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## New LED Lighting in Display Cases at Rosenborg Castle

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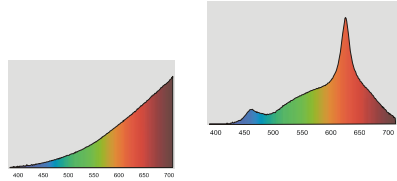
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**DTU Fotonik**  
Department of Photonics Engineering

Technical University of Denmark **DTU**



### Energy efficient and high quality LED illumination system for display cases



**Carsten Dam-Hansen, DTU Fotonik**

12. November 2010, NordLED Copenhagen

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**DTU Fotonik**  
Department of Photonics Engineering

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### DTU Fotonik, Department of Photonics Engineering


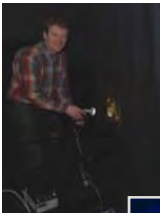
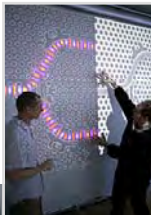
**Educational and research institute at the Technical University of Denmark**  
**Telecommunication and optical technologies**  
**190 employees incl. 60 Ph.D.-students**  
**80 M.Sc. candidates and 15 Ph.D students per year**

**LED group:**  
**Research projects on LEDs, materials and characterisation**

**Master course on LED and PV technology**  
**Annual Industrial LED conference/workshop**

**Application specific R&D projects in collaboration with Danish industry and Danish Energy Association**

**Test & characterisation of LED systems/products**



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## R&D project

Research and development project on energy efficient and high quality lighting. Collaboration between:

**The Royal Danish Collections, Hazze Nyström  
Lumodan, Brian Markussen  
DTU Fotonik, Department of Photonics Engineering**

Financed by the Danish Energy Association under ELFORSK  
grant no. PSO 339-029

**Kvorning Design & Kommunikation**



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## The exhibition display cases



**Rosenborg Castle, Copenhagen**

**The Royal Danish Collections  
Denmark's greatest cultural treasures**

**The Treasury in the  
Palace basement**

**Crown Jewels and the  
Danish Crown Regalia**

**High security display  
cases**



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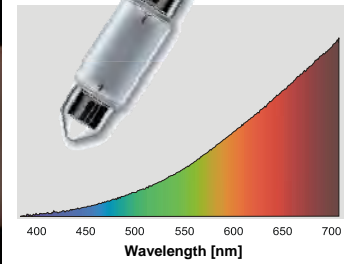
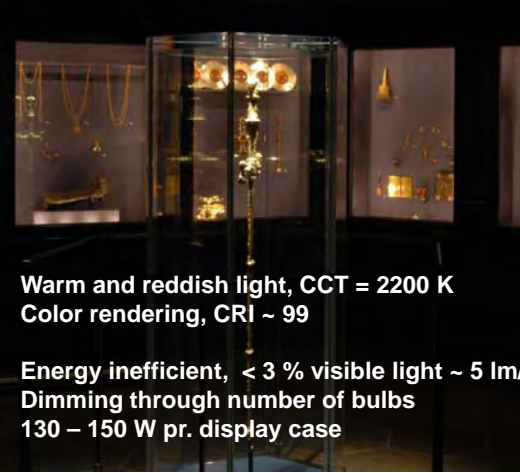
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## The present illumination

### 5 W pinol incandescent bulbs



Warm and reddish light, CCT = 2200 K  
Color rendering, CRI ~ 99

Energy inefficient, < 3 % visible light ~ 5 lm/W  
Dimming through number of bulbs  
130 – 150 W pr. display case

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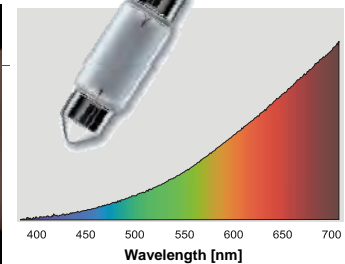
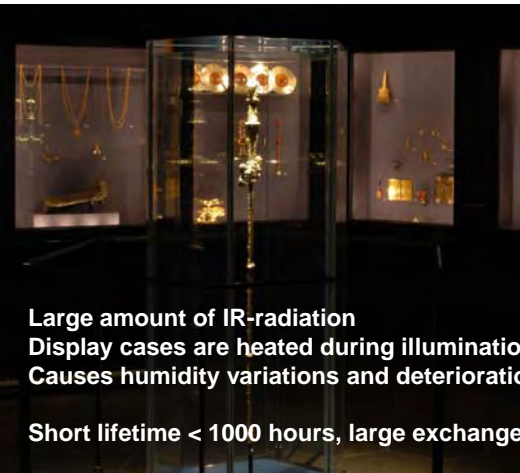
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## The present illumination

### 5 W pinol incandescent bulbs



Large amount of IR-radiation  
Display cases are heated during illumination, 9-12 deg.  
Causes humidity variations and deterioration of objects

Short lifetime < 1000 hours, large exchange expenses


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## LED as an alternative



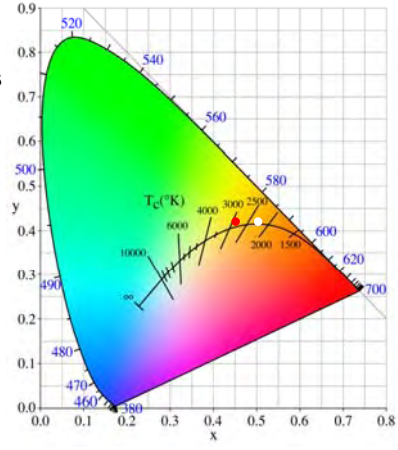
**High power LEDs (~ 1-5 W, 50-200 lm)**

**Compact robust units with high luminous flux and high energy efficiency**

**Cold and neutral white LEDs**  
6500 – 3500 K, 104 lm/W

**Warm white LEDs**  
3500 – 2700 K, 81 lm/W

**No UV and IR-radiation**  
**Long lifetime 20.000 – 50.000 hours,**  
**if efficiently cooled**



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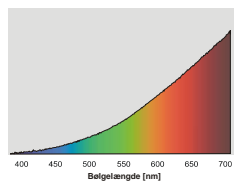
## On-site spectral design

**Visual inspection and evaluation of spectrally designed LED illumination**



**Computer controlled demonstration LED light source**

**Reference: 5 W incandescent bulb at 2200 K**



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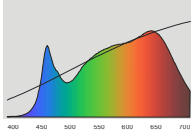
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## Spectral design

### Visual inspection and evaluation of spectrally designed LED illumination

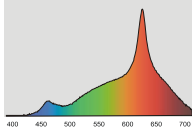


**Warm white LED**  
CCT = 2960 K  
Ra = 90





CCT = 2200 K  
Ra = 95



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













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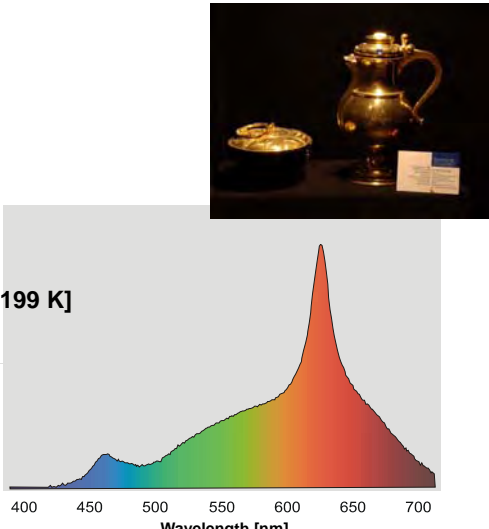
## Color quality

Correlated color temperature:  
CCT = 2199 K

Color rendering:

Object	Ra <sub>i</sub>
	97.4
	99.6
	93.6
	94.9
	97.4
	96.7
	98.1
	98.7
	95.0
	97.3
	91.2
	97.7
	97.8
	94.4

**CRI = 97.0**  
**[Planckian 2199 K]**



Wavelength [nm]

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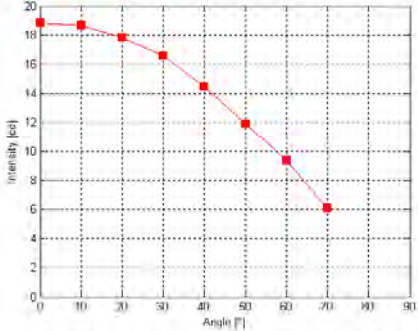
## Color quality

**Problems with LED color mixing using LED clusters is the appearance of colored shadows**

**Designed a new optical system:  
Mixes the light perfectly and produces diffuse light with no colored shadows**

**Low efficiency : 50-60 %**

**Measured intensity as a function of angle, close to a cosine distribution**

Angle [°]	Intensity [cd]
0	19.5
10	19.0
20	18.5
30	17.5
40	16.0
50	14.0
60	11.5
70	6.5

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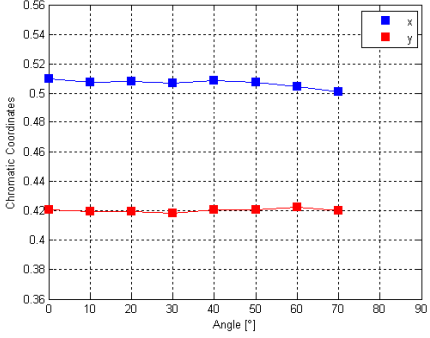
## Color quality

**New optical system:  
Investigation of the color distribution**

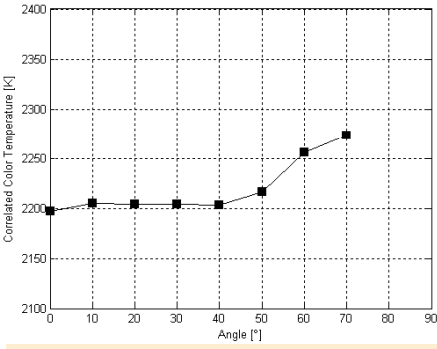
**Measured chromatic coordinates as a function of angle.**

**Measured correlated color temperature as a function of angle:  
CCT = 2200 K.**

**Homogeneous light quality with no colored shadows.**



Angle [°]	x	y
0	0.51	0.42
10	0.51	0.42
20	0.51	0.42
30	0.51	0.42
40	0.51	0.42
50	0.51	0.42
60	0.51	0.42
70	0.51	0.42



Angle [°]	Correlated Color Temperature [K]
0	2200
10	2200
20	2200
30	2200
40	2200
50	2220
60	2250
70	2275

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## PinolLED

A new energy efficient and high quality LED illumination system



**2200 K, CRI > 93**  
**No colored shadows**  
**Low glare**

**Energy efficiency > 25-30 lm/W**  
**26-32 W pr. case, > 75% energy saving**  
**Low heating of the display case (< 1 deg)**  
**Lifetime > 25.000 hours**  
**Dimmable without color change**  
**Blue background is enhanced**

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## PinolLED

LED illumination rail system



**Design: Kvorning Design & Kommunikation ©**

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## PinolLED

**Pinol incandescent bulbs**  
~ 130 W



**PinolLED**  
~ 30 W



DKKS, Kvorning Design & Kommunikation  
Lumodan og DTU Fotonik

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