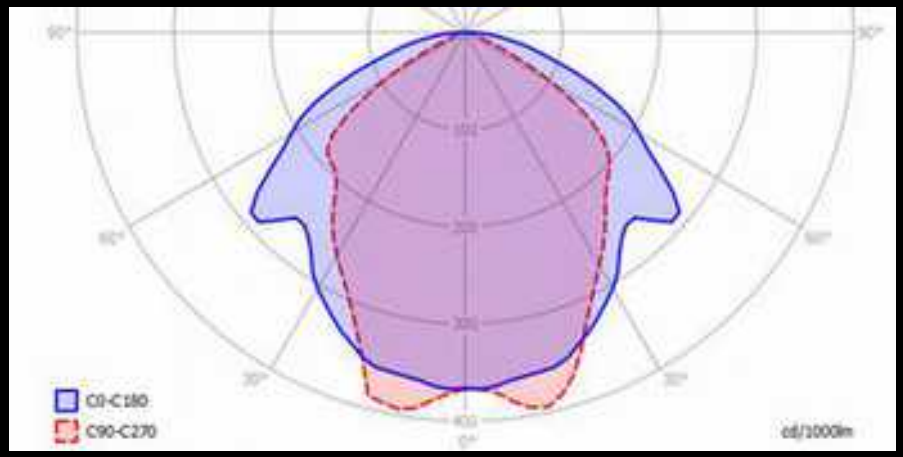


- Luminance of more LEDs is lower than luminance of less LEDs providing the same luminous flux
- Less glare in result

03 LED luminaires for roadlighting:

Symmetrical optics:

- Some LED luminaires for road lighting have symmetrical optics in the C90-270 plane
- These luminaires can be used for illumination of non-linear structures or areas like squares or parks, not for roads or footpaths
- Otherwise illumination is highly inefficient



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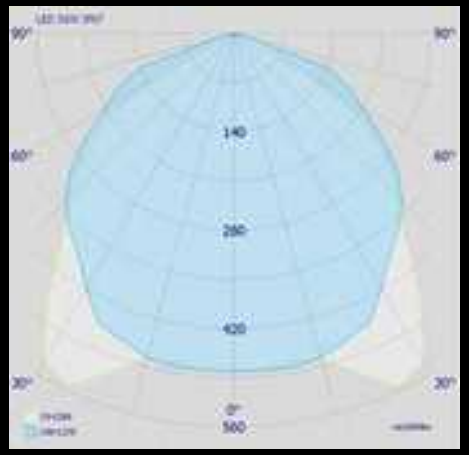
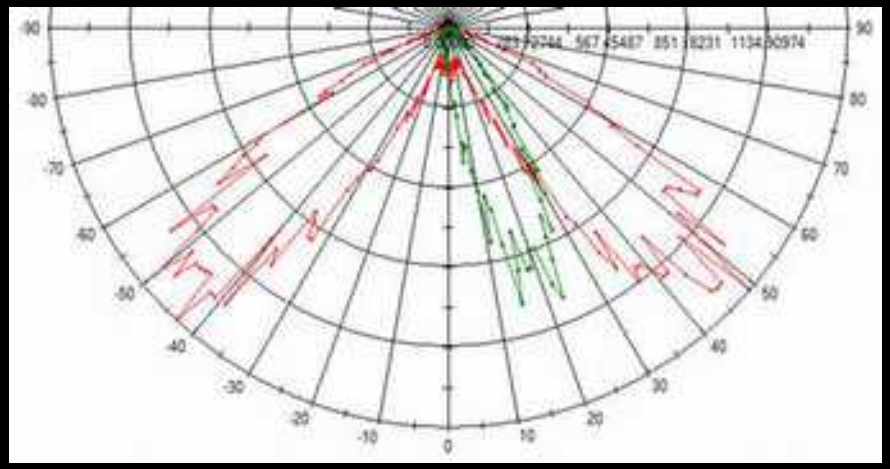


03 LED luminaires for roadlighting:

Shape of the LIDC:

- Published luminous intensity curves are smooth, similar to LIDC of HID lamps
- Measured luminous intensity values provided in an accepted data exchange format (I-tables) are interpolated, therefore smooth
- Due to small dimensions of light sources and sharply directed light, real LIDCs are of zigzag shape with sharp peaks in narrow angular ranges – it may result to uneven illumination of road surface (light spots)

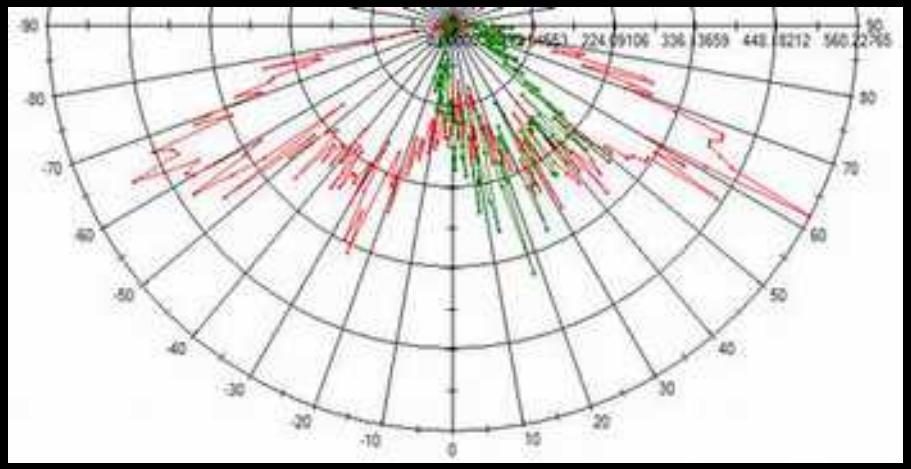
Shape of the LIDC:



9 304 lm (150 W)

I_{max} = 14 993 cd

Δα = ca. 2 – 5 °



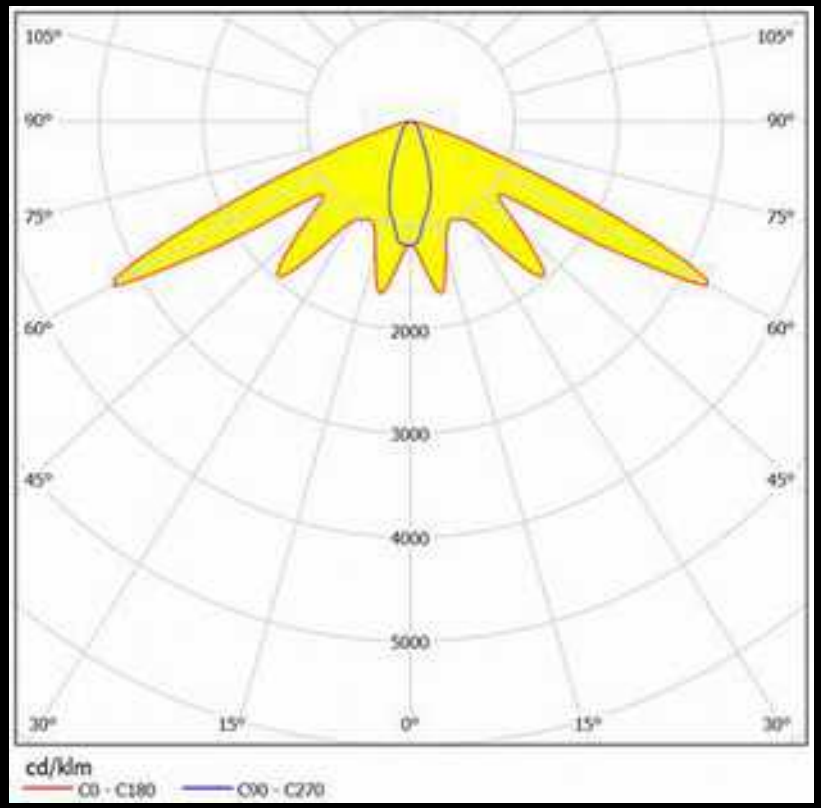
5 842 lm

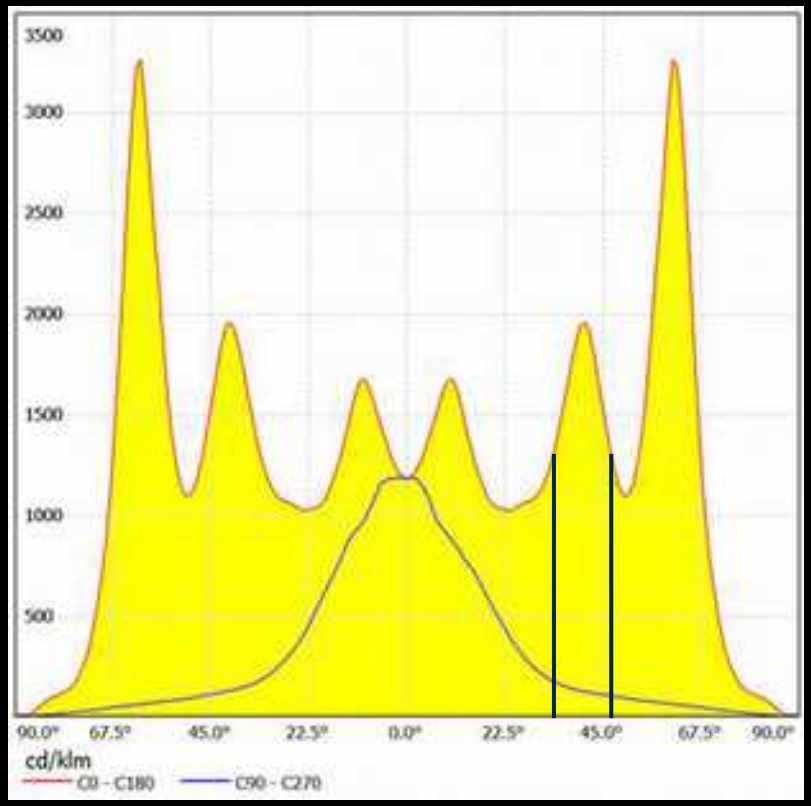
I_{max} = 3 623 cd

Δα = ca. 1 – 3 °

03 LED luminaires for roadlighting:

Shape of the LIDC:





Δα = ca. 10°

03 LED luminaires for roadlighting:

Design of optics:

- Technically advanced LED luminaires are designed by means of sophisticated software aids with simulation tools (e.g. Light Tools)
- Very small dimensions of LED chips (quasi point source) was a dream of luminaire designers and not possible with classical lamps
- Advantages of LEDs are not used up – designers are stranded in classical imaginations on LED luminaires
- LED retrofits: a step backwards

03 LED luminaires for roadlighting:

Design of optics:

Reflectors

Alanod

MIRO 5

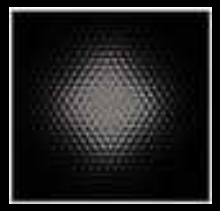
Alanod

MIRO 20

Alanod

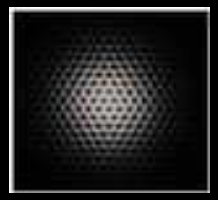
MIRO 85

Diffusers



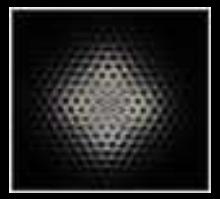
D 14 mm

P 9,8 mm



D 14 mm

P 5 mm



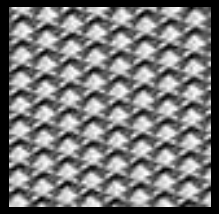
D 14 mm

P 8 mm

D 32 mm

P 17 mm

Refractors



Prism

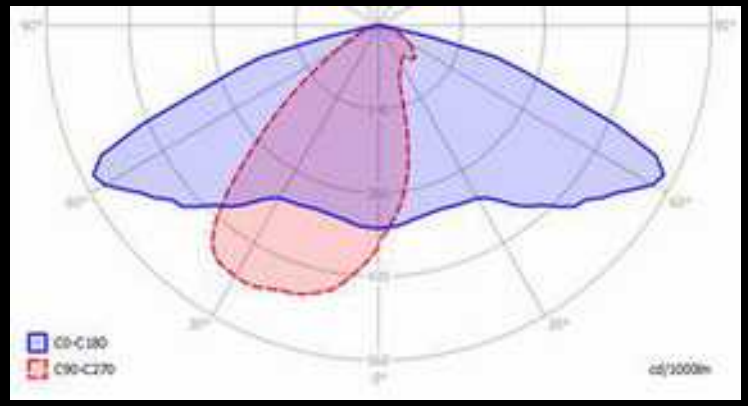
Microprism

Nanostructures

Index of refraction is changing with time!

03 LED luminaires for roadlighting:

Measurements:



Type: LED Street ME 90

48 x LED (Cree)

Optics: XM-L2 T6

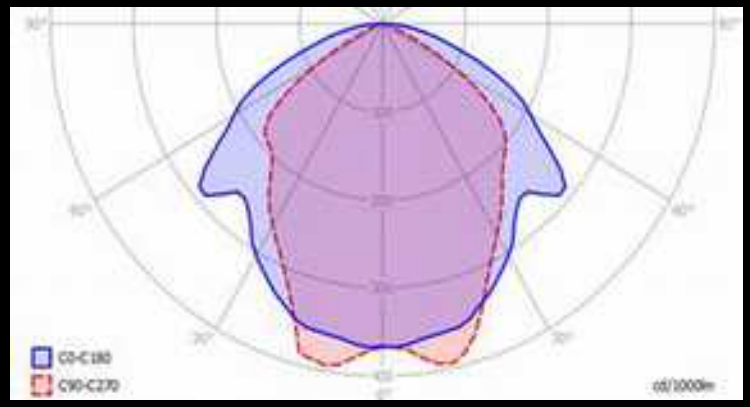
P_n = 106 W / P_{meas} = 105,5 W

Φ = 11 610 lm

PF = 0,97

η = 110,6 lm/W

T_c = 4 620 K / Ra = 72



Type: LED Street Light 100W

96 x LED (Epistar)

P_n = 100 W / P_{meas} = 103,1 W

Φ = 9 908 lm

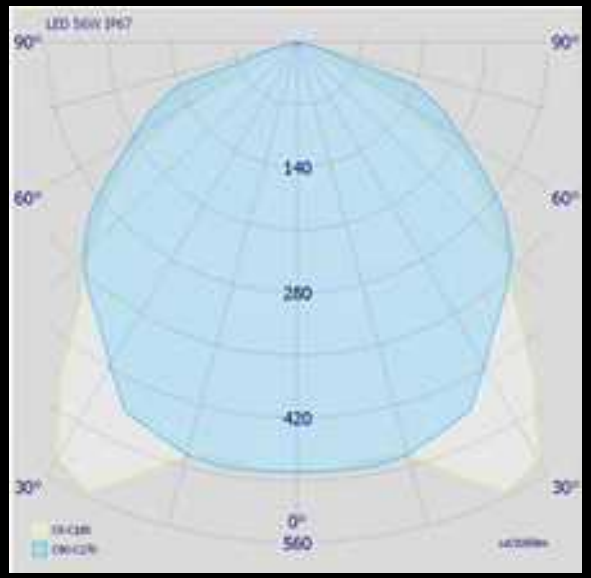
PF = 0,91

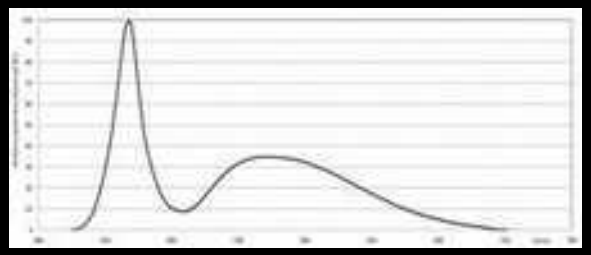
η = 96,1 lm/W

T_c = 6 700 K

03 LED luminaires for roadlighting:

Measurements:





Type: Noname

56 x LED

P_n = 56 W / P_{meas} = 51,3 W

Φ = 3 173 lm

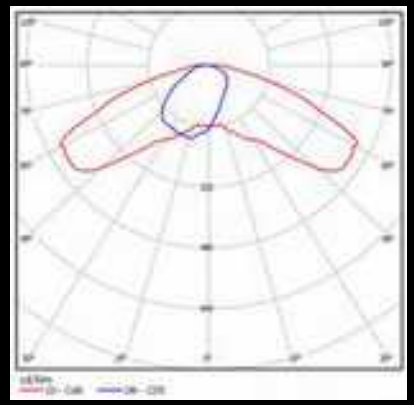
PF = 0,91

η = 61,9 lm/W

T_c = 7 850 K

03 LED luminaires for roadlighting:

Measurements:



Type: Nano 1

48 x LED (Cree)

Optics: XM-L2 T6

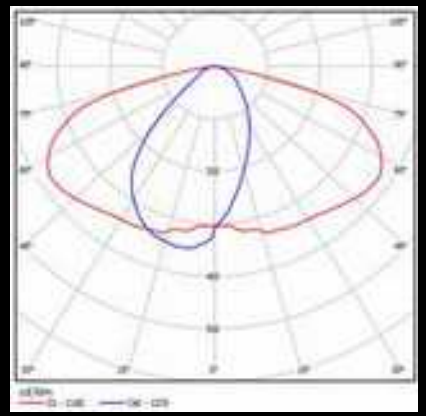
P_n = 106 W / P_{meas} = 105,5 W

Φ = 11 610 lm

PF = 0,97

η = 110,6 lm/W

T_c = 4 620 K / Ra = 72



Type: Teceo 1

96 x LED (Epistar)

P_n = 100 W / P_{meas} = 103,1 W

Φ = 9 908 lm

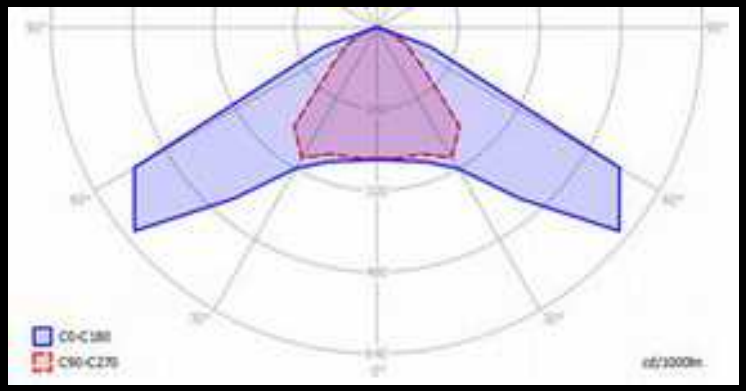
PF = 0,91

η = 96,1 lm/W

T_c = 6 700 K

03 LED luminaires for roadlighting:

Measurements:



Type: STF72U1-P2VD1

45 x LED

P_n = 72 W / P_{meas} = 69,2 W

Φ = 4 553 lm

PF = 0,95

η = 65,8 lm/W

T_c = 5 500 K / Ra = 65

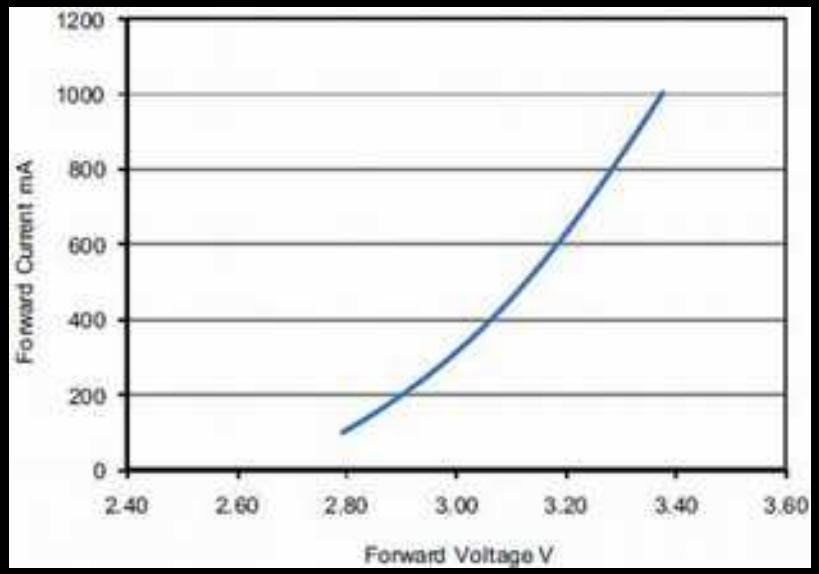
03 LED luminaires for roadlighting:

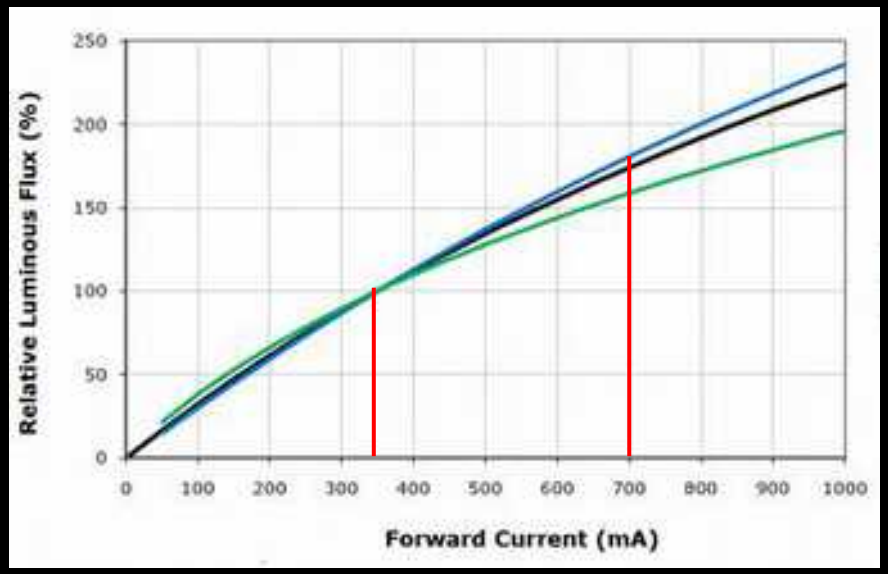
- Electrical components are as important as LEDs themself: both in relation to LEDs they supply and backwards to the power network
- Published lifetime of LED luminaires often equals to the lifetime of LEDs and do not take into account lifetime of the driver
- Bigger number of LED drivers connected to the same network may influence to power quality and thus to the operation of individual LED luminaires
- These phenomena are the subject of current research
- LEDs are easy to dim but public lighting networks provide very limited means for the control

04 LED luminaires for roadlighting:

Current supply:

- LED current is a non-linear function of Forward Voltage
- Luminous flux increases with LED Forward Current

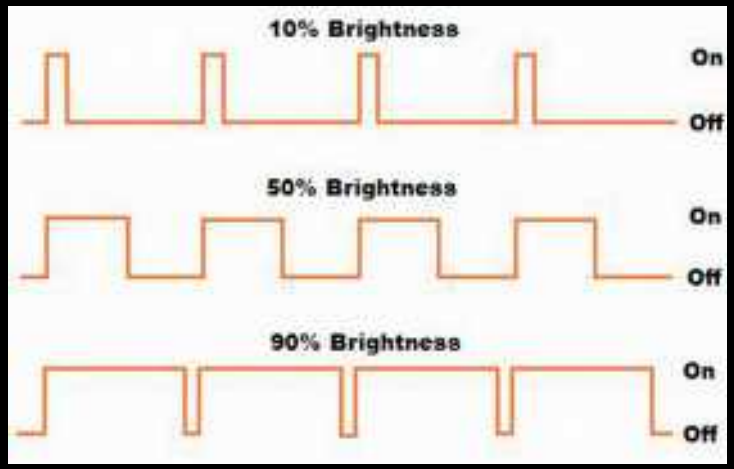




04 LED luminaires for roadlighting:

Dimming:

- LED Response Time is very fast (~ 100 ns)
- Allows for PWM dimming (this can result in undesirable flicker)
- Improves potential for control (e.g. occupancy sensing)

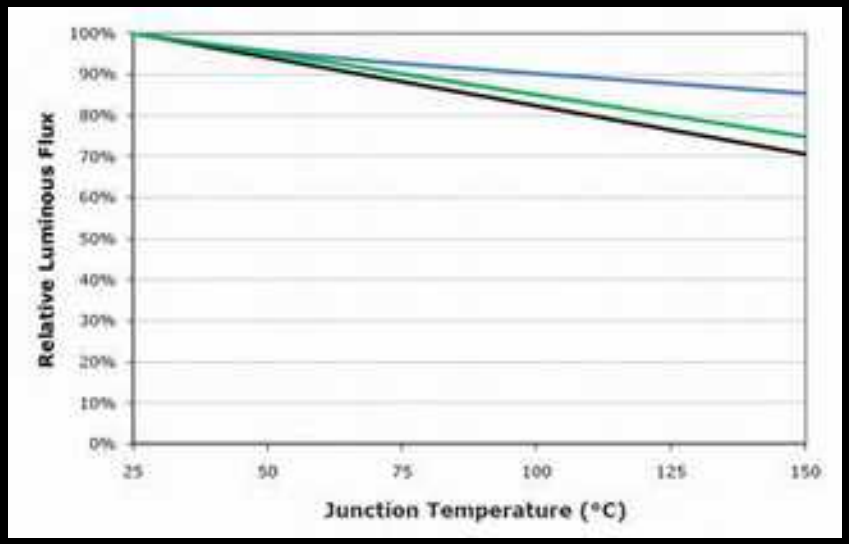


04 LED luminaires for roadlighting:

System efficacy:

System efficacy (lm/W) = LED efficacy (lm/W) x Electrical Efficiency (%) x Optical Efficiency (%)

- LED Efficacy: Drops at higher currents and higher junction temperatures

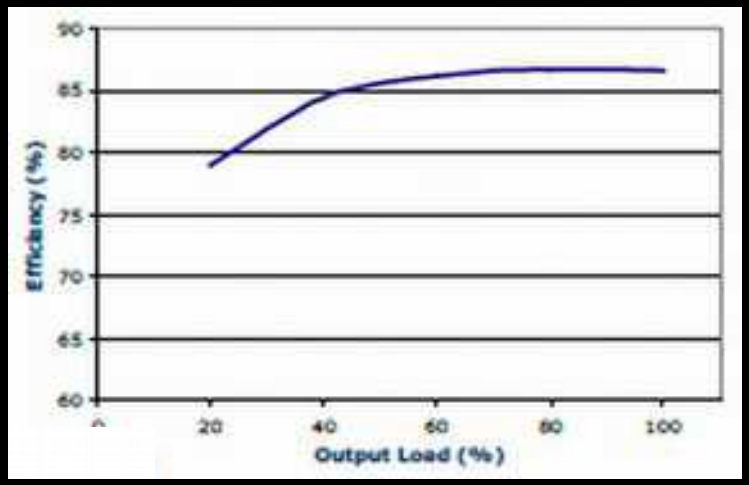


04 LED luminaires for roadlighting:

System efficacy:

System efficacy (lm/W) = LED efficacy (lm/W) x Electrical Efficiency (%) x Optical Efficiency (%)

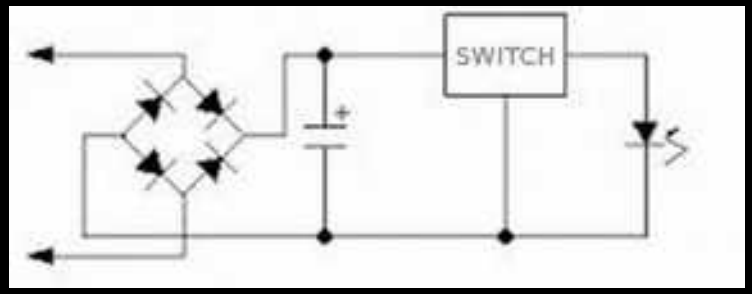
- Electrical efficiency: Depends on load



04 LED luminaires for roadlighting:

LED drivers:

Standard LED driver



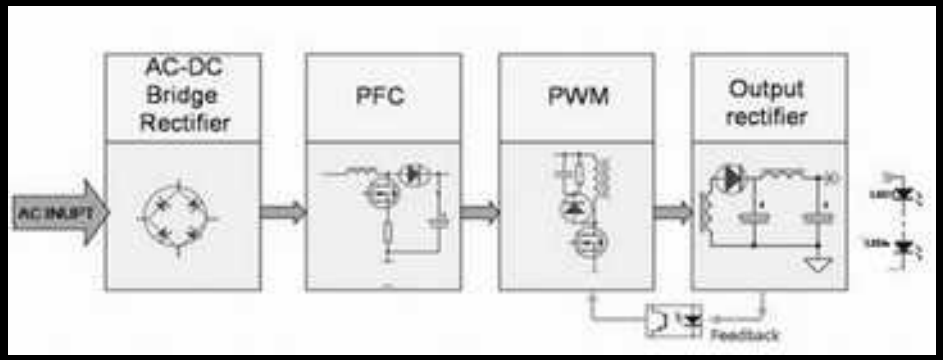
Bad PFC (EN 61000-3-2)

Low efficiency

No thermal feedback

High inrush current

Advanced LED driver



Good PFC

High efficiency

Thermal feedback

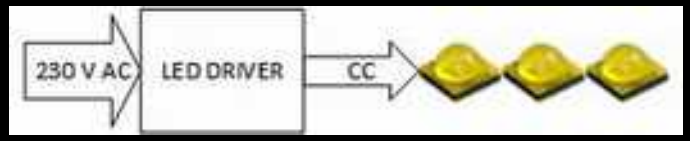
Low inrush current

Dimming capability

04 LED luminaires for roadlighting:

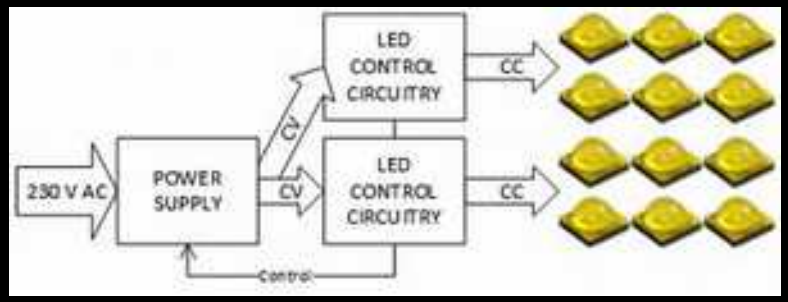
LED drivers:

Basic LED driver



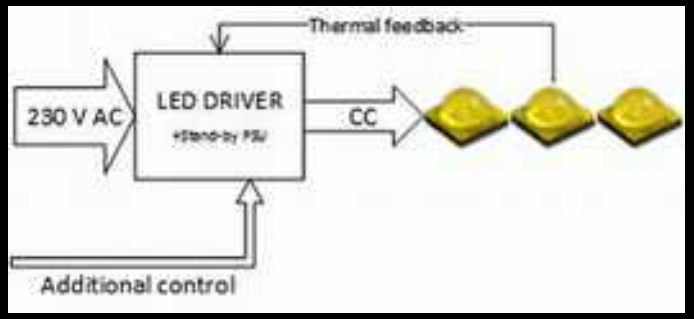
for basic luminaires with no other interfaces or added value

Distributed LED driver



ideal for large LED arrays - roadlighting

Intelligent LED driver



with thermal feedback

various control interface

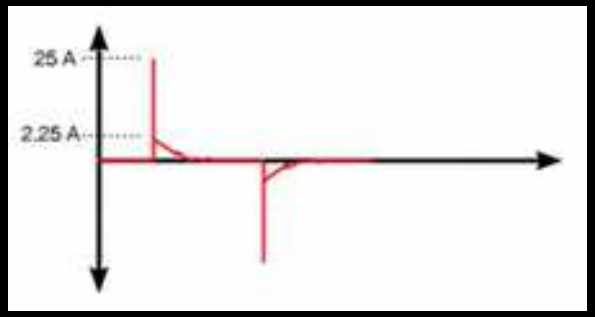
very low stand-by power consumption (<o,3W)

Thermal Feedback: current is regulated depending on actual LED temperature, it blocks excessive overheating and ensures the defined lifetime

04 LED luminaires for roadlighting:

Most important parameters of LED drivers:

- Repetitive peak current: due to low quality dimmers - shorter lifetime of the LEDs
- Inrush Current: steep increase of input current from mains right after switching on - shorter lifetime of the driver
- Ripple current: periodic peak-to-peak variation of output current's mean value - negative impact on efficiency



Repetitive peak current

Inrush Current

Ripple current

04 LED luminaires for roadlighting:

Measurements:

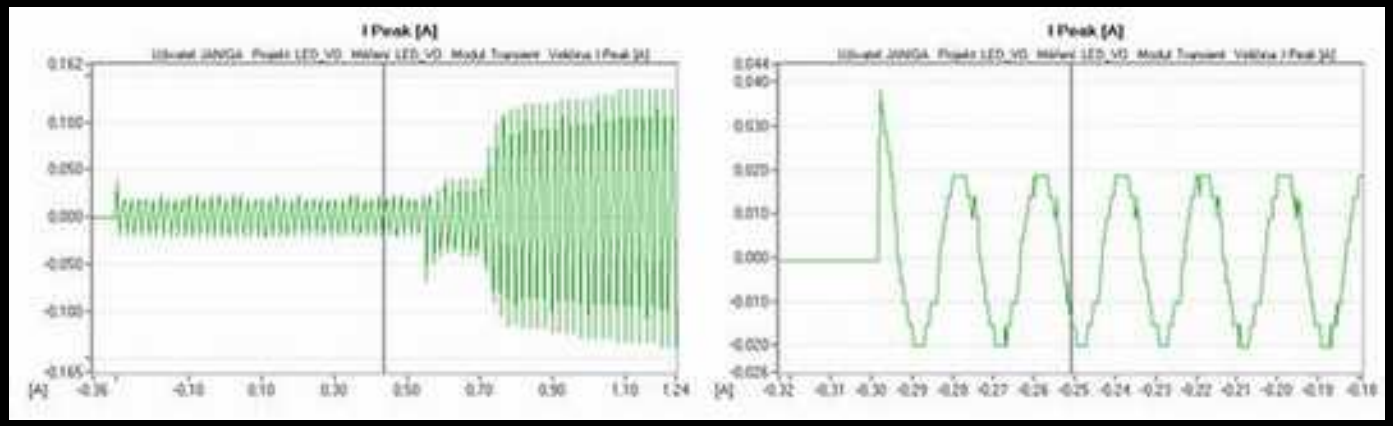
Operation regimes:

- Start-up at nominal voltage
- Start-up at +/- 10 % of nominal voltage
- Voltage variations during operation
- Mains supply by distorted voltage

Measured parameters:

- U, I
- P, Q, S, PF (Power Factor)
- Total harmonic distortion

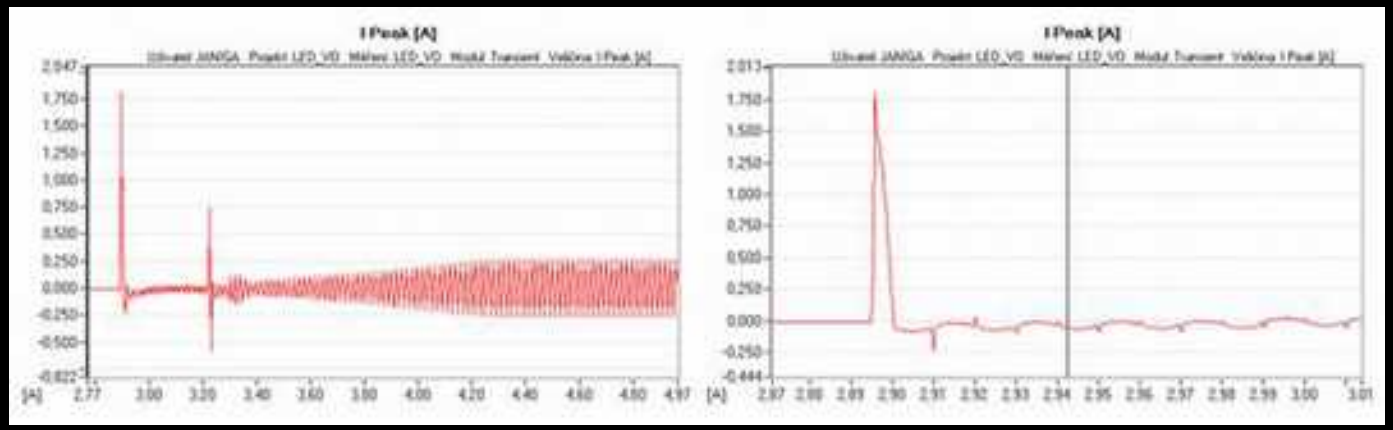
Measurements (examples):



Inrush current

Nominal voltage

Nano 1



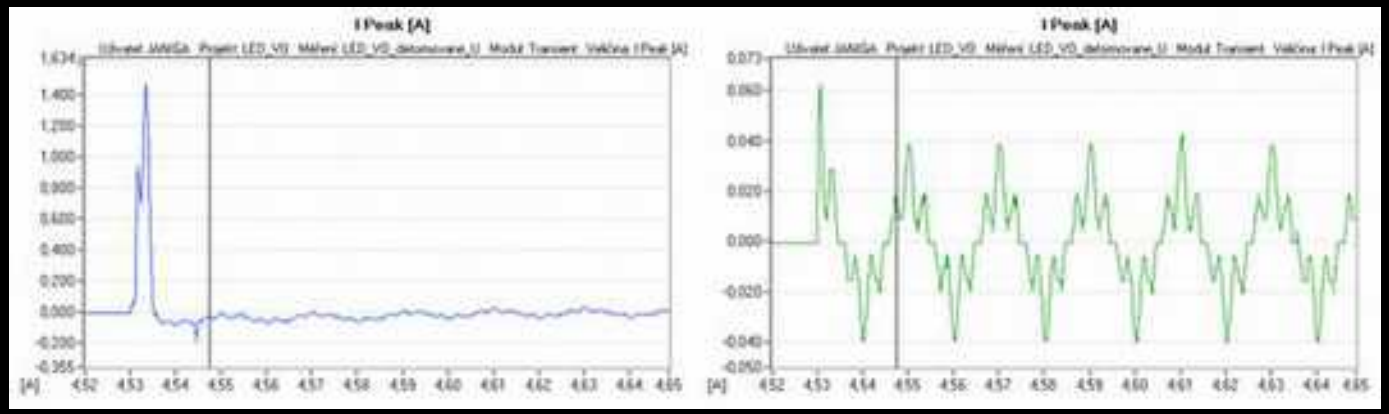
Inrush current

Nominal voltage

TCO 1

04 LED luminaires for roadlighting:

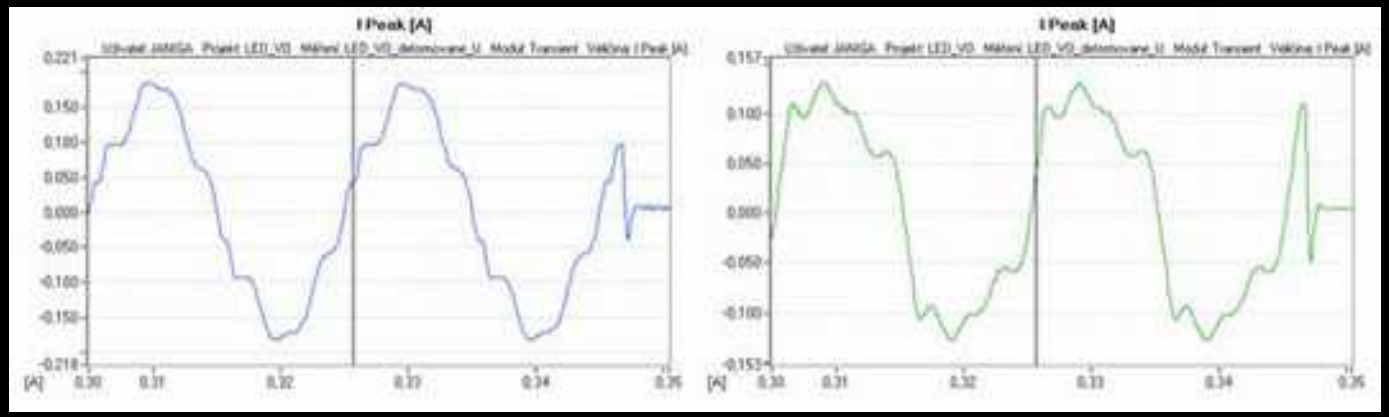
Measurements (examples):



Inrush current

Distorted supply

JRA2-30 / Nano 1



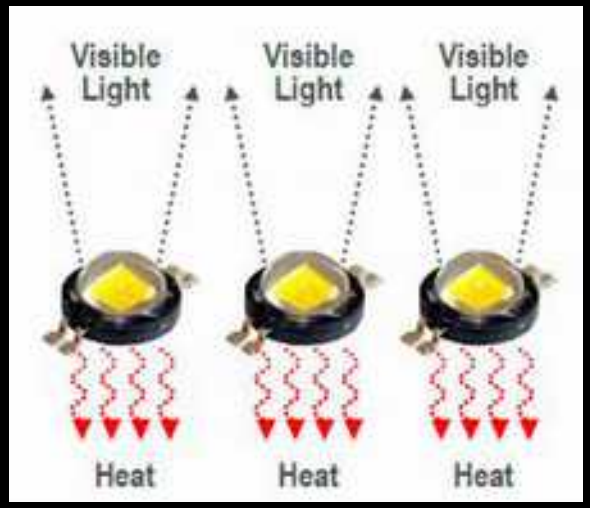
current

Distorted supply

JRA2-30 / Nano 1

04 LED luminaires for roadlighting:

- Generated heat is mainly transferred by conduction

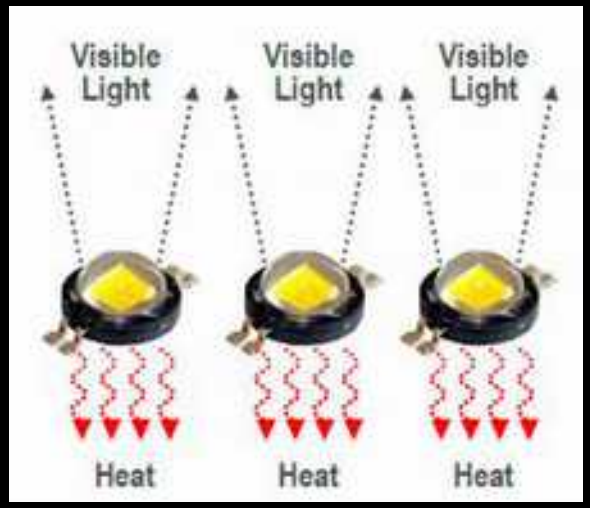


- Heat is the biggest problem to LEDs
- Optimum operating junction temperature 80 °C to 110 ° C
- Failure mechanism is being studied well

- In roadlighting the ambient temperature is less than 25 °C
- Luminaire's thermal management is crucial
- Efficiency of cooling may decrease if heat sink is covered by dust

04 LED luminaires for roadlighting:

- Generated heat is mainly transferred by conduction



- Heat is the biggest problem to LEDs
- Optimum operating junction temperature 80 °C to 110 ° C
- Failure mechanism is being studied well

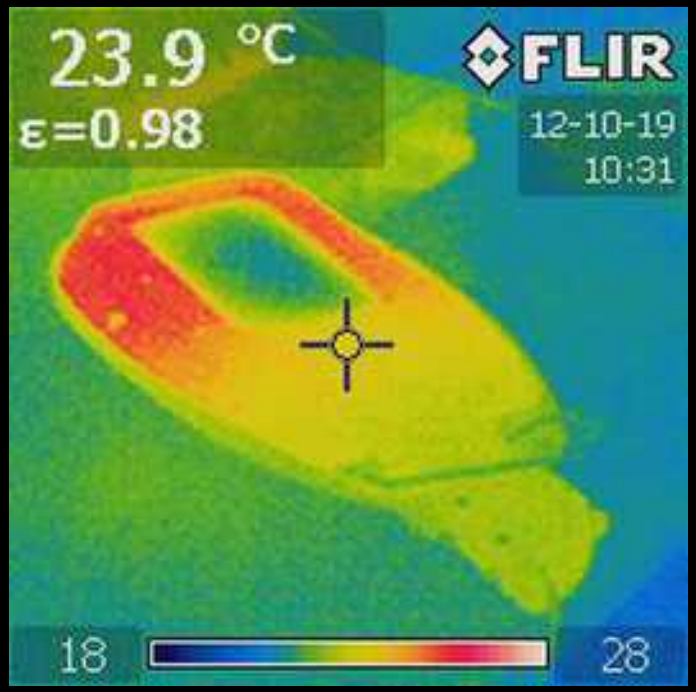
- Active cooling: more energy consumption, risk of failure of mechanical parts
- Luminaire body and/or top cover used for cooling: bigger area of the heat sink
- Smooth outside surfaces for easy and self-cleaning

04 LED luminaires for roadlighting:

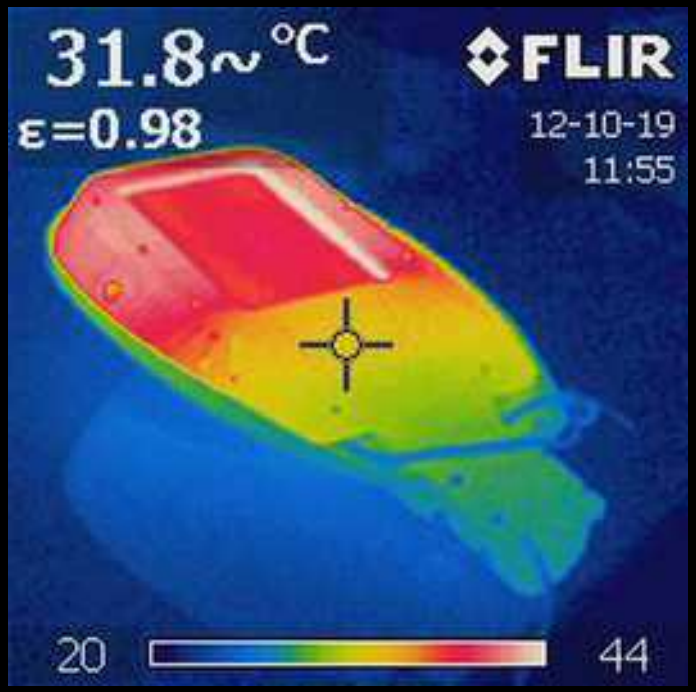
- Heat sink on the top of luminaire: dust in narrow drains is hard to remove, efficiency decreases
- Any other openings have the similar effect

04 LED luminaires for roadlighting:

Measurements:



OFF

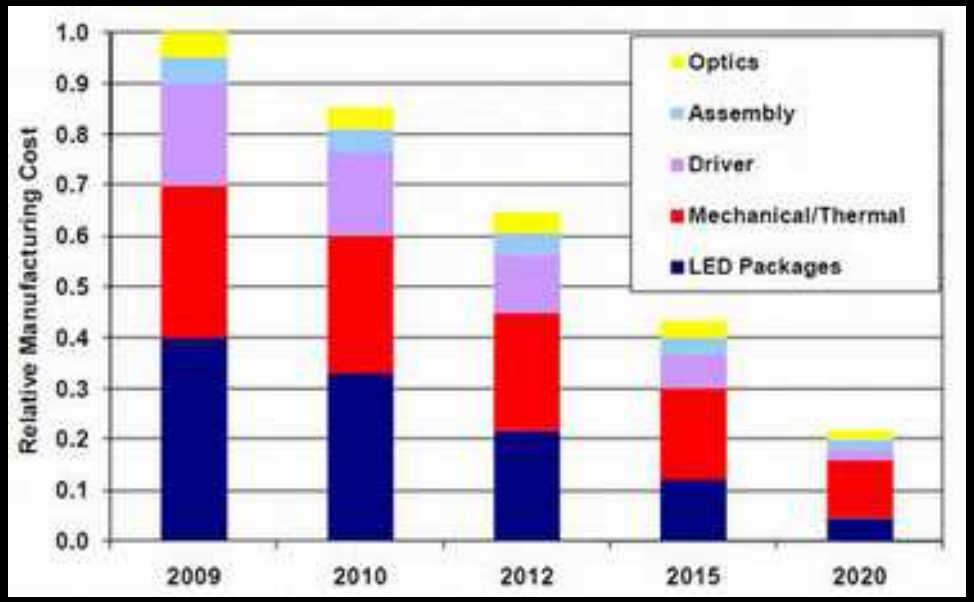


ON (steady state)

04 LED luminaires for roadlighting:

- Lifetime is a statistical metric
- Determination of lifetime: prediction (models) / measurement (accelerated tests)
- Calculation of lifetime: LM-80, TM-21
- Lifetime depends on: driving current, junction temperature
- Input electrolytic capacitor is the critical component

04 LED luminaires for roadlighting:



04 LED luminaires for roadlighting:

... and many other villages

05 LED installations:

Tomášov

noname LEDs

Nová Dedinka

05 LED installations:

Senec

Pribinova

Chalupkova

SNP

- Senec is the first town fully illuminated by LED luminaires
- Up to now, LED was installed on selected streets to demonstrate and experience the technology
- Feedback from inhabitants was highly positive

05 LED installations:

Senec

Lichnerova

- 1 987 light points installed
- Luma 1 and MiniLuma luminaire types
- Dynadimmer lighting control

05 LED installations:

05 LED installations:

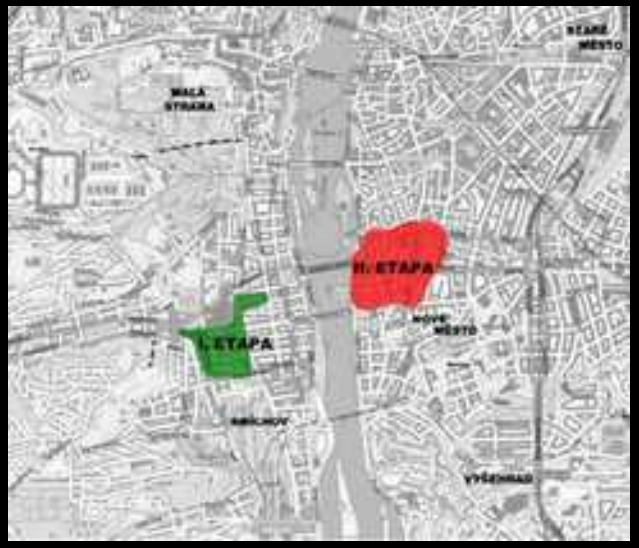
Siófok

05 LED installations:

1st phase:

- Place: Andel (Praha 5)
- Year: 2010
- 6 brands
- 8 luminaire types
- 5 streets + 3 pedestrian
- 106 light points

05 LED installations:



1st phase:

- Nádražní: Siteco
- Nám. 14 října: Philips
- Radlická: iGuzzini
- Portheimka: Indal
- Stroupežnického: LG
- Bozděchova, Klicperova: MSC

05 LED installations:

2nd phase:

Dittrichova (ME4b)

Venus (Gaash)

8 light points

Gorazdova (ME4b)

R250 (GE)

14 light points

Jenštejnská (ME4b)

SHLED-90W (Showa)

3 light points

Karlovo nám. (ME2)

Luma 3 (Indal)

5 light points

05 LED installations:

2nd phase:

Karlovo nám. (S2)

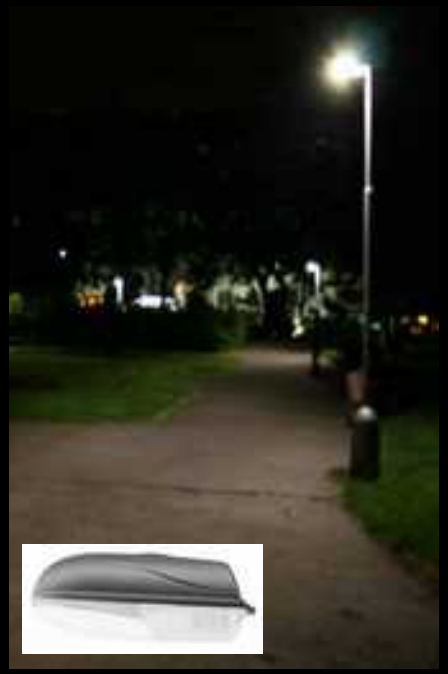
Stela Long (Indal)

7 light points

Karlovo nám. (S2)

Stela Long (Indal)

7 light points



Karlovo nám. (S2)

NanoLED (Schréder)

22 light points

Karlovo nám. (ME4b)

Apollo (Phoenix)

7 light points

05 LED installations:

2nd phase:

Na Moráni (ME4b)

Livorno XL (Hess)

12 light points

Na Zbořenici (CE4)

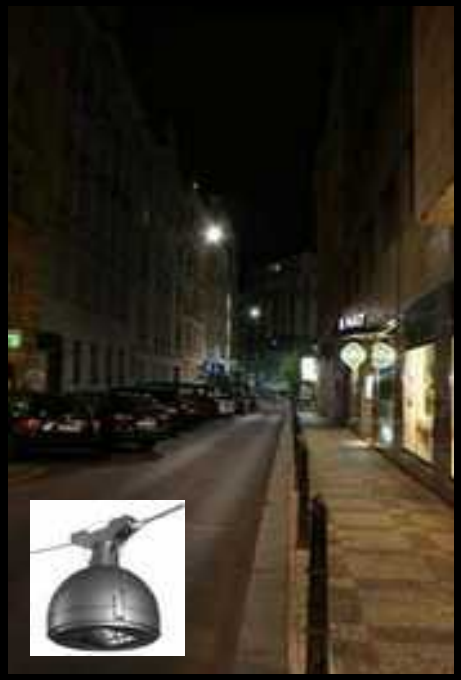
SHLED-90W (Showa)

6 light points

Náplavní (ME4b)

Solera (MSC)

6 light points



Odboru (CE4)

Argo (Etna)

6 light points

05 LED installations:

2nd phase:

Resslova (ME3c)

Solera (MSC)

20 light points

Resslova (ME3c)

Dolphin (MSC)

20 light points

Trojanova (ME4b)

Indra (Thorn)

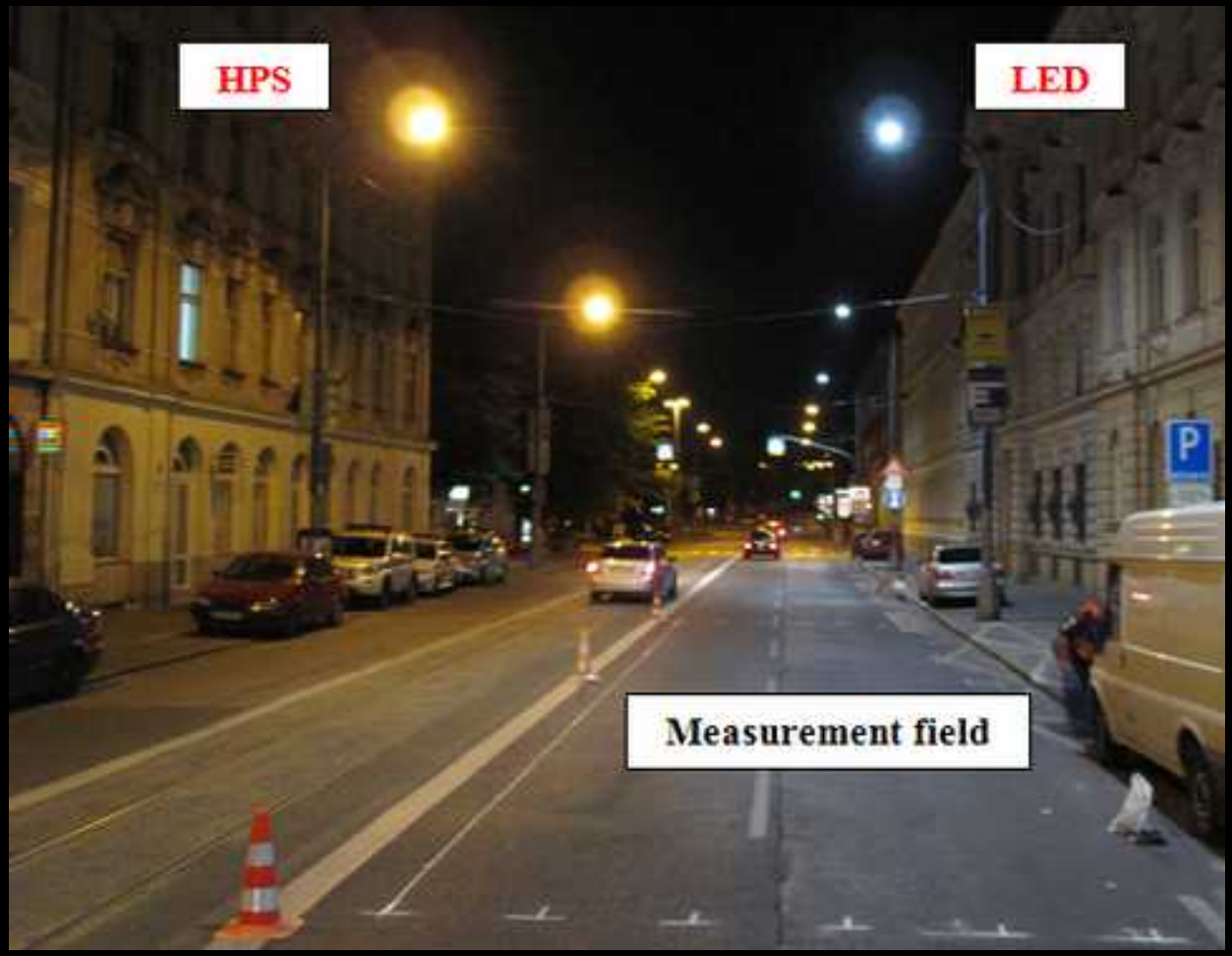
8 light points

Václavská (ME4b)

Vela (Fara)

13 light points

05 LED installations:

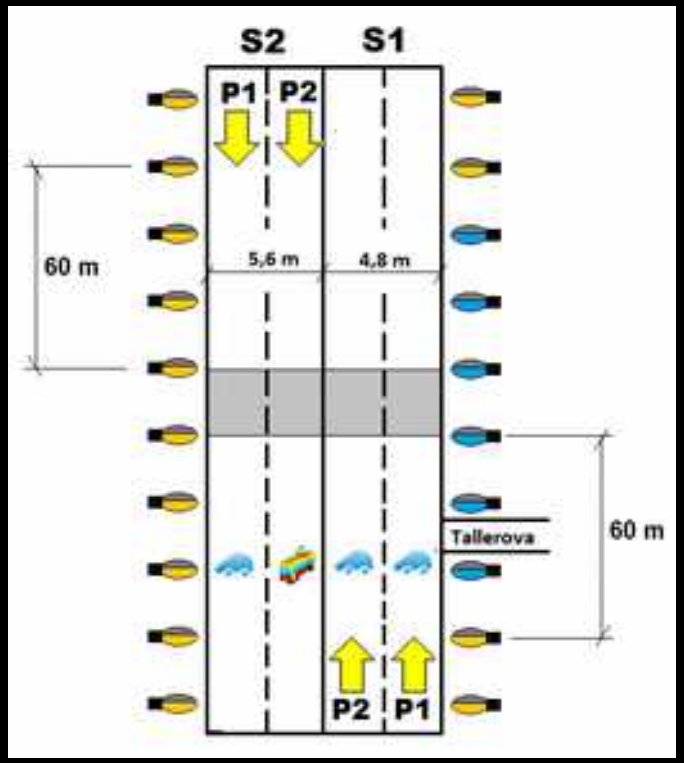


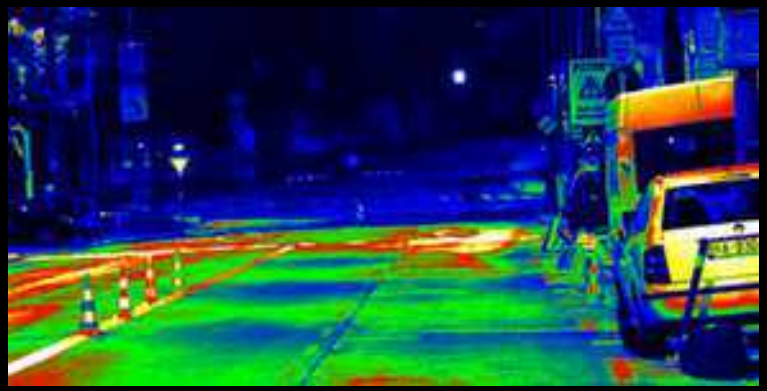
Bratislava

Štúrova ul.

Mounting height **H**:	12 m
Bracket **t**:	1,7 m
Tilt angle **δ**:	5°
Distance from road **a**:	1,3 m
Spacing **S**:	21 m

05 LED installations:





L_{av} = 2,65 cd.m^{-2}

Uo = 0,67

Ul = 0,65

Bratislava

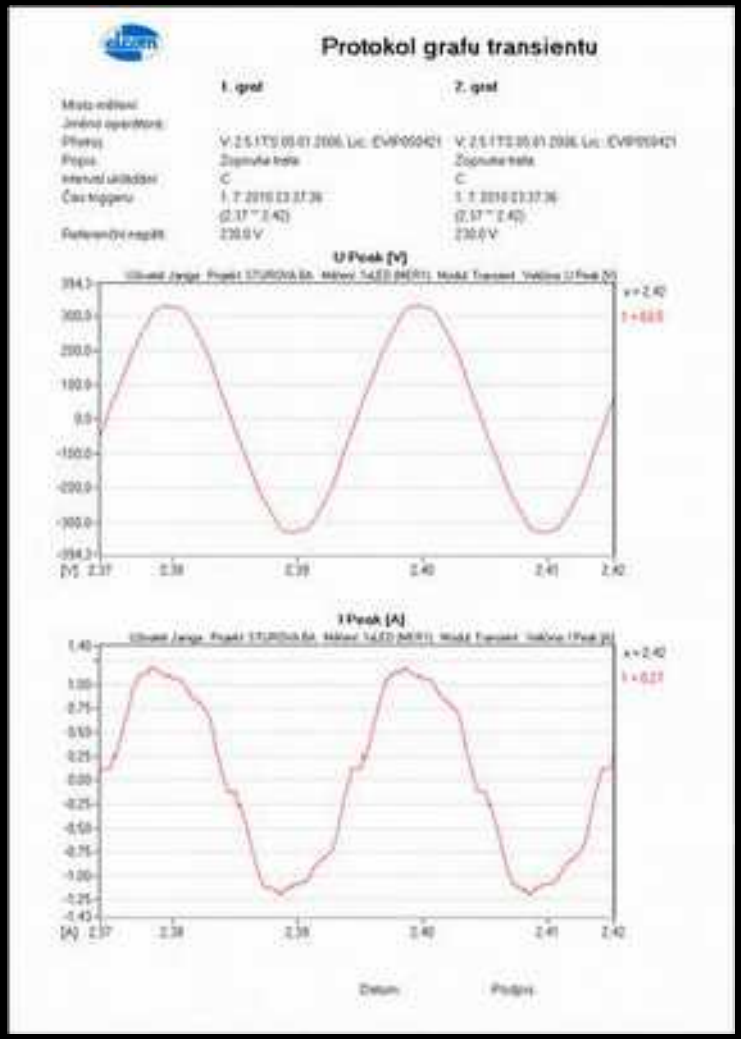
Štúrova ul.

05 LED installations:

Bratislava

Štúrova ul.

05 LED installations:



Single luminaire

U = 233 V

I = 0,84 A

P = 194 W

Q = 34 VAr

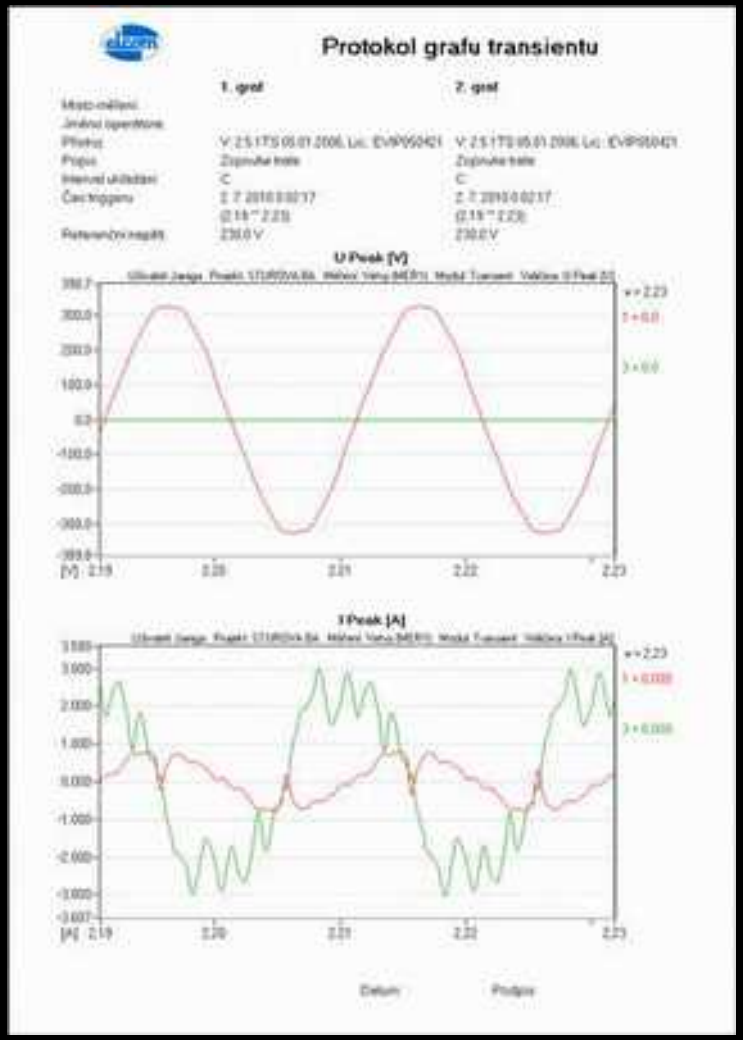
THD_I = 9,7 %

THD_U = 1,9 %

Bratislava

Štúrova ul.

05 LED installations:



Network

U = 234 V

I_1 = 0,48 A

I_2 = 1,865 A

THD_U = 1,9 %

THD_{I1} = 45 %

THD_{I2} = 29 %

Too high THD values!

Bratislava

Štúrova ul.

05 LED installations:

The multishadow effect

New phenomenon in roadlighting

Unsharp shadows casted by LED luminaires

Visual discomfort

Affects like inability of eye to focus

05 LED installations:

Persons

05 LED installations:

Trees

05 LED installations:

Mesopic vision:

- LED solution with white light is offered as good performing in mesopic conditions
- The effect is more perceptible at lower adaptation luminances, i.e. lower lighting classes
- In contradiction, LED suppliers prefer the illustration on major roads

Illumination of minor streets:

- For the mesopic reasons residential areas (low class) can be efficiently illuminated by LEDs
- But minor streets of low usage, apart from roads i.e. in villages – are the LEDs here a cost effective solution?

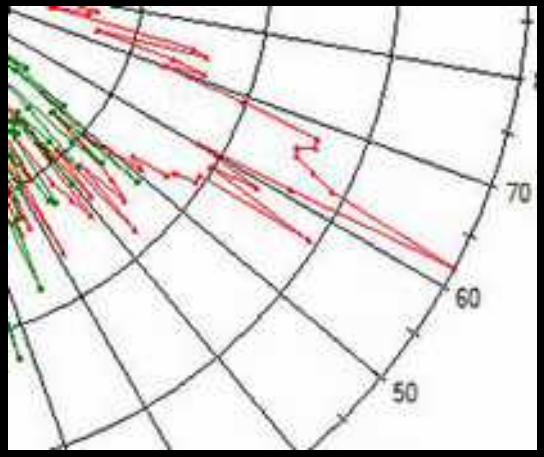
05 LED installations:

LED luminaire for a particular lighting class:

- Nowadays luminaire manufacturers are requested to design luminaires suitable for a particular lighting class
- Is this possible?
- Manufacturers try to do, based on „standard" situations
- But principially – road profile and for refurbishment also lighting system geometry are significantly affecting the resulting luminous parameters thus their satisfaction purely by the luminaire is impossible

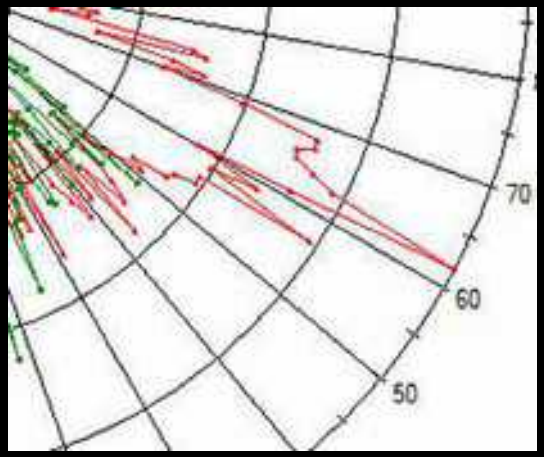
Interpolation method:

- Linear interpolation is only allowed in new CIE and EN documents
- Sharp peaks in LIDC: linear interpolation is inaccurate
- Spline interpolation?



Calculation grid density:

- Grid points are exactly specified in the CIE / CEN documents
- For common installations: 3 x 10 – 3 x 12 (spacing about 3 m!)
- Sharp peaks in LIDC: maximum luminous intensity may hit surface between grid points – inaccurate calculation or measurement



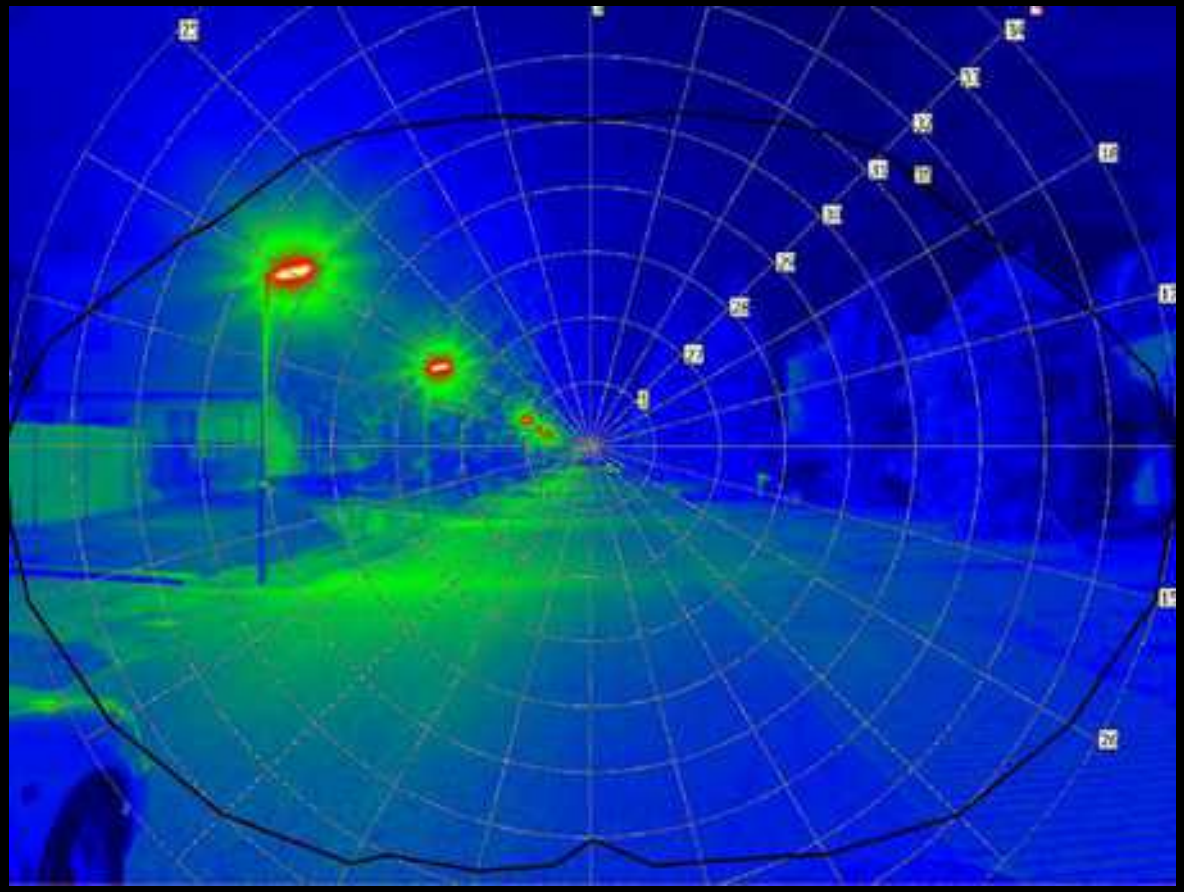
- Software aided calculation can be easily and quickly performed in much more calculation points
- increase of the grid density

Mesopic vision:

- LEDs provide white light which is better for mesopic conditions
- Mesopic photometry is published in 2010 (CIE 191)
- Application for roadlighting is still the subject of research (CIE JTC-1)

		Photopic luminance cd·m^{-2}									
	S/P	0,01	0,03	0,1	0,3	0,5	1	1,5	2	3	5
LPS –	0,25	-75 %	-52 %	-29 %	-18 %	-14 %	-9 %	-6 %	-5 %	-2 %	0 %
	0,45	-55 %	-34 %	-21 %	-13 %	-10 %	-6 %	-4 %	-3 %	-2 %	0 %
HPS –	0,65	-31 %	-20 %	-13 %	-8 %	-6 %	-4 %	-3 %	-2 %	-1 %	0 %
	0,85	-12 %	-8 %	-5 %	-3 %	-3 %	-2 %	-1 %	-1 %	0 %	0 %
	1,05	4 %	3 %	2 %	1 %	1 %	1 %	0 %	0 %	0 %	0 %
	1,25	18 %	13 %	8 %	5 %	4 %	3 %	2 %	1 %	1 %	0 %
MH warm white –	1,45	32 %	22 %	15 %	9 %	7 %	5 %	3 %	3 %	1 %	0 %
	1,65	45 %	32 %	21 %	13 %	10 %	7 %	5 %	4 %	2 %	0 %
	1,85	57 %	40 %	27 %	17 %	13 %	9 %	6 %	5 %	3 %	0 %
	2,05	69 %	49 %	32 %	21 %	16 %	11 %	8 %	6 %	3 %	0 %
LED cool white –	2,25	80 %	57 %	38 %	24 %	19 %	12 %	9 %	7 %	4 %	0 %
MH daylight –	2,45	91 %	65 %	43 %	28 %	22 %	14 %	10 %	8 %	4 %	0 %
	2,65	101 %	73 %	49 %	31 %	24 %	16 %	12 %	9 %	5 %	0 %

Mesopic vision:



- The shape and size of visual field depends on adaptation luminance

- New materials for optical parts: nanostructures
- Design of LED luminaires for road lighting can be free of classical approaches: LED strips, low mounting heights, on-surface LEDs?
- Thermal management should be studied in real environments
- Role of the lighting society is to advice municipalities on LED lighting solutions
- Strategic position of the lighting society: to mark out the roadmap for modernization of the public lighting on a national level

07 Conclusions

Further information, data and support courtesy of:

Marek MÁCHA (OMS): LED luminaire design

Eduard KAČÍK (Lightech): LED installations experience

Peter JANIGA (STU): Electrical measurements

Roman DUBNIČKA (STU): Photometric measurements

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Projekt je spolufinancovaný zo zdrojov EÚ

Európska únia

Thank You for attention!