Pierantonio Cinzano

Come combattere efficaciemente l'inquinamento luminoso e i suoi effetti sul cielo notturno

ISTIL - Istituto di Scienza e Tecnologia dell’Inquinamento Luminoso

www.inquinamentoluminoso.it

cortesia Luigi Boschian, San Canzian d'Isonzo

Quali possibilità per limitare l'inquinamento luminoso ?

Spegnere tutte le luci: non realizzabile nel mondo moderno

Rinunciare all'installazione di nuovi impianti di illuminazione: azzera l'incremento dell'inquinamento luminoso e non crea il buio ma non consente sviluppo

Consentire la crescita dell'illuminazione ma con un tetto all'incremento annuo del flusso luminoso installato (2%) e dei consumi di energia elettrica (1%):favorisce impianti senza sprechi, lampade ad elevata efficienza, risparmio di risorse

Ciascuno è libero di illuminare quello che vuole ma deve seguire, nel fare l'impianto, alcune regole fondamentali
E' quello che prevede la legge Regione Lombardia 17/2000

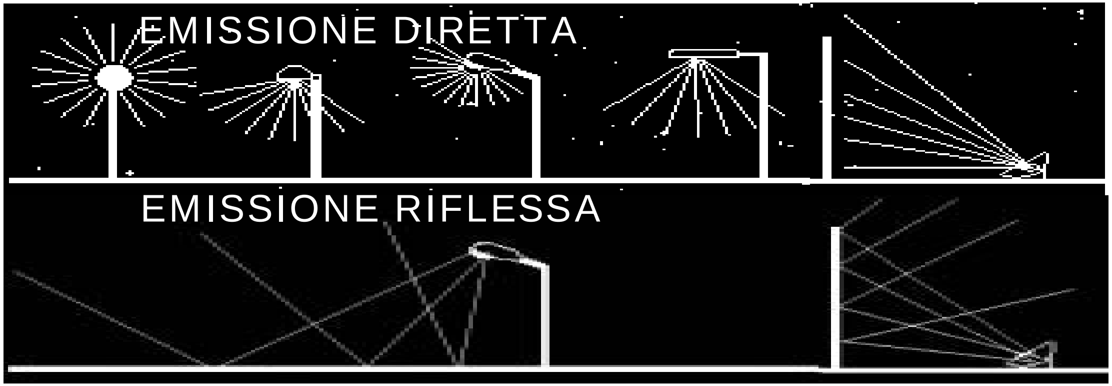
Applicare i provvedimenti su tutto il territorio (almeno per impianti nuovi)

Caratteristiche: a) Propagazione a grande distanza

b) Proprietà addittiva

Cortesia International Dark-Sky Association

Dispersione di luce nell'ambiente notturno



1) Limitare la dispersione dalle superfici illuminate

- I livelli di luminanza non devono superare i valori minimi necessari (previsti dalle normative di sicurezza, oppure 1 cd/m^2 ove non previsti)
- Diminuire l'intensità dell'illuminazione negli orari in cui la superficie è meno utilizzata (riduttori di flusso)
- Spegnere gli impianti negli orari in cui non vengono utilizzati
- Dirigere la luce verso l'utente e non in alto

2) Limitare la dispersione dagli apparecchi di illuminazione

- Scelta accurata del tipo di apparecchi (ottica totalmente schermata sopra l'orizzonte)
- Accurata progettazione (attenzione a dove finisce la luce)
- Cura nel tipo di installazione e di montaggio (ottica perfettamente orizzontale)

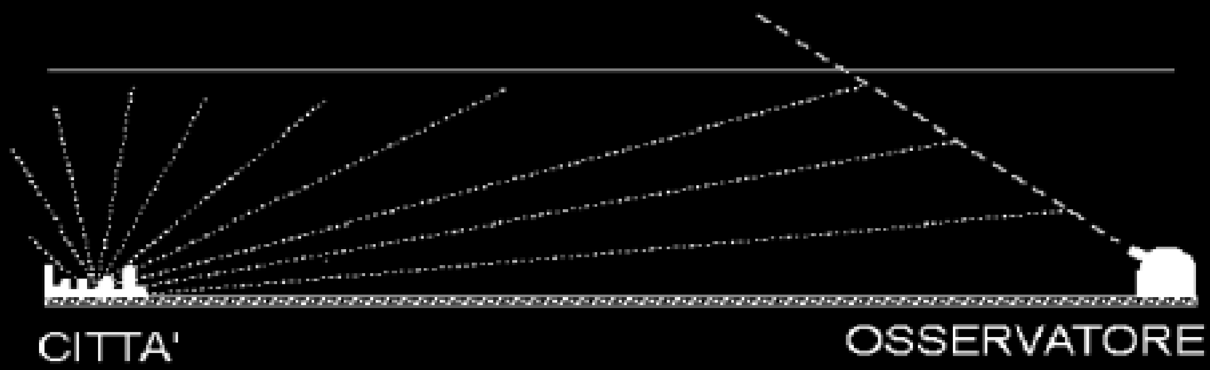
Significato dei limiti alla percentuale di flusso emesso verso l'alto da un impianto

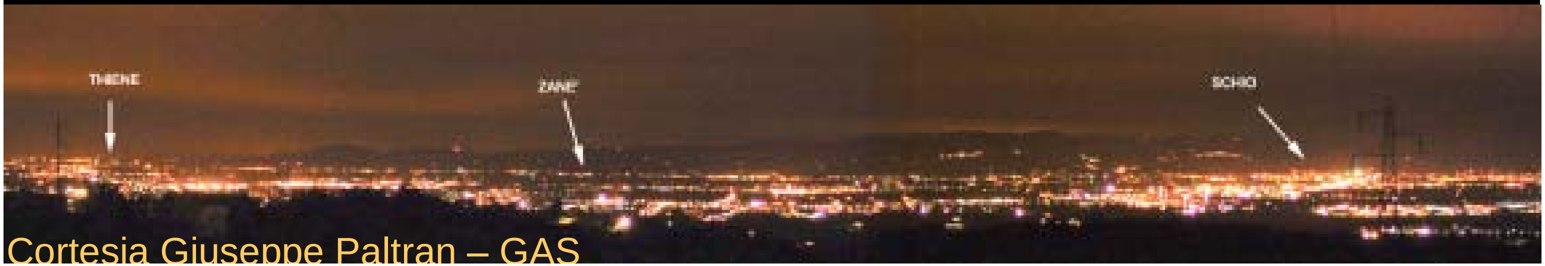
	norma	diretto in alto	diretto in basso	riflesso in alto	totale in alto	incre-mento
1%	UNI 10819	1	99	9.9	10.9	+10%
3%	LR Veneto LR Toscana	3	97	9.7	12.7	+31%
5%	UNI 10819 CIE 126-1997	5	95	9.5	14.5	+53%
10%	UNI 10819	10	90	9	19	+111%
15%	CIE 126-1997	15	85	8.5	23.5	+176%
23%	UNI 10819	23	77	7.7	30.7	+298%

Effetti dell’angolo di emissione della luce

L’EMISSIONE
A BASSI ANGOLI
SI PROPAGA DI PIU’

A 20 km dalla sorgente il 95% della luminanza del cielo allo zenith è prodotto da luce emessa tra 90 e 135 gradi





Cortesia Giuseppe Paltran – GAS

2.3.4 Luminanza

È una grandezza impiegata per valutare l'intensità luminosa prodotta (o riflessa) da una superficie, così come appare all'osservatore.
La *luminanza* di una superficie infinitesima in una determinata direzione viene definita come il rapporto tra l'intensità luminosa da essa emessa in tale direzione e la sua area apparente (ossia la proiezione dell'area della superficie infinitesima su un piano perpendicolare alla direzione stessa, figura 2.11), ovvero

$$L = dI/dA \cos\beta \qquad (2.11)$$

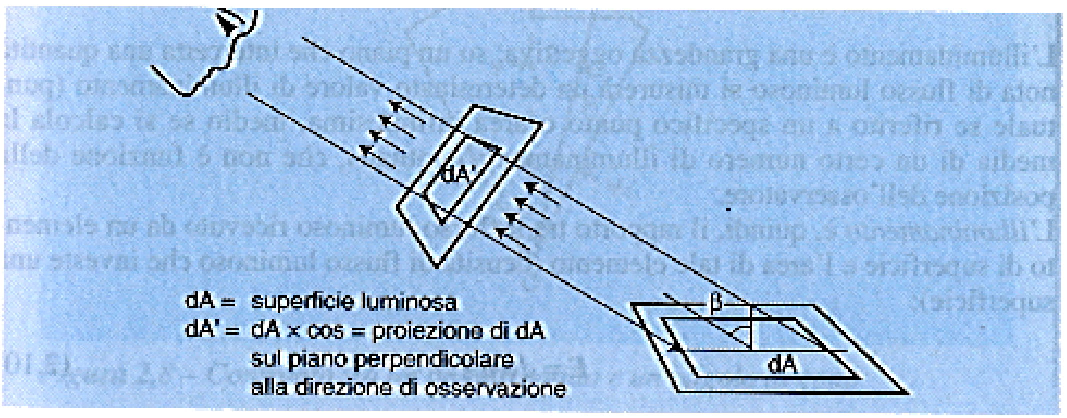


Figura 2.11 – Luminanza

P. Palladino, Lezioni di illuminotecnica, Tecniche Nuove, 2002

Significato dei limiti alla intensità luminosa emessa sopra i 90 gradi

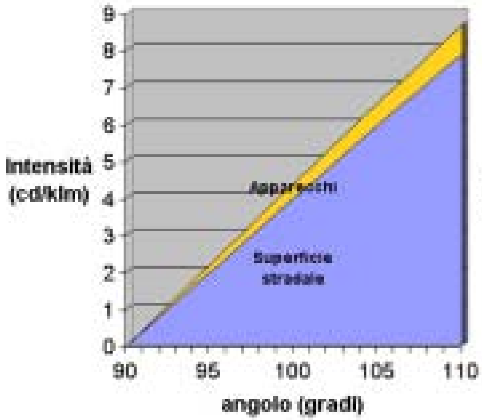
nel caso di una strada

Angolo	95 gradi	100 gradi	110 gradi
Intensità media in senso longitudinale di un campione di 21 strade	2.0 cd/klm	4.0 cd/klm	7.8 cd/klm
In senso trasversale l'intensità della luce emessa dalla strada è molto più piccola			

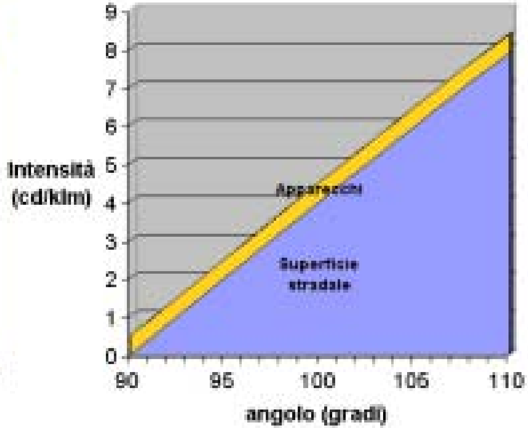
Quindi se vogliamo che l'effetto inquinante degli apparecchi sia piccolo (10%) rispetto a quello delle superfici il limite alla loro intensità luminosa sopra i 90 gradi deve essere di **qualche decimo** di candela per kilolumen

Limiti all’intensità della luce emessa dagli apparecchi in impianti nuovi	>90 gradi	>95 gradi
Lombardia LR 22/2000	0 cd/klm ±0.5	
PDL 696 in generale <u>se corretto l’errore di stampa</u>	0 cd/klm	
Lazio LR 23/2000 - PDL 2403 stradale aree prot.	0 cd/klm	
Lazio LR 23/2000 - PDL 2403 lanterne aree prot.	2 cd/klm	0 cd/klm
Lazio LR 23/2000 - PDL 2403 stradale/lanterne	5 cd/klm	0 cd/klm
Lazio LR 23/2000 - PDL 2403 torri-faro	10 cd/klm	0 cd/klm
PDL 696 torri-faro	10 cd/klm	
PDL 696 globi, lanterne <u>(già esistenti?)</u>	15 cd/klm	
Lazio LR 23/2000 - PDL 2403 arredo urbano aree pr.	25 cd/klm	5 cd/klm
Lazio LR 23/2000 - PDL 2403 arredo urbano	35 cd/klm	5 cd/klm
PDL 696 globi, lanterne <u>(già esistenti?)</u>	30 cd/klm	
Per confronto: intensità di una lampadina nuda	79.6 cd/klm	

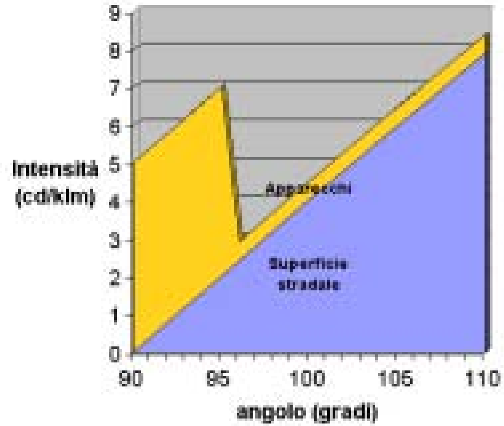
Limite del 10%



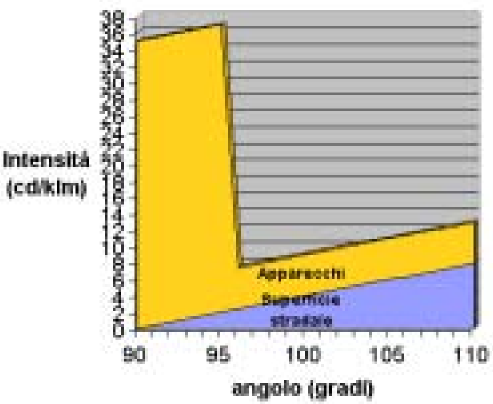
Legge Lombardia LR 17 / 2000



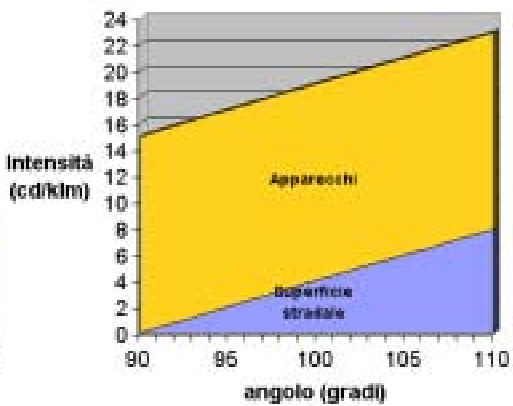
Legge Lazio LR 23 / 2000 - PDL 2403
stradale - lanterne



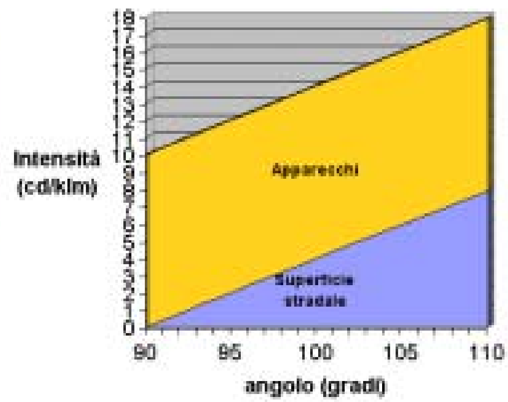
Legge Lazio LR 23 / 2000 - PDL 2403
arredo urbano



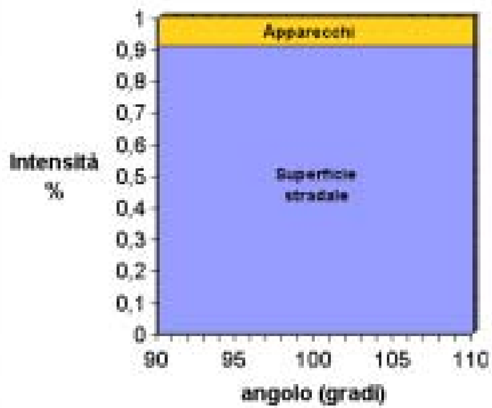
PDL 696
globi - lanterne



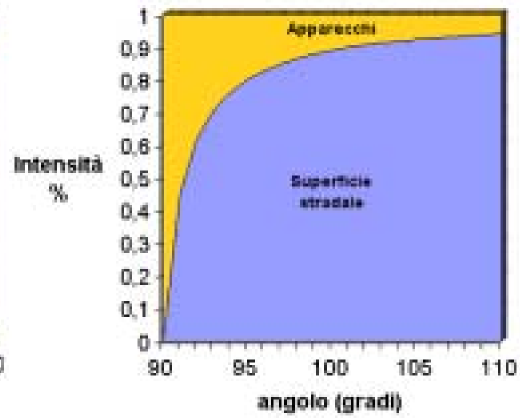
PDL 696
torri faro



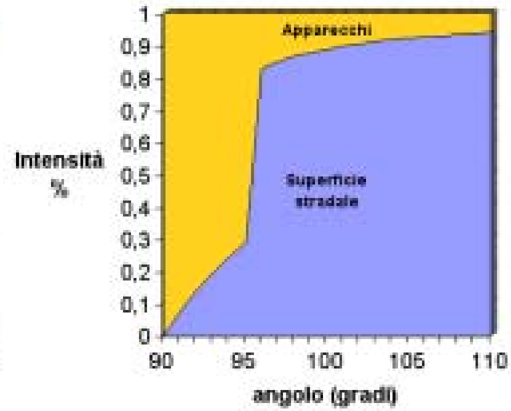
Limite del 10%



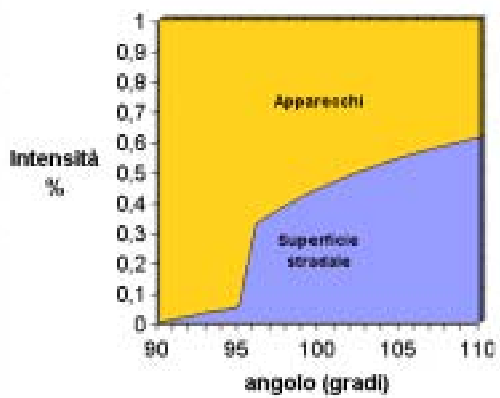
Legge Lombardia LR 17 / 2000



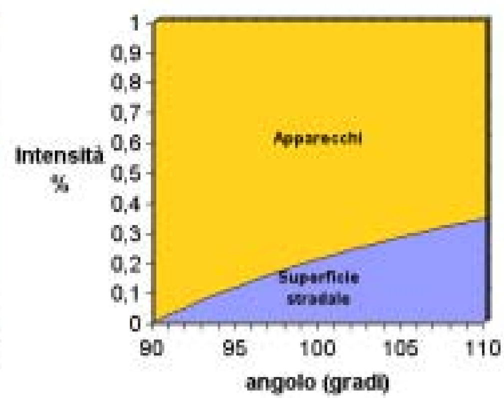
Legge Lazio LR 23 / 2000 - PDL 2403
stradale - lanterne



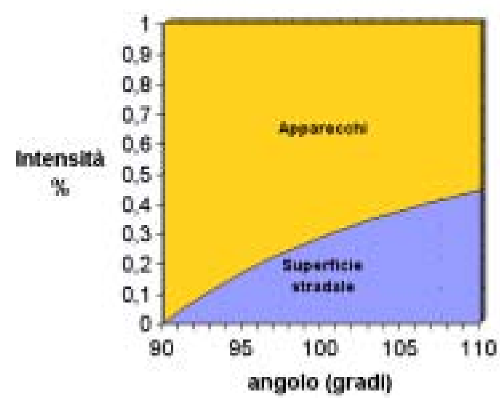
Legge Lazio LR 23 / 2000 - PDL 2403
arredo urbano

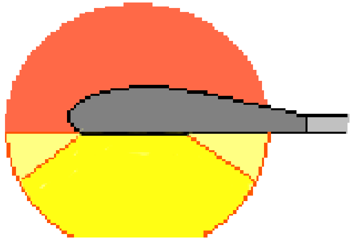


PDL 696
globi - lanterne



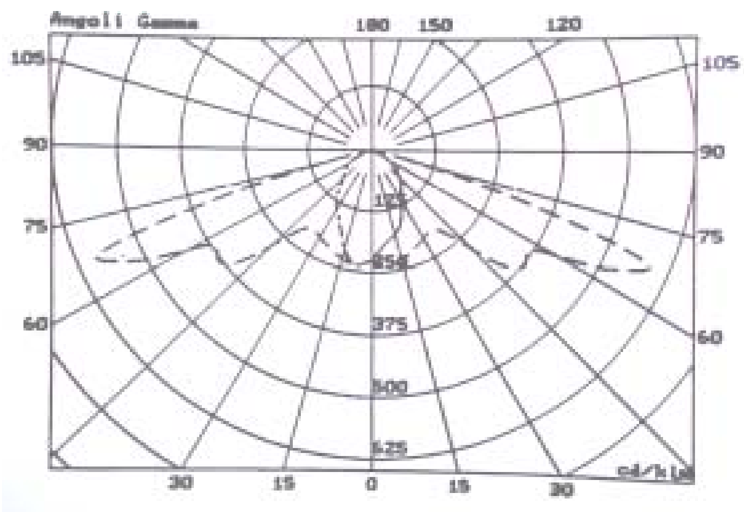
PDL 696
torri faro

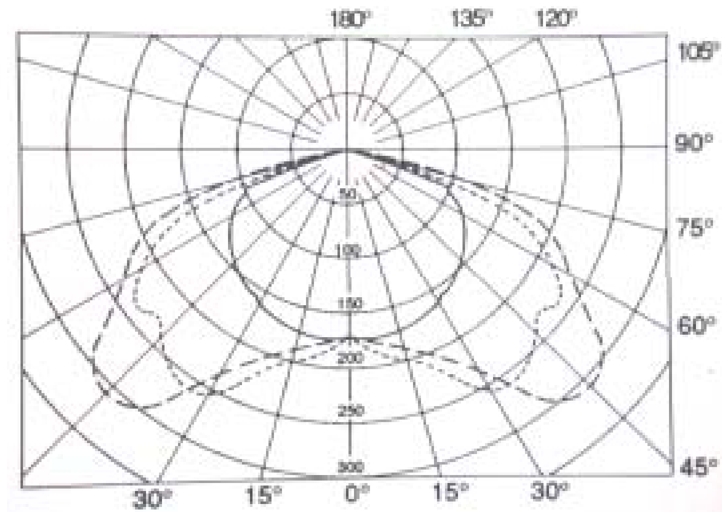




Cut-off (CIE)

- Oltre 90 gradi: <10 cd/klm
- Oltre 80 gradi: <30 cd/klm





Rendimento e rendimento effettivo

tipo di apparecchio	rendimento (efficienza)	rendimento verso l'alto	rendimento verso il basso
Lampada nuda	100%	50%	50%
Globo	85%	45%	40%
Rifrattore prismatico lampada 150W NaHP tubolare	81%	3% - 5%	<78%
Vetro piano lampada 150W NaHP tubolare	78%	~0%	78%

Roadpollution: a software to evaluate and understand light pollution from road lighting

Meeting CIE Division 4 TC 4-21 28 Sept-3 Oct 2002, IEN Torino

Pierantonio Cinzano

Universita` di Padova, Padova, Italy

Istituto di Scienza e Tecnologia dell'Inquinamento Luminoso (ISTIL), Thiene, Italy

email:cinzano@lightpollution.it

Methods

- INPUT
- Road parameters & luminaire photometry
- Road design computation (UNI10439)
- OUTPUT
- Road lighting data
- Parameters related to energy saving
- Integrated upward light parameters
- Parameters dependent on the direction of emission of the light
- Parameters related to scattering (along light paths via Garstang models)
- Reflected light by road (Gillet et al. 2002) and surfaces outside of the road (estimate)

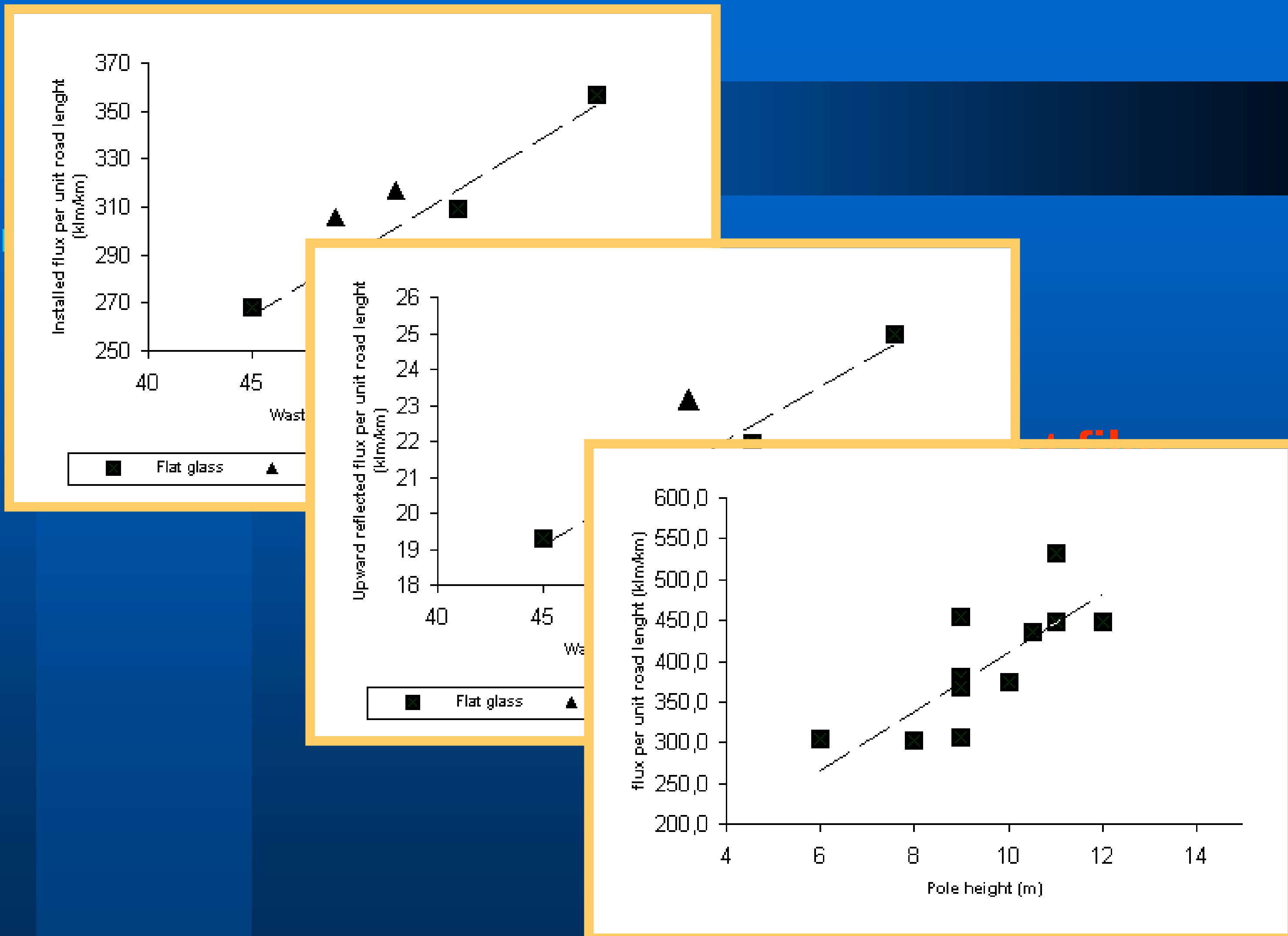
An application

- 5 road installations: ULOR_inst = 2.2%,0.2%,≈0%
- searching at our best for the minimum installed flux per unit length and the maximum pole spacing
  - Average maintained luminance ≈1cd/klm
  - Overall uniformity $U_0 \geq 0.4$
  - Lengthwise uniformity $U_l \geq 0.5$
  - Threshold index TI≤ 15%
  - Lumen depreciation factor 0.8
  - C2 standard road surface
  - Road width 7 m
  - Overhang free
  - No tilt

DESIGN PARAMETERS					
code number	09170114	09170102	09170043	09162356	09170209
luminaire kind	prismatic glass	convex transparent glass	flat glass	flat glass	flat glass
lamp flux (klm)	11	13	15	10.8	7.5
pole spacing (m)	36	41	42	35	28
luminaire height (m)	8	8	12	10	8
lamp	HQL	SON-T	NAV-T	NAV-T	NAV-T
ROAD PARAMETERS (luminaires at right/luminaires at left)					
average maintained luminance	1.0/1.0	1.0/1.0	1.0/1.0	1.0/1.0	1.0/1.0
overall uniformity U_0	0.4/0.5	0.4/0.4	0.5/0.4	0.5/0.4	0.5/0.4
lengthwise uniformity U_L	0.5/0.5	0.5/0.5	0.5/0.6	0.5/0.6	0.5/0.7
max threshold increment TI%	10.4/11.0	13.6/9.6	6.3/9.0	6.8/9.9	6.8/9.9
ENERGY SAVING PARAMETERS					
average luminance coefficient (luminance per unit illuminance) (10^-2 cd/klm)	89	68.2	93	91	87
used fraction of the lamp flux %	35.4	40.7	28.6	33.5	40.9
wasted fraction of the downward flux %	51.0	51.9	61.6	54.9	45.0
light output ratio of the luminaire LORL %	71	84.9	74	74	74
luminaires per km	27.7	24.4	23.8	28.6	35.7
installed lamp flux per unit length (lm/m)	306	317	357	309	268
installed lamp flux per unit area (lm/m^2)	44	45	51	44	38

Some comments …by the way

- For the same pole height, the installation with flat glass fixtures results the less consuming (only 268 lm/m) due to his minor wasting of light out of the road. This likely depends on the more concentrated emission of these specific fixtures on the plane perpendicular to the road axis. The installed flux per unit road length seems depending mainly on the fraction of light wasted out of the road (I.e. on the good design) rather than on the throw.
- However the number of luminaires per unit road length is the larger one. Number of luminaires and installed flux per unit road length seems to be conflicting. E.g. using 1/3 less luminaires we would spend 1/3 more light flux. However saved energy pay the installation cost.
- The number of luminaires per km of the flat glass installation is only 3% larger than that of the prismatic glass installation, when comparing installations with the same installed flux per km and same luminance
- An accurate design seems more important than the kind of glass



Installed flux per unit road lenght (klm/km)
370
350
330
310
290
270
250
40
45
Wast
Flat glass
Upward reflected flux per unit road lenght (klm/km)
26
25
24
23
22
21
20
19
18
40
45
Wa
Flat glass
flux per unit road lenght (klm/km)
600,0
550,0
500,0
450,0
400,0
350,0
300,0
250,0
200,0
4
6
8
10
12
14
Pole height (m)

I compared the installed light flux per unit road length with the light flux wasted outside of the road surface by the lighting installations in the sample of the paper:

Remande, C. (Syndicat de l'Eclairage Francais) **Pollution and harmful effects: high performance lights can overcome these**

I obtained the installed light flux per km from the column "Lamps (1)" of his tables 4, 5 and 6. I obtained from his figure 3 the light flux reflected upward by areas surrounding the road (called by him "flux reflected by the environment"). Due to the resolution of the figure 3 there is some approximation on the last numbers but they are sufficient for our purposes. On page 9 Ramande wrote that the reflection coefficient adopted by him "for the whole of the ground except the road surface" was 5%, so we obtained back the light flux wasted outside of the road dividing the "flux reflected by the environment" by 0.05. Then I plotted them in figure A.

It is easy to see that the sample of Ramande follows very well the same tendency shown both by the sample in the paper of Cinzano (2002) and by the sample of 12 prismatic and curved glass installations in my presentation:

The larger the fraction of the downward light flux wasted outside of the road the larger the installed light flux per unit road surface. See that paper for a deeper discussion.

In conclusion, the differences in the installed flux per unit road surfaces that Ramande found in his sample of installations are likely depending on the lighting design, which produces different quantities of light wasted outside of the road (transversally to the road axis), rather than by the differences in throw along the road axis between flat-glass fixtures, prismatic glass fixtures and the other kinds of fixtures.

So his conclusions about the larger installed light flux required by a flat glass luminaire appear invalidated.

Ramande seems somehow to notice this behaviour when at page 12 he says "The more high-performance in optics in luminance, the less significant the reflected flux will be".

References: Cinzano, P. 2002, Light pollution by luminaires in roadway lighting, preliminary draft

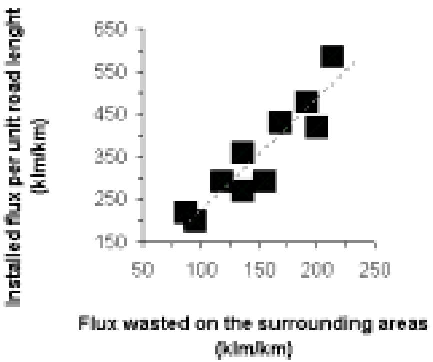
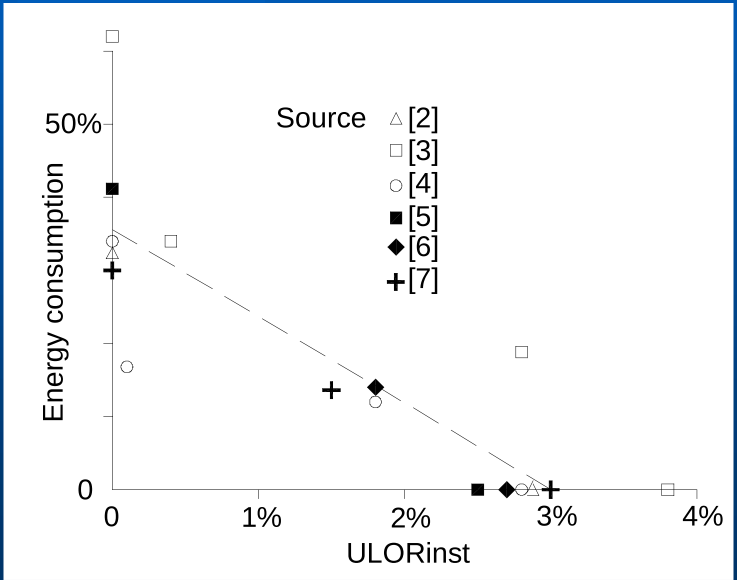
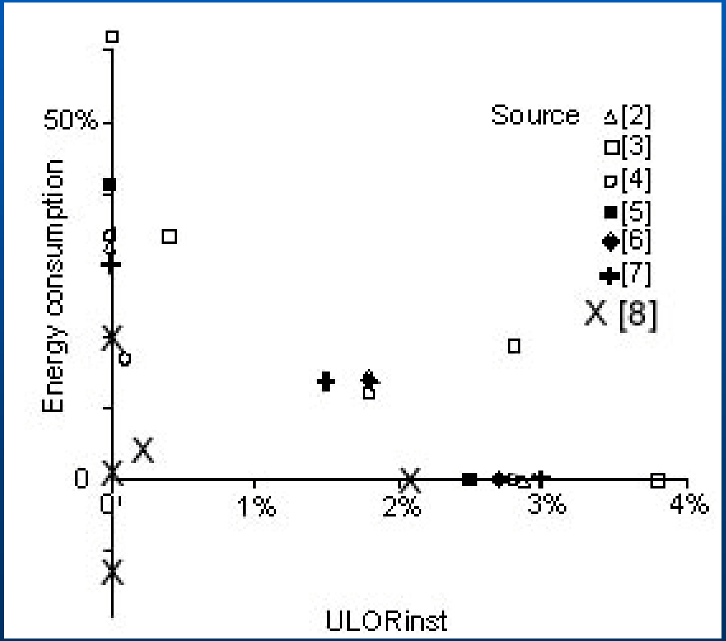


Figure A, Installed light flux per unit road surface compared with the light flux wasted outside the road surface.

ENERGY CONSERVATION AND LIMITATION OF LIGHT POLLUTION

P. Soardo (CNR), L. Fellin (University of Padua), P. Iacomussi (IEN), G. Rossi (IEN)





Preliminary results: direct light

upward light output ratio ULOR (calc) %	1.6	0.17
upward flux ratio $UFR_{luminaire}$ %	2.2	0.2
road upward flux ratio UFR_{road} %	3.7	3.8
increase of upflux ratio due to direct emission %	60	5.3
increase of scattered light due to direct emission %	85	NA
increase of low-angles upward flux due to direct emission %	167	16
increase of low-angles scattered light due to direct emission %	212	21

- **Luminaires with upward flux factors apparently as small as 0.2% and 2.2% produces increases of scattered light at low elevations of the order of 20% and 200%.**

Preliminary results: road reflected light

installed lamp flux per unit length (lm/m)	306	317	357	309	268
road upward flux ratio UFR_{road} %	3.7	3.8	2.9	3.4	4.2
road upward flux (lm/m)	1132	1204	1035	1050	1125

- **The *road upward flux ratio* can be misleading. Installations could show an increasing road upward flux ratio but a decreasing installed lamp flux per unit road length, so the upward flux does not changes.**
- **Our flat glass luminaires produces slightly less road upward flux than the other two kinds (even 10-15% at the same pole height), just the opposite of what has been frequently claimed.**
- **Low angles road intensity depends on the required luminance**

Preliminary results: out of road refl.

upward flux ratio $UFR_{luminaire}$ %	2.2	0.2	0	0	0
road upward flux (lm/m)	1132	1204	1035	1050	1125
increase of low angles scattered light due to direct + out-of-road emission % (reflectivity=13.5%)	348	170	227	172	114
increase of low angles scattered light due to direct + out-of-road emission % (reflectivity=7%)	280	95	113	86	57

- **The upward flux due to reflection by out-of-road surfaces is strictly depending on the wasted fraction of the downward flux which must be minimized as much as possible.**
- **For accurate installations, reflection of downward light wasted outside the road can add to the low angles scattered flux approximately another 60% - 110%, depending on the reflectivity**
- **The control of downward light wasted out of the road, i.e. the control of the wasted flux ratio cannot be neglected, in particular in fully shielded installations**

Conclusion of this exercise:

- **A luminaire with ULR=0.2% still add non negligible light pollution to the road (unavoidable) one. So fully shielded luminaires are needed.**
- **When we cut the direct spill light, the light reflected by surfaces outside of the road could remain (depending on their reflectance) a non negligible source of pollution even at low angles and should be limited with an accurate design.**

igura 2.21: Illuminazione di un area con un proiettore simmetrico (a sinistra) e
n un proiettore asimmetrico (a destra).

Emissione verso l’alto dalle superfici illuminate

- Un apparecchio di illuminazione emette 100
- Sulla superficie da illuminare arriva (se va bene) 75
- Una pavimentazione stradale (asfalto scuro e levigato - Bonomo 1986) riemette verso l’alto circa il 13%
- Le superfici verticali riemettono verso l’alto mediamente <20%
- Quindi ritorna verso l’alto 10-15

intonaco chiaro 40-50% (Palladino 1993)
intonaco scuro 25%
intonaco sporco 10%
cemento chiaro 40-50%
cemento scuro 5-10%
marmo chiaro 60-65%
granito chiaro 10-15%
di cui vanno in alto non più di due terzi

Campione bona fide di 21 impianti stradali di vario tipo				intensità in senso longitudinale		
Luminanza media	larghezza	interdistanza	flusso lampada	cd/klm a 5 gradi	cd/klm a 10 gradi	cd/klm a 20 gradi
0,87	6	24	6,3	1,75	3,47	6,81
0,80	6	24	5,8	1,75	3,46	6,80
0,73	6	26	6,3	1,59	3,15	6,19
1,18	7	30	13,5	1,61	3,20	6,29
0,86	8	30	9,5	1,91	3,79	7,44
0,73	6	25	6,3	1,53	3,03	5,95
0,99	8	30	13,5	1,55	3,07	6,03
0,93	8	35	10	2,29	4,54	8,92
1,02	8	38	14,5	1,88	3,73	7,33
1,24	14	50	29	2,63	5,22	10,25
1,34	10	45	27	1,96	3,89	7,65
1,09	10	40	19	2,02	4,00	7,86
1,98	16	50	52	2,68	5,31	10,44
1,34	12	45	27	2,36	4,67	9,18
2,38	12	45	48	2,35	4,67	9,17
1,90	11	40	31,5	2,33	4,63	9,09
2,88	20	60	96	3,16	6,28	12,33
2,97	9,5	52	48	2,69	5,33	10,47
0,69	4	20	3,8	1,28	2,53	4,98
0,95	5	20	5,8	1,44	2,86	5,61
1,00	10	40	23	1,53	3,03	5,96