



Oficina de Protección
de la Calidad del Cielo
del Norte de Chile



Criteria for Lighting Design in Observatory Facilities

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June 2026



Las Campanas
Observatory



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0.1/ Introduction

This report details the **guiding criteria for designing lighting in optical observatory facilities or in contexts where minimizing the volume of installed light is crucial.**

Lighting design in these types of facilities is critical across various factors, regarding both indoor and outdoor lighting. On one hand, these are sites where night shift work takes place indoors; simultaneously, they are locations where outdoor lighting must have strict optical and spectral control due to the photosensitivity of the instruments to be installed (or already installed) and the need to reduce light pollution to its minimum expression.

+ The relevant lighting considerations are as follows:

	Indoor Lighting	The importance of circadian lighting (tunable white and dimmable) in workspaces.
	Outdoor Lighting	The importance of implementing specialized fixtures with ultra-protected enclosures, along with a spectral component containing zero blue light, applied strictly to areas where it is necessary for security and safety purposes.
	Beacon Lighting / Markers	The implementation of shielding accessories for beacon-type fixtures or luminous indicators is deemed necessary.
	Window Coverings	Finally, there is a clear need to develop window coverings that are completely light-opaque, given that an open window with indoor lighting can become a highly bright source in the context of extremely dark environments.



0.2/ Indoor Work Lighting



2.1/ Introduction to Circadian Rhythms. Shift Work and the Biological Clock

Electric lighting has reduced dependency on natural light in work environments; however, humans maintain a biological daytime predisposition, relying on light to regulate their circadian rhythms. In this context, shift work—especially night shifts—forces activities to be carried out at biologically inappropriate times, causing circadian misalignment, fatigue, and sleep disturbances, which impact health, safety, and performance.

Shift work, particularly night shifts, is associated with a high prevalence of health issues, with insomnia being one of the leading conditions globally. This is because humans are biologically adapted to daytime functioning, where variables

such as alertness, concentration, and performance reach their peak levels during the day.

This behavior is regulated by the internal biological clock (suprachiasmatic nucleus—SCN), located in the hypothalamus, which synchronizes primarily through light perceived by the eye. Under normal conditions, exposure to daylight—which is particularly rich in the blue spectrum component—promotes alertness, while nighttime darkness induces the secretion of melatonin, an essential hormone for rest and recovery.

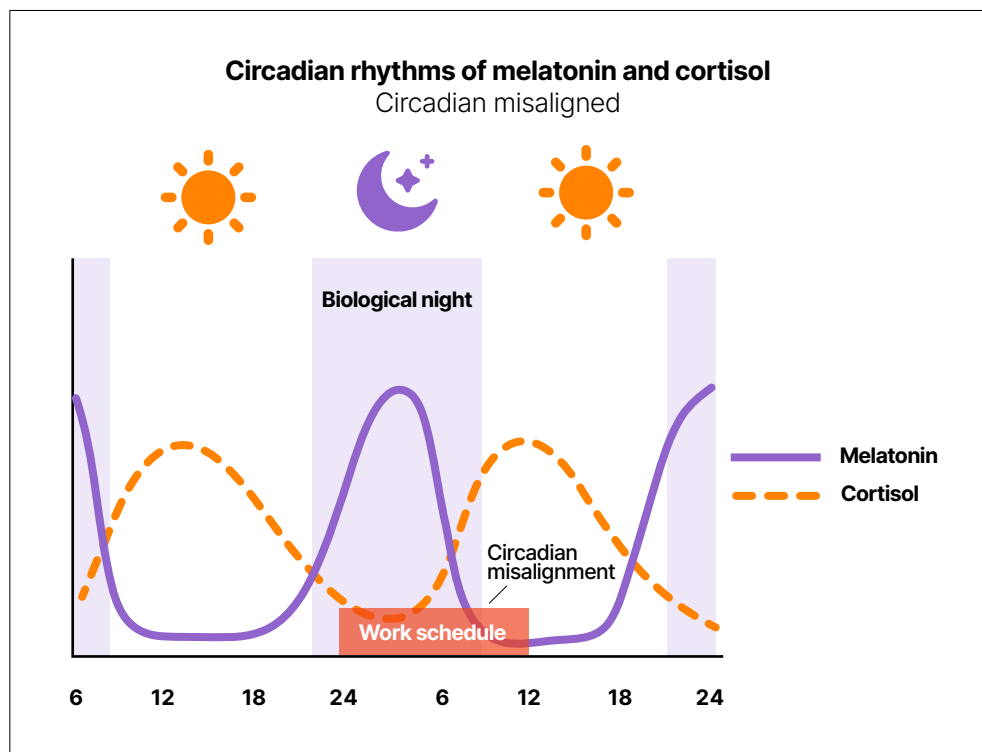


Fig. 1. Schematic daily temporal variation of melatonin and cortisol in the human body, substances regulating sleep and wake states.

Source: Meijer et al. (2017), *Proactive fatigue countermeasures*.

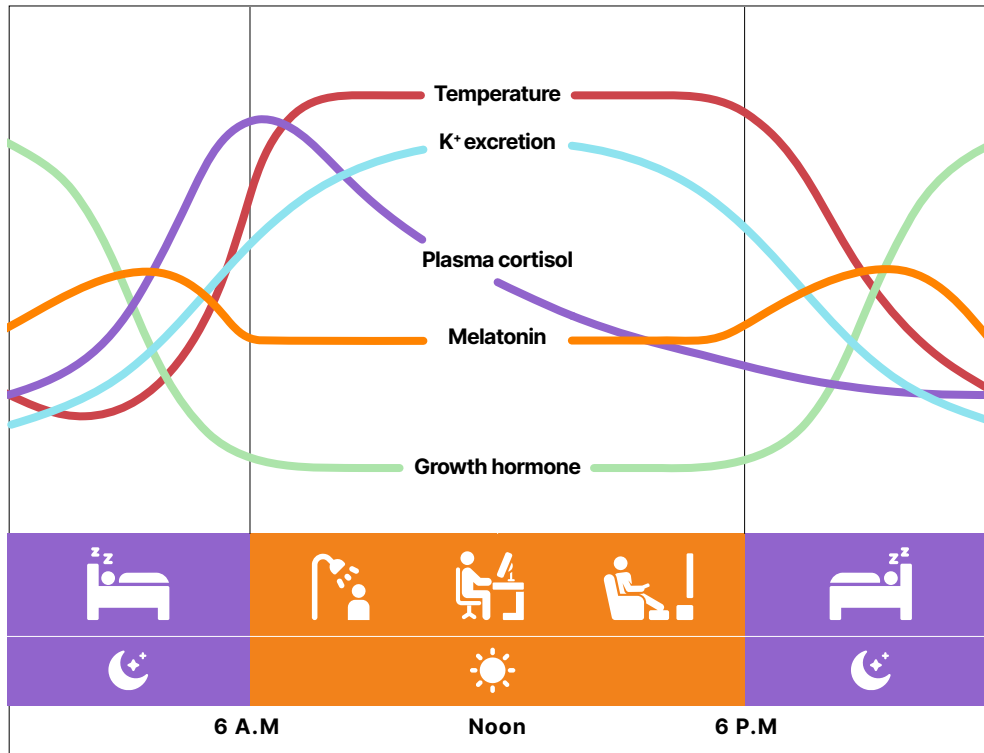


Fig. 2. Schematic daily temporal variation of other important chemical substances in the body under an unaltered circadian rhythm.

Source: Evans et al. (2022), *The Suprachiasmatic Nucleus and the Circadian Timekeeping System of the Body*.

In the context of night shift work, circadian misalignment occurs—that is, a mismatch between the internal biological clock and work, sleep, and eating schedules. As a result, workers must remain active during their “biological night” and sleep during their “biological day,” which negatively affects sleep quality and duration. In particular, daytime sleep exhibits a lower proportion of deep and REM stages, as well as greater fragmentation, generating cumulative rest deficits.

This misalignment has direct consequences on performance and safety. Evidence shows that unadapted workers experience lower alertness, cognitive impairment, and a higher incidence of errors and accidents. In fact, it has been estimated that the risk of occupational accidents can increase

by approximately 28% under conditions of circadian misalignment.

In this context, managing factors such as light exposure and shift scheduling is key to mitigating the negative effects of night work, promoting both the performance and well-being of workers^{1, 2}.

1 Source: <https://km-humanfactors.com/nl/the-science/shift-work-and-our-biological-clock/>

2 Source: <https://journals.sagepub.com/doi/10.1177/14771535211012251>

2.2 / Objective of Circadian Lighting for Night-Shift Workers

Recent evidence demonstrates that implementing circadian lighting strategies can significantly mitigate the adverse effects of night-shift work, particularly in terms of alertness, performance, and subsequent recovery. Various experimental and field studies, as well as systematic reviews, agree that light, as the primary synchronizer of the circadian system, can be used as an effective tool to optimize working conditions during biologically unfavorable hours.

For night-shift workers, the primary objective of circadian lighting is to maintain alertness and cognitive performance during the shift, minimizing drowsiness and, at the same time, facilitating a proper transition toward subsequent rest. This is achieved through the controlled stimulation of the circadian system via light, preventing excessive deregulation that could affect daytime sleep quality.

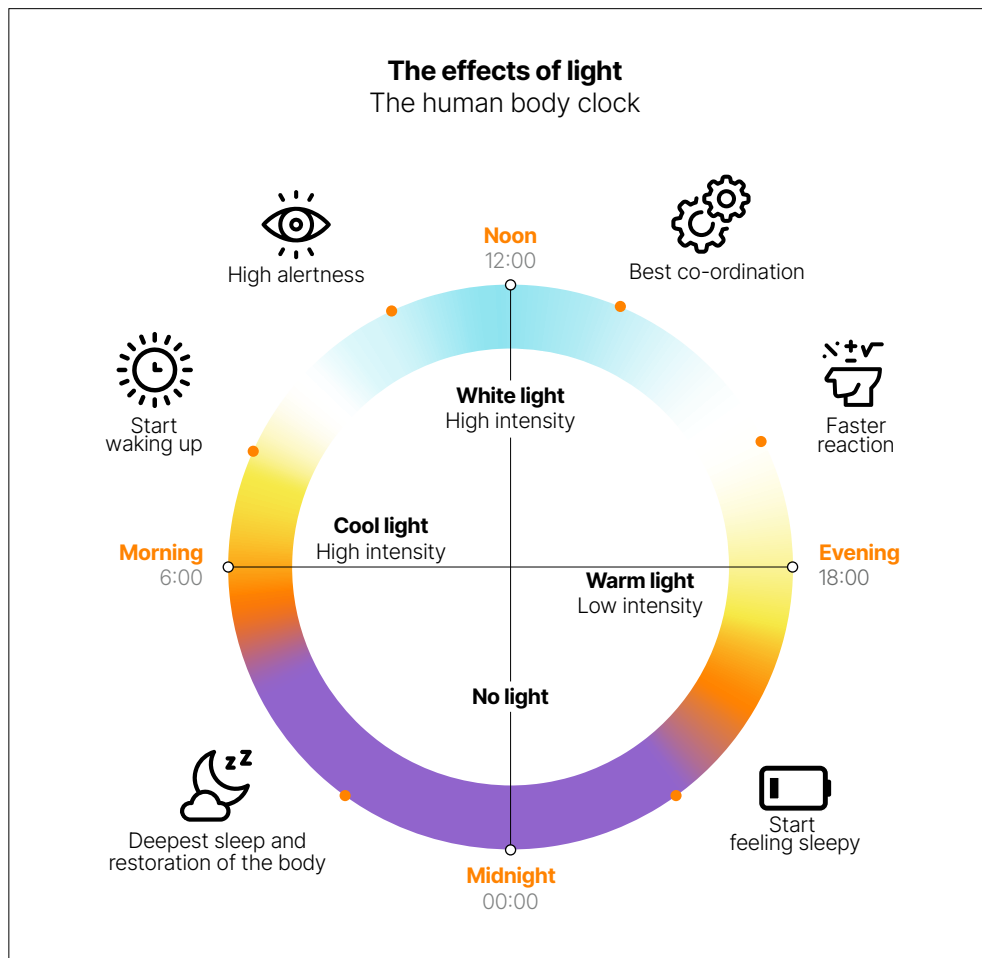


Fig. 3. Graphical representation of the circadian rhythm in humans.

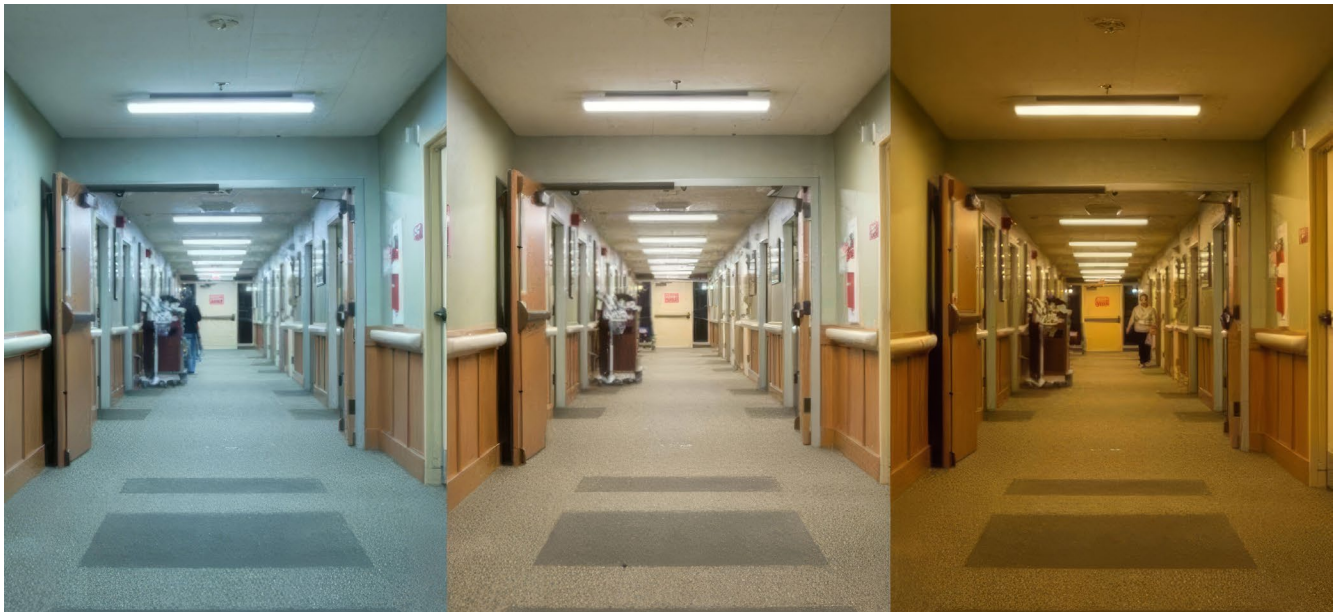
Fuente: Zimmer (2019), *Luz natural en interiores y exteriores – HCL (Human Centric Lighting)*.

2.3 / Necessary Characteristics of the Circadian Lighting System

To implement the benefits of circadian lighting, a lighting design is required that incorporates tunable white as a fundamental feature of the fixtures and, secondly, the capability for dimming, control, and/or remote management, in order to create lighting scenes that simulate an artificial day within workspaces during the night.

Tunable white is a term used to describe fixtures capable of varying the color temperature of white light (optimally within ranges between 2200 K and 6000 K), while also allowing this variation to be programmed via a compatible control system.

Fig. 4. Chromatic appearance of the variation in correlated color temperature (CCT), from approximately 6500K (left), 3000 K (center), and 2200 K (right), while keeping the luminous flux output of the fixtures relatively constant.



Source: Cleveland (2019), *The Science Behind Human Centric Lighting*.

Meanwhile, the term dimmable refers to those fixtures whose operation, through the use of suitable drivers or auxiliary equipment, allows for the continuous variation of both luminous flux and power output, typically within a range of 10% to 100% of their capacity.

A third fundamental aspect is the incorporation of a control system that allows variations in both color

temperature and the system's lighting level to be programmed over time. From a physical standpoint, this control system may require a dedicated panel, additional data cabling for each fixture, and/or the use of wireless protocols such as Bluetooth or Zigbee, along with control software compatible with all the previously described hardware.



Fig. 5. Extreme lighting scenes: top, a lighting simulation for a circadian activation phase in an office environment; bottom, the lighting programmed for a pre-rest phase or minimum circadian interference.

Simulator available at: <https://www.zumtobel.com/com-en/tunablewhite-office.html>

Additionally, the lighting design must provide both diffuse or indirect lighting as well as direct lighting. To achieve this, a combination of downlights can be used alongside fixtures with indirect emission (via reflection off diffusing surfaces), which can also be achieved through cove lighting and valance lighting. The characteristic of direct/indirect lighting can be diagrammed in the following figure, which shows the light emission of a typical fixture in a cross section.

Regarding the zones where this type of lighting should be implemented, the following priority levels are identified:

- + **Priority zones:** Those where the worker spends most of their time, or more than 2 to 4 continuous hours. A prime example of this is an observatory's control room.
- + **Secondary priority zones:** Those where the worker is present intermittently, such as circulation hallways, kitchens, and/or restrooms.

- + **Zones that do not require circadian or tunable white/dimmable lighting:** Those for occasional or specific use, such as server rooms and electrical rooms, among others.

Regarding recognized lighting manufacturers or brands with an international presence that offer this technology to design a circadian lighting system, these include:

- + *Bios Lighting (specialized)*
- + *Cooper Lighting (Signify)*
- + *Zumtobel Group*
- + *Acuity Brands*
- + *ERCO*
- + *iGuzzini*

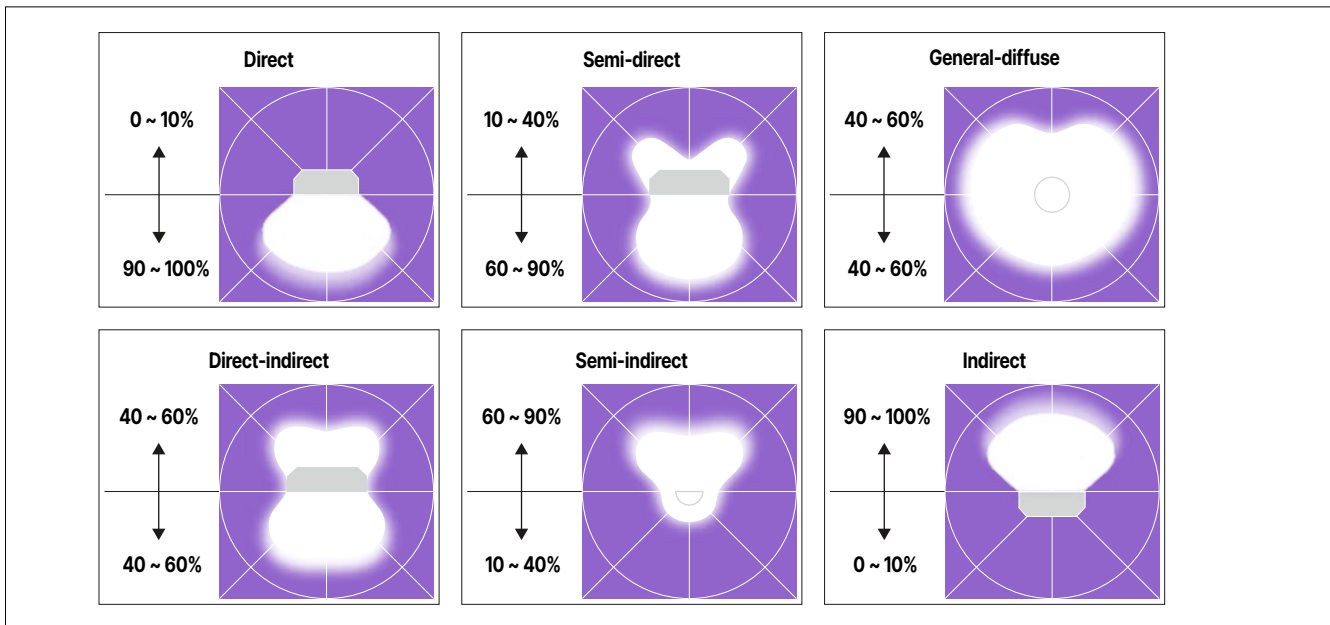


Fig. 6. Schematic representation of the spatial distribution of light emission from indoor fixtures. The diagrams represent the light distribution pattern on a vertical plane, illustrating how each fixture illuminates surfaces such as walls.

Source: Indalux (2022), *Manual de Luminotecnia*.

2.4 / Recommended Basic Programming (Occupancy and Semi-Occupancy Zones)

Considering the above, a tentative, basic programming for the behavior of the circadian lighting system can be implemented as follows. A plan based on three main phases is suggested:

A. Adaptation Phase (Shift Start):

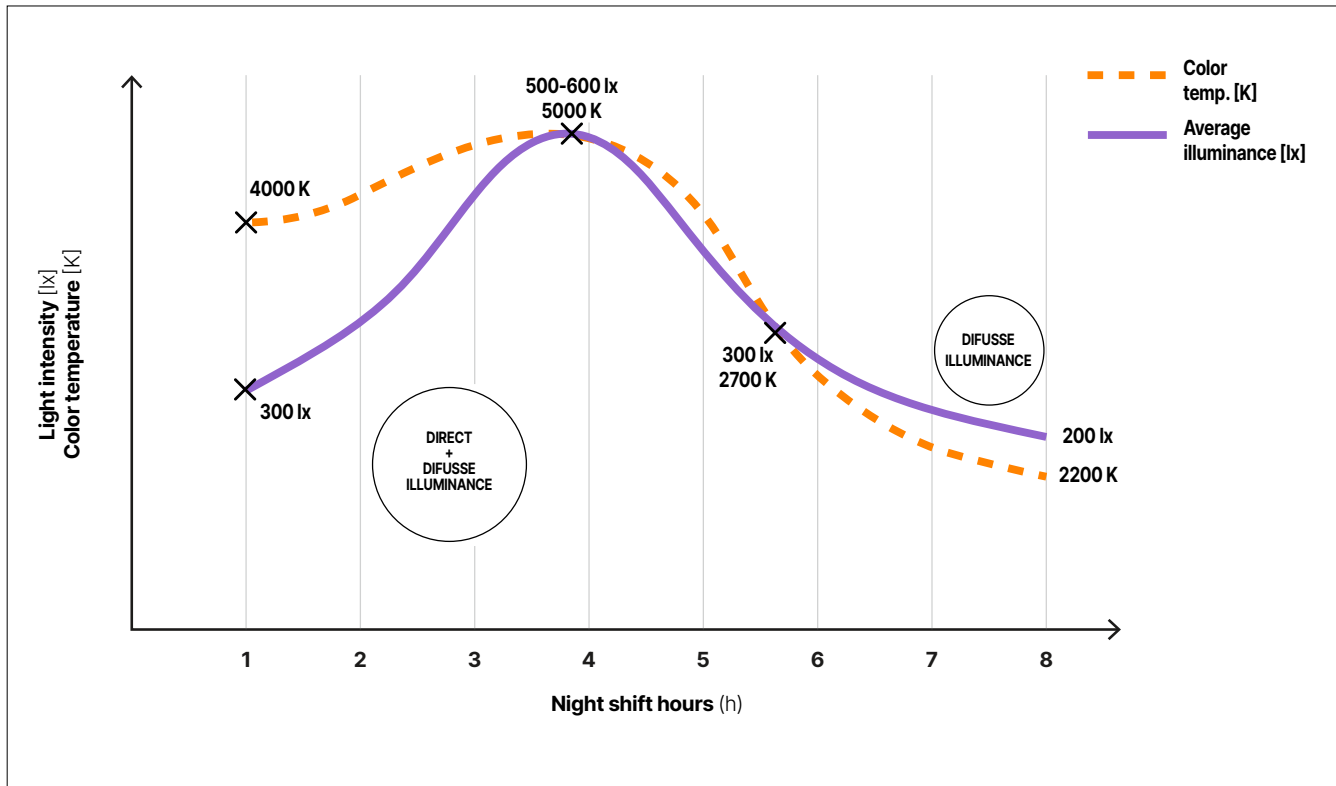
- + General color temperature: 4000 K (neutral white).
- + Workstation illuminance: 300–400 lux
- + Objective: To progressively interrupt melatonin production, temporarily and at a low intensity.
- + It is recommended to use a higher proportion of diffuse light and, to a lesser extent, direct light, in order to promote proper visual adaptation at the start of the work shift.
- + Workstation illuminance: 200–250 lux.
- + Objective: To reduce circadian stimulation and restart full melatonin production, promoting preparation for subsequent sleep.
- + In this stage, it is recommended to prioritize diffuse lighting and progressively reduce the direct component.

B. Active Phase (Mid-Shift Period):

- + General color temperature: 5000–6000 K (cool white).
- + Workstation illuminance: 500–600 lux.
- + Objective: To maximize alertness and vigilance, while reducing drowsiness.
- + In this phase, it is suggested to use direct and indirect light in similar proportions. At this point, the lighting system would operate at maximum capacity (power and luminous flux); therefore, the absence of glare must be verified, and reflections on screens must be controlled.

C. Final Phase of the Shift (Last 1–2 Hours):

- + General color temperature: 2700–2200 K (warm white).



Source: Author.

Fig. 7. Schematic summary of the variation in color temperature and average illuminance at workstations.

2.5 / Advantages of the Circadian Lighting System for Daytime and Evening Workers

Daytime and evening workers can also benefit from the circadian capabilities of the lighting system. To achieve this, it is possible to program similar lighting scenes, with specific adjustments tailored to their respective work schedules.

The general rule is that both light intensity and color temperature (spectral component) must follow the dynamics of natural light, especially the behavior of the sun. This involves utilizing higher intensity along with the maximum color temperature toward midday, and then progressively decreasing both intensity and color temperature toward sunset,

mimicking natural light. In this manner, circadian adaptation is reinforced, strengthening the natural dynamics of the circadian cycle for these workers.



0.3/ Outdoor Lighting

This aspect must be carefully designed and/or programmed to provide lighting only in areas where it is strictly necessary. Examples include building entrances, stairs, ramps, changes in floor level, and back sections of parking lots, among others.

In this context, the traditional criterion of lighting uniformity should not be adopted for transit paths—whether pedestrian or vehicular—or any other types of areas, because the nature of the site demands minimizing the volume of implemented light. Consequently, continuously illuminating the entirety of these surfaces is inappropriate.

Currently, Supreme Decree No. 01 (D.S. N°01, Chile's lighting pollution regulation, 2022) establishes that fixtures located in Special Protection Areas (Astronomical Communes) must comply with the following requirements:

- A. Full enclosure requirement:** Fixtures must exhibit zero upward hemispherical flux, emitting a maximum of 0.49 cd/klm at a gamma angle of 90°, and zero emission above said angle in any photometric C-plane, considering the fixture in its mounting position, generally at 0° relative to the horizontal. This guarantees an upward hemispherical flux (Upward Light Ratio—ULR) equal to zero.
- B. Spectral requirement:** Fixtures must emit less than 1% of flux in the blue band (380–499nm), less than 1% in the ultraviolet band (300–379 nm), and less than 10% in the infrared band (780–1000 nm). All of this is based on the total radiance content in the visible spectrum (380–780 nm).
- C. Certification requirement:** The aforementioned conditions must be verified through a

certification process, in which these parameters are evaluated, measured, and duly accredited.

However, the fixtures to be specified in an installation project for an optical observatory operating in the visible and infrared spectrum should, ideally, exceed these requirements, considering the nature of the site and the high sensitivity of the instruments to be deployed.

3.1 / Need for Ultra-Narrow Spectrum Fixtures

Currently, there are LED technologies specifically designed to further narrow the emission spectrum, aiming to minimize the environmental impact of outdoor lighting while simultaneously improving luminous efficiency by concentrating the emission within the range of the human eye's highest sensitivity.

One of the most relevant solutions in this context is amber LED fixtures of approximately 590 nanometers, which are particularly suitable for ecologically sensitive environments or areas near natural habitats. For example, the company Access Fixtures (USA) offers products in both "PC amber" and "590 Nanometer Amber" versions, thereby covering two distinct spectral categories.

PC amber typically corresponds to the light spectrum considered acceptable under D.S. N°01 in Chile, as it significantly reduces emissions in the blue-violet band (between 380 and 499 nm), keeping it below 1% relative to the total spectrum (between 380–780 nm).

"590 Nanometer Amber" features an even stricter spectral cutoff, limiting practically all emission in the blue and part of the green bands (up to

approximately 570 nm). This could contribute to a further reduction in light pollution by minimizing atmospheric scattering and the impact on biodiversity sensitive to these wavelengths.

This type of spectrum can be described as an intermediate state between the spectrum of a blue-free LED (with less than 1% emission between 380 and 499 nm), commonly referred to as “amber LED,” and the spectrum of low-pressure sodium—a practically monochromatic technology in the yelloworange range that is currently obsolete. This can be seen in Figure 8.

A. Main Benefits of the “590 Nanometer Amber” Technology:

- + **Wildlife-friendly:** The 590 nm wavelength is practically imperceptible to many nocturnal species (such as sea turtles, birds, and insects), which reduces disruption to them.
- + **Low light pollution:** These fixtures minimize glare and skyglow, favoring the conservation of the night sky.

- + **High energy efficiency:** They require lower energy consumption, offer a long lifespan, and contribute to the reduction of maintenance costs and carbon emissions.

B. Limitations

- + Due to their low color rendering index (CRI), these fixtures are not suitable for applications requiring precise color perception, such as indoor workspaces or inspection tasks.
- + Their application should be reserved for contexts where environmental protection and the mitigation of impact on wildlife are priorities.

More information: <https://www.accessfixtures.com/590-nm-led-lighting/>

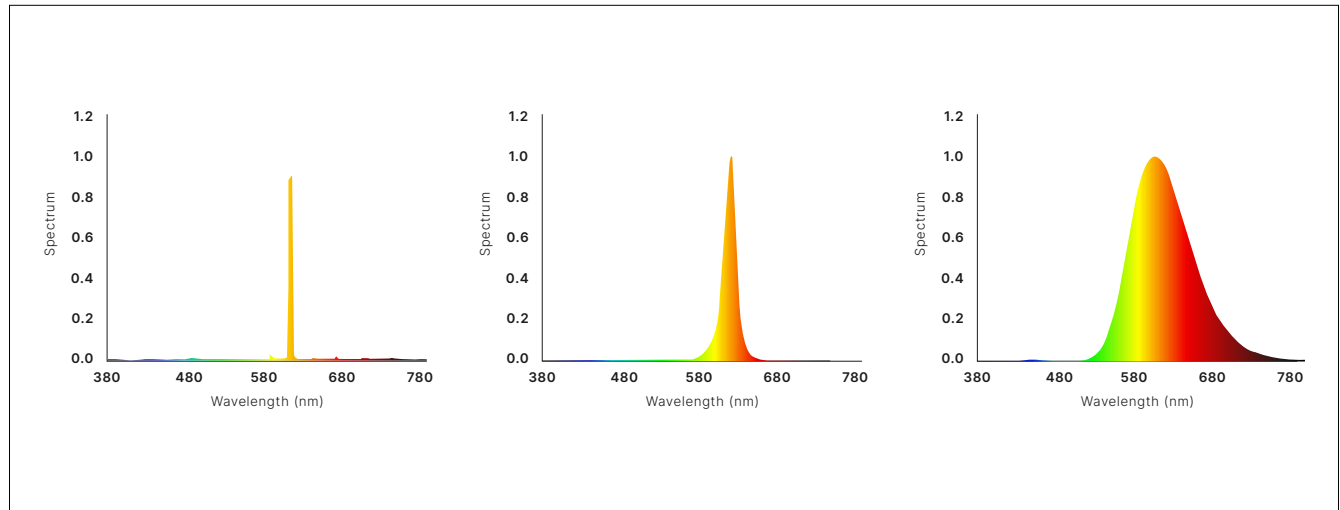


Fig. 8. Comparison between light spectra: low-pressure sodium (left); “590 Nanometer Amber” (center), and “PC Amber” (right). Source: Access Fixtures, 590nm Light: Amber LED Fixtures - FWC, PC Amber, and 2200K.

Source: Access Fixtures, *590nm Light: Amber LED Fixtures - FWC, PC Amber, and 2200K*.

Source: <https://www.accessfixtures.com/amber-led-fixtures-fwc-pc-amber-590nm-amber-and-2200k/>

3.2 / Need for Ultra-Shielded Fixtures

Regarding outdoor fixtures intended primarily for circulation purposes, it is necessary to exceed the full enclosure requirement established by D.S. No. 01. In other words, the probability of a direct line of sight to the light-emitting sources from any possible observation point associated with photosensitive instruments must be minimized to the greatest extent possible.

A. Practical Example: Cerro Tololo (AURA-NOIRLab)

Figure 9 shows a type of fixture implemented at the Cerro Tololo observatory facilities. This fixture is characterized by a monochromatic color within the red spectrum; however, its enclosure is far from being considered full, generating an upward hemispherical flux of approximately 30–40%.

The protective grille is an accessory intended to prevent the glass enclosure from breaking (mechanical protection) and marginally reduces the luminous flux output; however, it is not designed to contribute to shielding toward the upper hemisphere. It is worth noting that these fixtures are currently out of service.



Fig 9. Photographs of the existing fixtures at the Cerro Tololo (AURA-NOIRLab) facilities.

Credit: OPCC

B. Practical Example: Temporary Facilities of the Future Giant Magellan Telescope (GMT) Observatory)

The fixtures currently installed for circulation lighting consist of low-mounted LED wall sconces. From a spectral standpoint, they exhibit suitable characteristics for this type of site, as their emission is concentrated within the monochromatic red range (Figure 10).

However, regarding their degree of enclosure, they exhibit certain deficiencies. In particular, these sconces are not fully shielded because the light-emitting surface is slightly tilted at an angle greater than 0° relative to the horizontal. As a consequence, residual emission occurs toward the upper hemisphere, which is incompatible with the strictest light pollution control criteria required for astronomical facilities.



Fig 10. Photographs of the existing fixtures at the temporary facilities of the future GMT site.

Credit: OPCC

C. Practical Example: Differences Between Step-Light Recessed Fixtures Installed at the Giant Magellan Telescope (GMT) and Las Campanas Observatory (LCO).

Regarding wall-recessed fixtures for step and pedestrian circulation lighting, two different configurations currently exist in these types of facilities. Regardless of the spectral component of the light source used, the fundamental difference between a properly shielded fixture and one that is not lies in the design of its front enclosure and, particularly, in the arrangement of the optical control louvers or grilles.

The first configuration incorporates a front accessory with angled louvers, designed to limit light emission toward the upper hemisphere. Through this geometric arrangement, a direct line-of-sight to the light source is restricted from high angles, favoring compliance with strict light pollution control criteria.

The second configuration uses a front grille with parallel slats that do not provide effective shielding toward the upper hemisphere. This condition is wors-

ened when the fixture incorporates a diffusing glass enclosure (opal or translucent), as the light is distributed in multiple directions.

In the latter case, the combination of the mounting position and the optical configuration of the fixture can cause a significant fraction of the emitted luminous flux, estimated to be on the order of 50%, to be directed toward the upper hemisphere. The grille-type accessory primarily contributes to the mechanical protection of the glass enclosure and a slight reduction in the emitted flux, but it does not serve the function of redirecting light toward the lower hemisphere.

Figure 11 illustrates the differences between both configurations. From the standpoint of light pollution control and the specific requirements of astronomical facilities, fixtures that do not incorporate effective upper-shielding systems are considered unsuitable for these types of project.

Credit: OPCC.



Fig. 11. Photograph of two types of recessed fixtures for step or pathway lighting. The fixture on the left, due to the morphology of its front enclosure, is considered fully shielded. In contrast, the fixture on the right features a configuration that allows luminous flux emission toward the upper hemisphere, and therefore cannot be considered fully shielded.

D. Outdoor Fixtures with Varying Degrees of Enclosure

When specifying fixtures, alternatives must be considered whose degree of enclosure minimizes the probability of a direct line-of-sight to the light sources (for example, LED boards), by both instruments and individuals. This is achieved through the use of opaque optical elements around the perimeter of the light source, which also allows the fixtures to be installed at higher mounting heights without increasing the direct exposure of their light source.

As an example, the company Access Fixtures (USA) offers a product range called "FWC Sea Turtle Lighting," whose optical quality can be described as ultra-enclosed.



Fig. 12. For each typology (arranged in columns), three fixtures intended for different uses are presented (wall sconces in two sizes and ceiling fixtures), featuring different degrees of enclosure.

From the standpoint of their morphology, none of the fixtures in the left column comply with D.S. No. 01. The center column shows fixtures that can comply with said regulation, while the right column presents ultra-enclosed fixtures, which are suitable for this type of facilities, if the specification of other fixture suppliers is required, it may be feasible to consider the custom fabrication of accessories to maximize the enclosure of traditional-morphology fixtures (compliant with D.S. No. 01), such as those corresponding to the center column of Fig. 10.

E. Luminous Flux and Illuminance:

Regarding the volume of output luminous flux from the fixtures, it is necessary to adopt prudent criteria with the goal of minimizing the total amount of installed light. In this regard, a maximum value on the order of 1,000 lumens is appropriate for wall sconces or ceiling fixtures installed at standard heights (2.5–3 m).

For fixtures intended for stairways or installed at lower heights, it is recommended to reduce the luminous flux to values on the order of 500 lumens maximum, in order to avoid over-illumination and limit unnecessary light emission.

From the standpoint of illuminance levels, average values on the order of 0.25 to 5 lux are appropriate, with localized maximum values not exceeding approximately 15 lux.

3.3 / Beacon Lighting and Pilot Lights

These light sources serve signaling and safety functions. However, the vast majority of alternatives available on the market are designed to be visible at relatively large distances within illuminated indoor or outdoor contexts. Therefore, in an environment where a high degree of darkness is required, their luminous flux and deficient enclosure turn them into potentially polluting and disruptive sources.

For this reason, it is necessary to specify and develop louver-type accessories that limit the emission from these sources solely to the directions strictly necessary for their visibility.

A louver can be defined as an optical control element, generally consisting of opaque fins, slats, or cells, whose function is to limit, direct, and block light emission in specific directions, thereby reducing glare and preventing direct emission toward undesired angles—particularly toward the upper hemisphere or the observer's field of vision. From a structural standpoint, these elements can be manufactured from aluminum, steel, polymers, or other opaque materials, and arranged in linear, transverse, or honeycomb configurations, depending on the required photometric control.



Fig. 13. Example of a fixture with a louver for shielding toward the upper hemisphere.

Since commercial louvers are not available as independent accessories for this type of fixture, their ad-hoc fabrication is proposed using opaque materials, preferably metallic or equivalent, with a highreflectance interior finish to harness and redirect the blocked luminous flux toward useful directions.

Fig. 14. Top: Photograph of a beacon at the current GMT facilities. Bottom: Beacons currently installed at the Simons Observatory.

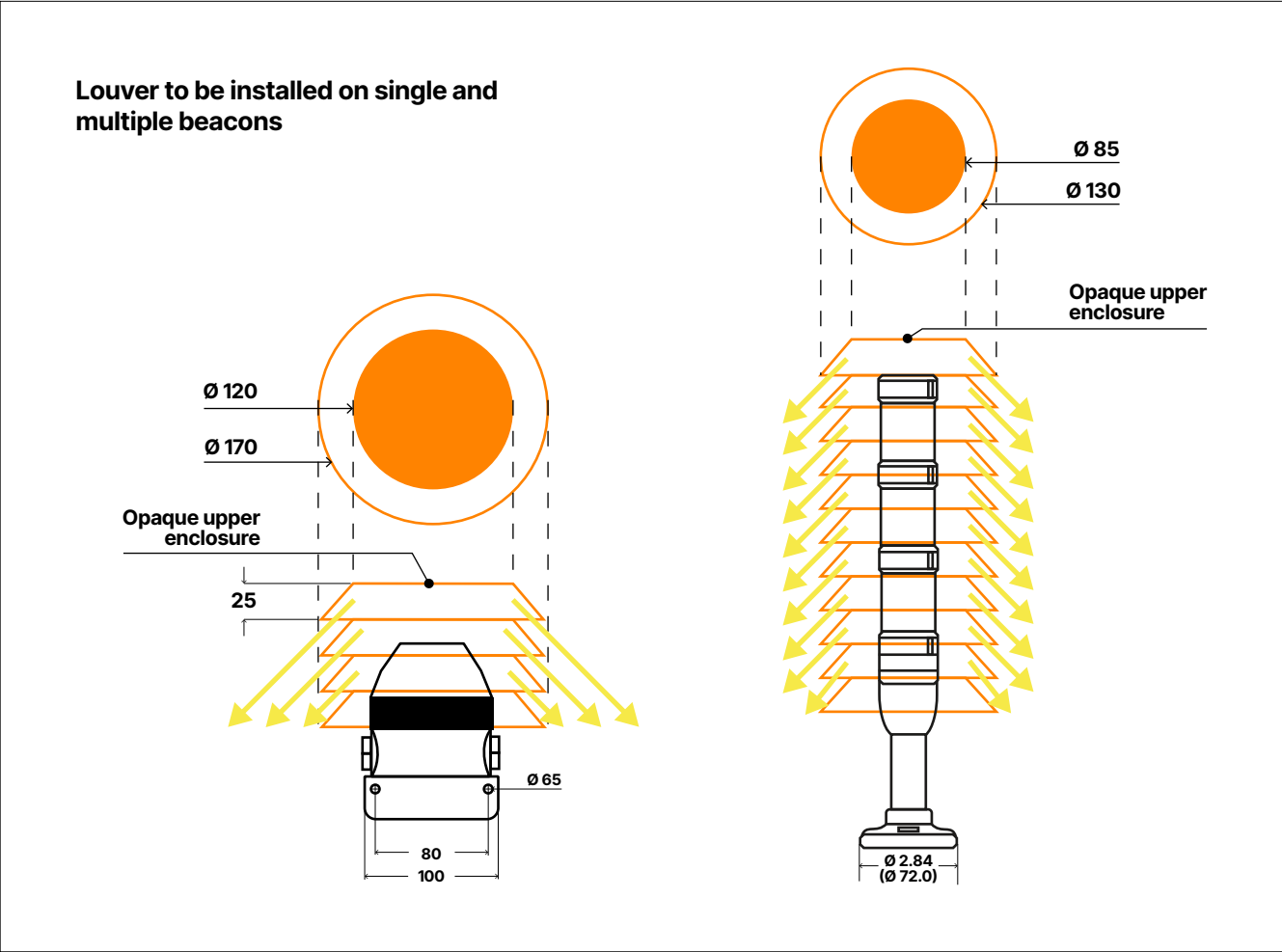


Credit: OPCC & FCC.

Regarding panel pilot lights, and considering that disabling them is not feasible due to signaling requirements, it is recommended to incorporate lateral and upper enclosures (mini-visor type) that block the direct line-of-sight to these sources outside their immediate field of use.

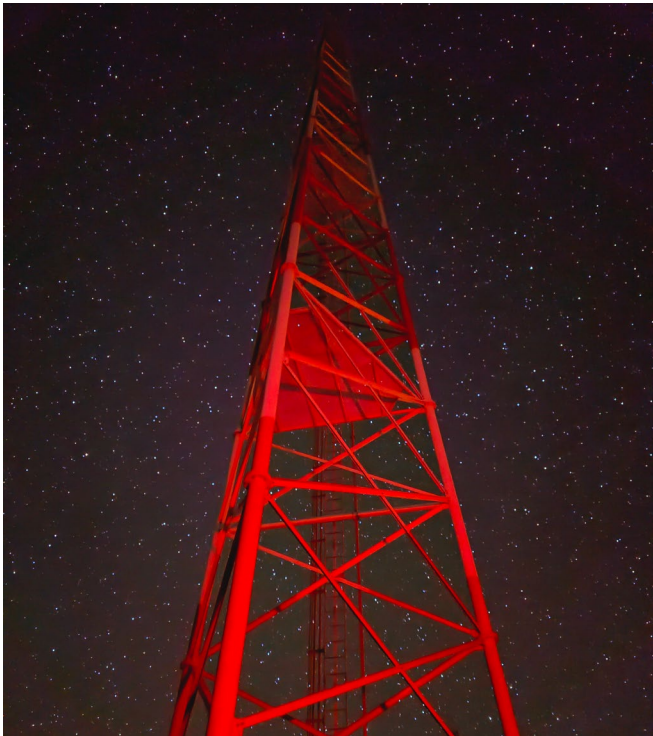
Additionally, the application of dimming filters or films that reduce their luminous intensity may be evaluated, provided that their operational function is not compromised.

Fig. 15. Schematic exploded view of the louver-type accessory required for a typical luminous beacon. The single beacon model NMS-HP LED (Auer Signal) and the multiple beacon model SL4-100-L-RYG-24LED (Eaton) are used as references



Source: Author.

Fig. 16. Top: Panel pilot lights at the Simons Observatory. Bottom: Effects of red pilot lights on a panel near an antenna at the future GMT site. Their luminous impact is visible in medium-exposure images. This sector is adjacent to where the OPCC conducts sky quality measurements.



0.4/ Discussion and Conclusions

Lighting design for astronomical observatories, both optical and infrared, cannot be approached using the conventional criteria applied to general outdoor lighting projects. The **extreme sensitivity of scientific instruments and the need to preserve night sky quality demand a specific design strategy**, where minimizing light pollution constitutes a priority objective.

In this context, **it is essential to restrict the spectral content in the blue and violet** bands to the greatest extent technically possible, prioritizing narrow-spectrum light sources with low atmospheric scattering. Furthermore, all outdoor fixtures should feature zero emission toward the upper hemisphere and provide shielding levels that exceed those required by regulations and recommendations, minimizing the probability of a direct line-of-sight to the light sources from any observation point or photosensitive instrument.

Similarly, installed luminous flux and illuminance levels must be kept significantly below those typically used in conventional outdoor lighting, illuminating only those areas where light is strictly necessary to guarantee the safety and operation of the facilities.

Finally, signaling elements such as luminous beacons, pilot lights, status indicators, and other similar devices require special consideration. This equipment is typically designed to operate in environments with relatively high ambient lighting levels and, therefore, exhibits luminous intensities incompatible with an environment of extreme darkness. Consequently, it is recommended to incorporate specific optical control solutions—such as louvers, visors, shielding, or dimming systems—that limit their visibility exclusively to the directions required for their operational function, **thereby reducing their contribution to the site's light pollution.**

Criteria for Lighting Design in Observatory Facilities

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June 2026