

Light Pollution: a Study based on the Assessment of Actual Cases

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SUMMARY: Artificial lighting, which has become a necessity to facilitate human activity at night-time, contributes to the so-called Light Pollution. When such pollution occurs, the visibility of the night sky is degraded and an unnecessary amount of energy is wasted. Since the 80s, light pollution has been under study and several cities around the world have already regulated the use of luminaires -specially regarding public lighting- in order to prevent it. In Malargüe, in the south of the Province of Mendoza, an ordinance was adopted on April 14th 2005 to protect the sky from light pollution. In accordance to this ordinance, an interdisciplinary team will address itself to the task of assessing the impact of regular luminaires and of those luminaires suitable for light pollution control in Malargüe. The present study includes a general description of the problem as well as the preliminary results of the measurements already conducted.

1 LIGHT POLLUTION

1.1 General Description

Artificial night lighting has become a necessity to facilitate life in modern downtown areas and –although to a less degree- in rural areas as well. Furthermore, night lighting proves necessary in order to carry out numerous commercial, industrial and leisure activities. The inappropriate design or use of light fixtures, however, adversely affects the biodiversity and the environment as the result of haphazard changes in the darkness conditions characteristic of the night-time.

On the other hand, excessive or defective night lighting constitutes a type of light pollution affecting the visibility of the sky. As integral part of the common heritage of all the citizens, the sky has to be protected from pollution. Furthermore, its protection proves vital to scientific purposes. Ref. [1], Ref. [2] y Ref. [3].

It is worth noticing that the sky in the southern area of Mendoza presents special natural conditions. As the result of this, the Pierre Auger Cosmic Ray Observatory has been built in Malargüe; the best location according to the international scientific community participating in the Auger Collaboration. Ref. [4]

Over the last years, Malargüe has experienced a significant growth resulting in an increase in the light emitted skyward as a by-product of inefficient lighting. Thus, it is necessary to prevent a further increase or -insofar as it is possible- even reduce light emission. Furthermore, declaring this area protected from light pollution is promoting adventure and ecological tourism and other related activities. According to recent studies, light pollution has an adverse impact on several animal species. Increasingly, birds fly away from the cities due to a large extent to the lack of darkness necessary for the night sleep. Ref. [5]

Flora is also being affected in the cities as the excessive artificial light and the reduced number of dark hours bring about changes in the photosynthesis process necessary not only for plants but also for human beings, as it produces the oxygen we breathe.

A sensible use of night lighting has a direct and immediate impact on the energy used, saving a significant amount of it. In this sense, it should be taken into consideration that an efficient use of the resources translates into cost savings benefitting the council and the taxpayers as well.

In Argentina, energy is produced -to a large extent- from non-renewable resources. As a consequence, saving energy means preserving the natural resources for the generations to come.

All this, together with a greater public environmental awareness, account for the need of regulations aiming at taking the necessary measures to reduce light pollution, without disregarding the importance of night lighting to commercial, tourist and leisure activities.

It is important to highlight that the regulations should improve the quality of life of the ordinary citizen without neglecting roadway visibility and safety. Studies show that crime rate is not related to public lighting levels.

Preliminary findings indicate that more than 90% of the people living in European and American big cities do not know the Milky Way. As inhabitants of planet Earth, we have the natural right to view the stars. Unfortunately, this right has been increasingly affected by the urban sprawl. The sense of calmness and well-being derived from watching a starry sky takes on an added importance in a world characterized by the fast pace of modern life resulting in stress.



Figure 1. Satellite picture depicting the light emitted skyward Ref. [6]

1.2 Malargüe's Municipal Ordinance

On April 14th 2005, a municipal ordinance was adopted in Malargüe by the Legislative Council. Said ordinance sets the requirements to be met by luminaires and regulates the lighting levels, the design and installation of light fixtures, and their lighting times and seasonal pattern. Ref. [7]

These regulations are a step forward in the society's commitment to the protection of the environment, in the context of a sustainable development leading to social welfare and economic prosperity compatible with the environmental issues to be addressed.

The ordinance was adopted in accordance with Malargüe's commitment to healthy policies and the UNESCO Universal Declaration on the Rights of Future Generations: "the future generations are entitled to an unharmed and unpolluted planet Earth, including the right to a clean sky" Ref. [8]

The enactment of similar light pollution regulations has taken place in some cities in Spain Ref. [9] and American states. The Czech Republic has passed national laws regarding this matter. In Argentina, Rosario is the only city with specific lighting regulations, although these are only intended as a set of recommendations. Ref. [10]



Figure 2. Light emitted from the city of San Rafael as seen from the “Cuesta de los Terneros” (1999)

2 EFFECTS OF LIGHT POLLUTION

Light pollution brings about changes in several fields of human activity, such as the following:

2.1 Ecology

- Indirect consequence: Overuse of natural resources causing more fumes from power stations and nuclear waste.
- Direct consequence: less evident and more difficult to assess.

Furthermore, there is a disruption to wildlife in the form of:

- Excess in spectral range and intensity: the natural day-night cycle is distorted.

- Birds, bats, amphibians, fish, insects, etc, find their night habits changed (reproduction, migrations, etc).
- Ultraviolet radiation: invisible to the human eye but perceptible by nocturnal insects, on which predators (different kinds of birds, bats, mammals, amphibians, etc) as well as those plants whose flowers open at night depend. Ref. [11].
- Toxic Elements: mercury in the atmosphere is toxic for living beings (mercury vapor lamps are the most widely used nowadays).

It's worth remembering that sodium vapor lamps -suitable for light pollution control- do not have heavy elements.

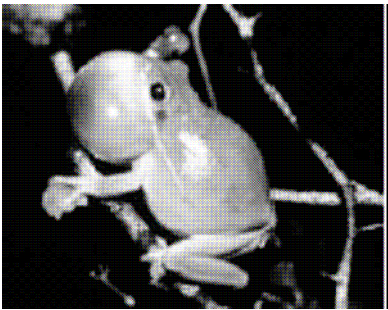


Figure 3: Certain frogs “freeze” for hours when exposed to intense light.

2.2 Human Health

The circadian rhythm may be disrupted, thus leading to:

- Changes in the sleep-wake cycle.
- Changes in body temperature.
- Unrestfulness. Neuroendocrine functions: melatonin and cortisol secretion.
- Disruption to the biological clock, considered in 24-hour periods of time according to sunlight.
- Resetting of the hypothalamic pacemaker (*Nature*, No 379, 1996)

2.3 Economy

- Public lighting: 50% of the municipal costs (according to data collected in Catalonia).
- The amount of light needed to illuminate clouds is equivalent to the one generated by a medium-power nuclear station. Germany (1998).
- Pilot experiences allow the estimation of the energy saved by appropriate public lighting.
 - In Figueres (Spain): an energy saving ranging from 20 to 44%. The costs of changing all the luminaires are recouped in 2 years.
 - Ley del Cielo (Sky Law) in the Canary Islands: a saving ranging from 40 to 60%.
 - As regards private lighting, the saving is similar when adjusting lighting times and power.
- Mercury vapor lamps: the energy use is
 - 70% higher than in high pressure sodium lamps.
 - 140% higher than in low pressure sodium lamps.
- Low pressure sodium lamps:
 - Incandescent lamps use 5 times the energy used by low pressure sodium lamps.
 - Fluorescent lamps use 1.5 times the energy used by low pressure sodium lamps.

2.4 Safety

- The eye finds it difficult to adapt when going from overlit areas to darker ones.
- Glare. "Light curtains" make it difficult to see beyond the lit area.

- Conclusions of "THE INFLUENCE OF STREET LIGHTING ON CRIME AND FEAR OF CRIME" report (University of Southampton), drawn from the analysis of a database comprising 100,000 cases:

- Lighting level and crime are not related.
- Street lighting provides reassurance and improves people's perceptions of safety.
- The reasons behind this are of a psychological nature.

- Similar studies in New York City show a lower crime rate as the result of changing mercury lamps for sodium lamps.

2.5 Social Issues

- Light pollution prevents or makes sky observation more difficult, thus causing a major cultural loss and a poorer landscape.

- Absence of starry nights, which are the common heritage of future generations and origin of our culture and civilization (mythology, philosophy, cosmogony, science, etc) Ref. [12]

- Section 41 of the National Constitution of the Argentine Republic: "All inhabitants have the right to a healthy and balanced environment, fit for human development in order that productive activities shall meet present needs without endangering those of future generations."

- UNESCO declaration: "the future generations are entitled to an unharmed and unpolluted planet Earth, including the right to a clean sky"

2.6 Technical issues:

- Efficient lighting: more light does not necessarily mean better lit. Ref. [13], Ref. [14].

Guidelines for the reduction of light pollution should take into consideration:

- The main characteristics of the population and the activities carried out.
- The lighting regulations regarding lighting times according to the time of the day and the different seasons.
- Well-designed light fixtures to reduce sky glow, light trespass and glare (see Fig. 4).
- The kind of lamp and luminaire to be used (see Fig. 5)

BASIC LIGHTING RULES

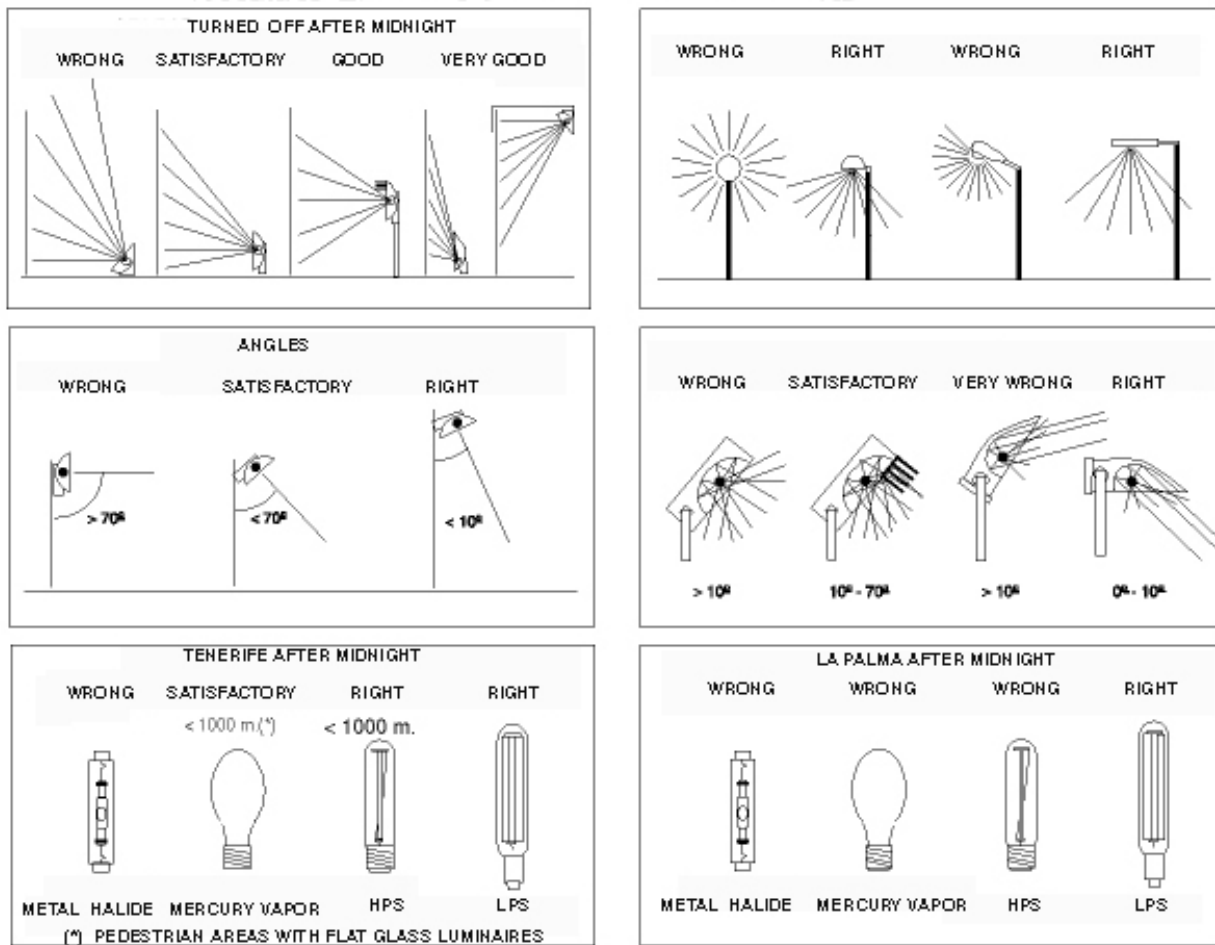


Figure 4. Basic lighting rules

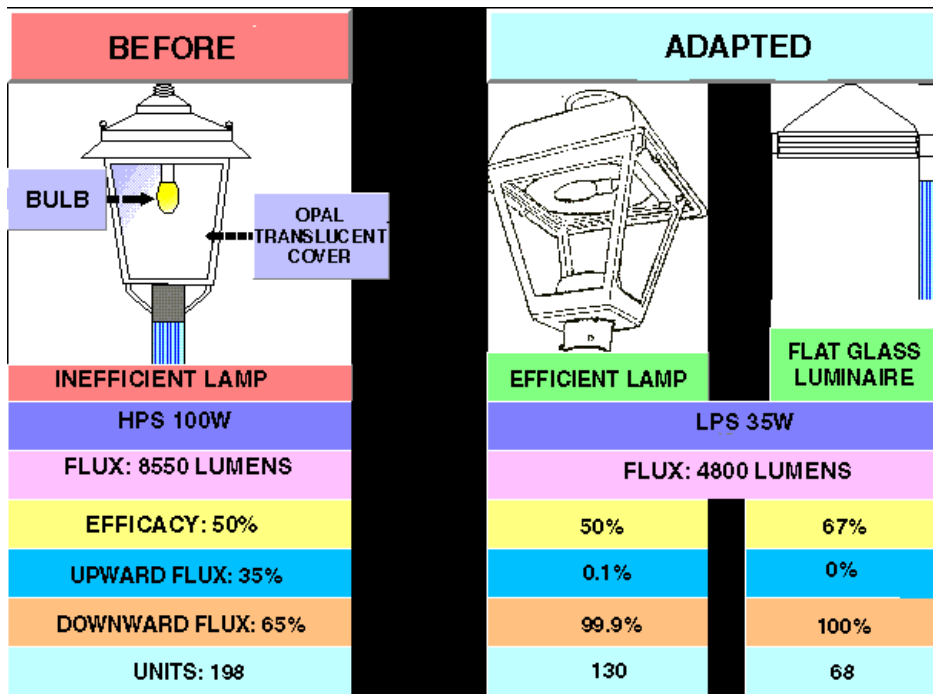


Figure 5. Different kinds of luminaries with/without light pollution control adjustments.

3 A PILOT EXPERIENCE IN MALARGÜE

Malargüe was the setting of a novel study regarding light pollution. As stated in section 1.2, a new municipal ordinance not only protects the sky from light pollution but also regulates, as of April 2005, the use of appropriate luminaries.

Figure 6 depicts Sarmiento Square at night, with its recently installed luminaires (globe lamp silvered at the top)

Figure 7 depicts San Martín Square -the main square in the city- and its standard light fixtures. Both pictures were taken with the same camera, film, aperture and exposure, from the opposite sidewalk and with no luminaires above.



Figure 6. Sarmiento Square

Pollution-control luminaire



Figure 7. San Martín Square

Standard luminaire

It can be clearly seen that in both cases the ground is satisfactorily lit, but the uplight is not the same: it is not about not lighting at all, but about lighting efficiently. The tops of the trees, also, show different levels of brightness.

4 LIGHT POLLUTION MONITORING PROTOCOL IN SQUARES IN THE CITY OF MALARGÜE

At this first stage of interdisciplinary work, we aimed at assessing the current situation in the city of Malargüe -where light pollution control measures are being taken- and collecting quantitative data for further analysis.

In order to achieve this, a comparative study of standard and pollution-control outdoor luminaires in two downtown squares was carried out. At this first stage, the following tasks were performed:

4.1 Physical assessment of the squares

In situ examination of the plans: the squares, including their demarcated pedestrian walkways, were measured.

4.2 Drawing of morphology diagrams.

This task involved the following steps:

- a) Urban morphology diagram
- b) Street lighting morphology diagram
- c) Morphology diagram of the trees

4.3. Photometric record (at daytime and night-time), consisting in:

- a) Photograph of the urban scenery of each square, taken with a regular lens. In each case, the premises were captured in a single picture.
- b) Detail photograph of luminaire and lamppost (regular lens)
- c) Detail photograph of the luminaire-tree relationship (regular lens)
- d) Photograph of the urban scenery of each square taken with a fish-eye lens (vertical).
- e) Photograph of luminaire and lamppost taken with a fish-eye lens (vertical).

This task was performed both at daytime and night-time.

4.4. Photometric measurement, comprising the following tasks:

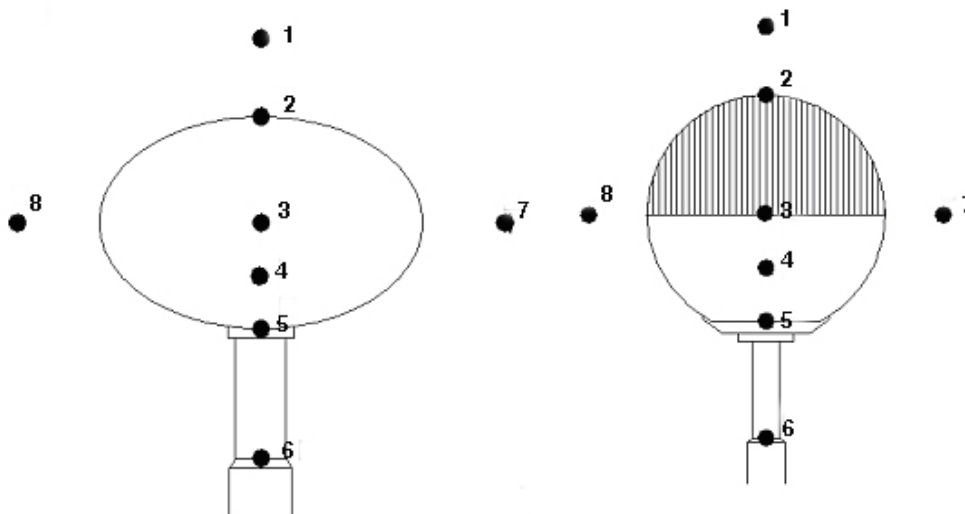
4.4.1 Measurement of surface reflectances.

The most representative areas were taken into consideration (size of the area in the square, e.g. paving, low vegetation, equipment, facades, etc).

The reflectances were measured using the KODAK reflectance cards (white and gray), luximeter (LI-COR) and a luminance meter. Great care was taken to ensure that the data were collected in the shade.

4.4.2 Luminance measurement (at night-time)

Luminance values (cd/m^2) were collected at seven different points of a standard luminaire and a pollution-control luminaire. Measurements were taken at the points specified in Figure 8, focusing the luminance meter lens before starting to measure.



San Martín Square (standard luminaires)

Sarmiento Square (pollution-control luminaires)

Figure 8. Location of the measurement points.

5 EARLY RESULTS AND CONCLUSIONS

5.1 Luminance measurement

Table 1. Luminance values, according to the type of luminaire

Points	San Martín (cd/m ²)	Sarmiento (cd/m ²)
1	142	1.72
2	3992	23.52
3	4747	3739
4	4813	7421
5	3328	1375
6	5.16	2.36
7	1	0.73
8	2.04	2.24

An early analysis of the results shows that, even though the values in the upper part of the pollution-control luminaire were significantly lower than those of the standard luminaire (see Table I), the adoption of measures related to light fixtures (in this case in squares) is insufficient to deal with the light pollution problem. A more comprehensive approach should take into consideration the urban context and the morphology of the surrounding environment as a preventive and palliative measure. Furthermore, the study shows that:

The differences regarding landscape composition show that adult and perennial plants are present in large numbers in San Martín Square, while the opposite situation applies to Sarmiento Square. This high percentage of perennial plants in San Martín Square may contribute to shield the spill light from the upper part of the luminaires. The large number of luminaries in the square, however, prevents the vegetation cover to act as a "sky shield".

In addition, it is worth noticing that both kinds of luminaires (standard and pollution-control) show different amounts of unnecessary amount of light emitted skyward (waste of energy) affecting the night landscape as a cultural concept, apart from the detrimental effect on those observatories located close to cities.

In this sense, the plant species, the ratio of the number of lamps to the area and the building morphology, among others, are important variables to be considered in the analysis because the interrelation between them or the independence of one another may prove vital when dealing with the light pollution problem.

Even though this is an early study, we deem it of a novel nature and very helpful in order to quantify the effectiveness of adapting public lighting according to pollution control criteria. Furthermore, the present study will provide an insight into the importance of raising people's awareness of the benefits of using efficient light fixtures and it will translate into a maximization of energy efficiency.

6 REFERENCES

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7 APPENDIX: Definitions

Pollutant

Any kind of substance or energy form in an amount that it is harmful to human beings or any other organisms or that may alter the natural conditions of the environment.

Light pollution

Light pollution is the result of the poor quality and wrong aiming of outdoor light fixtures.

- Light trespass
- Sky glow
- Glare
- Overuse

Light trespass

It is light being cast where it is not needed, trespassing adjacent areas. It is the most common type in large cities. It affects the family environment and people's privacy, a right recognized by the National Constitution of the Argentine Republic.

Sky glow

Light is scattered by dust and gas molecules in the atmosphere. As a consequence, the beam changes its original direction and is scattered in all directions, specially skyward (see Figure 7). Globes as the ones in San Martín Square are responsible for more than 50% of the light emitted skyward.

Glare

It takes place when there is a reduction in visibility -or a loss of it- from stray light being scattered from artificial light fixtures. Example: floodlight outside the Thesaurus Convention Center in Malargüe.

It is a form of light pollution that is specially dangerous when driving, causing a high number of car accidents.

Overuse

It takes place when there is an excessive use of energy derived from the lighting levels and times and/or the spectral distribution.