THE HIDDEN LAYER

White is an appearance, not a spectrum.

It is a spectral construction that happens to land on a white appearance.

READING RULE

Read where the energy is.

Warm, neutral, and cool describe how the source appears. The spectral power distribution shows how that appearance was actually constructed: where the source rises, where it falls away, and which wavelengths do most of the work.

WHAT THE EYE HIDES

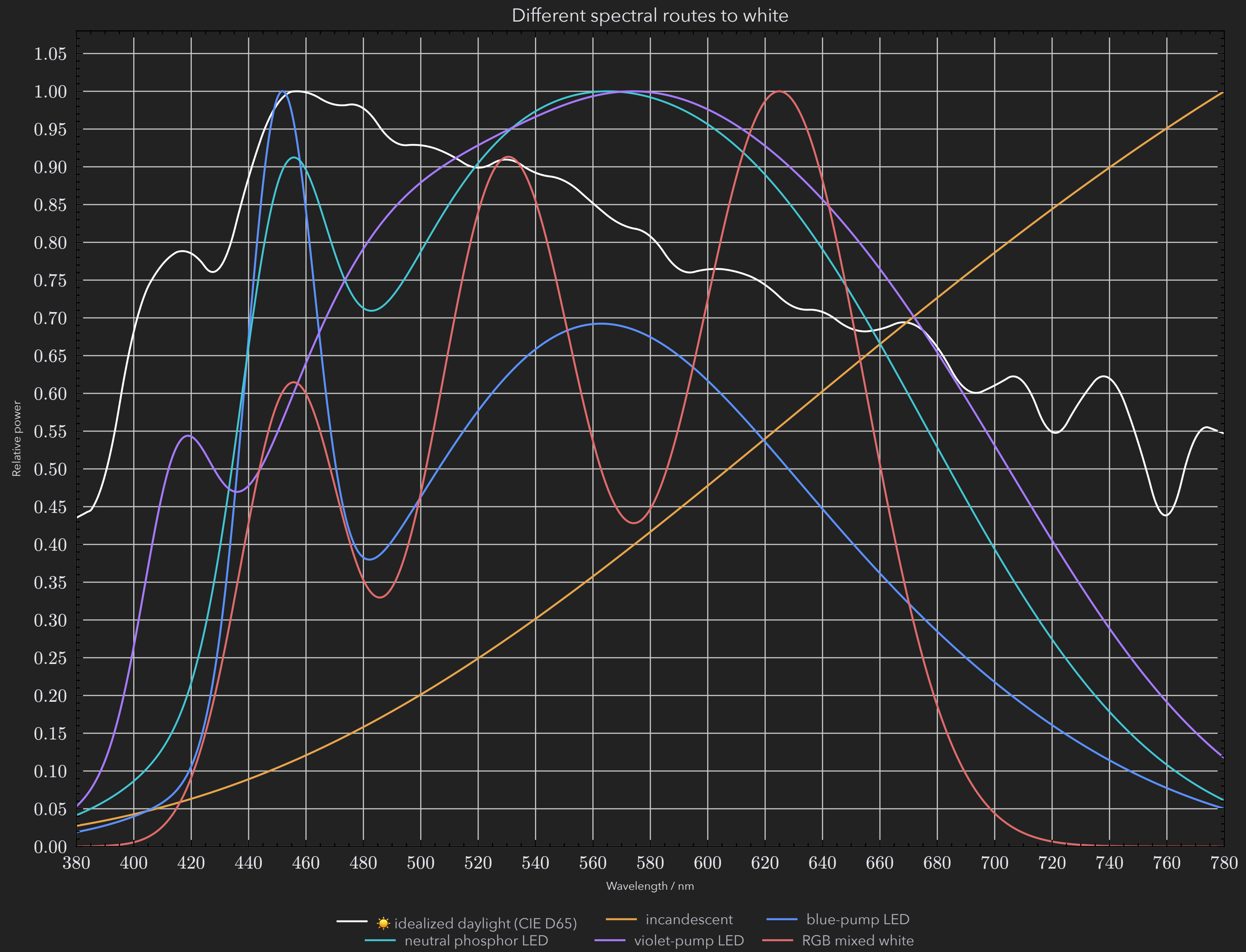
Chromaticity is a compression.

The visual system can collapse very different spectral distributions into a similar judgment of white. Matching appearance therefore does not imply matching spectral structure.

SOURCE VERSUS RESULT

“White” tells you where the source landed – not how it got there.

A glowing filament, a blue LED driving phosphor, a violet pump, or separate red, green, and blue emitters can all arrive at a white chromaticity by very different physical routes.



SAME CATEGORY

All six sources can occupy the broad visual category of white, despite radically different distributions underneath.

DIFFERENT PHYSICS

The peaks, slopes, gaps, and continua are fingerprints of the physical mechanism producing the light.

FIRST RULE

If the question concerns what the light physically contains, start with the spectrum. CCT is a useful visual summary; it is not a source description.

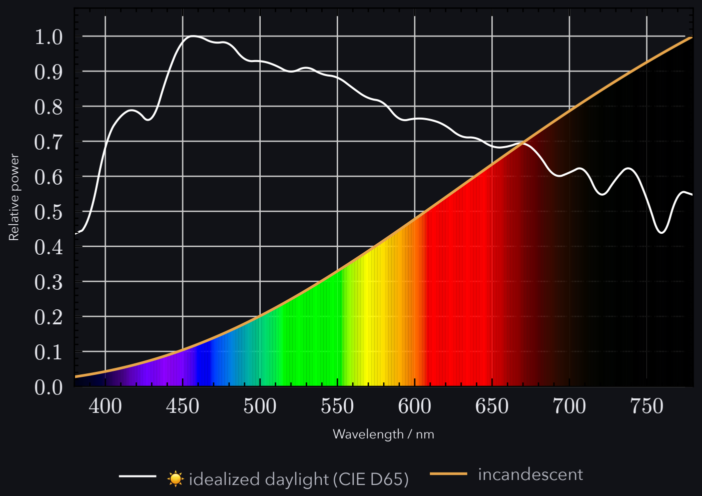
SOURCE ARCHITECTURE

How white light is made.

The spectrum reveals the physical process behind the appearance: thermal emission, phosphor conversion, or narrow-band mixing.

THERMAL SOURCE

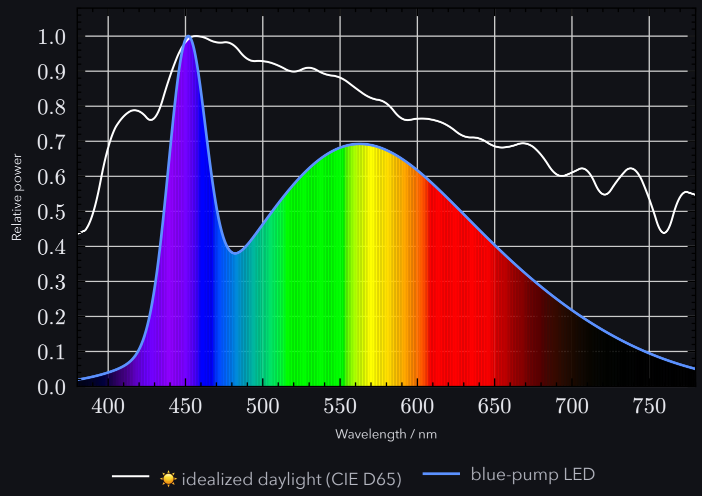
Continuous does not mean daylight-like.



Incandescent output forms a smooth thermal continuum, but the distribution is heavily weighted toward red and longer wavelengths.

PHOSPHOR SOURCE

White appearance can hide a pump spike.



The blue pump remains a distinct spectral feature even after the phosphor contribution broadens the source into visually white light.

THERMAL EMISSION

A continuum can still be strongly biased.

Incandescent light comes from a hot radiator. Its spectrum is smooth, but it climbs strongly toward longer wavelengths and continues beyond the visible range into infrared. Continuous does not mean daylight-like.

PHOSPHOR CONVERSION

A white lamp can retain the pump that created it.

In a blue-pump LED, a narrow blue emitter excites a much broader phosphor band. The resulting mixture can look ordinary and balanced while the pump remains plainly visible in the spectrum.

NARROW-BAND MIXING

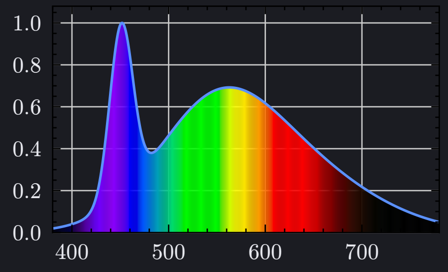
White does not require a continuous spectrum.

Red, green, and blue emitters can be mixed to a white chromaticity even though large portions of the visible range remain comparatively sparse.

THREE ENGINEERED ROUTES

BLUE PUMP

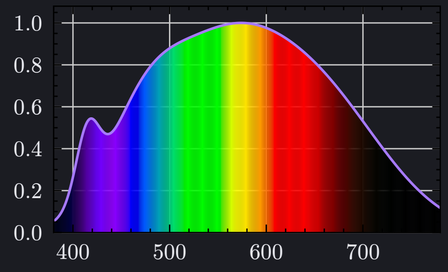
Phosphor white



A narrow blue emitter supplies the pump while a broad converted band fills the middle and long wavelengths.

VIOLET PUMP

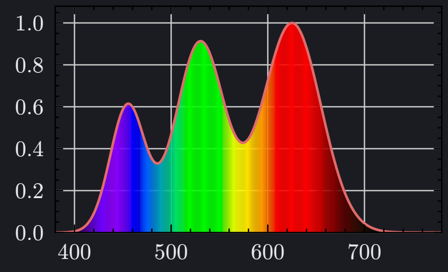
Broader conversion



Moving the pump toward violet allows the converted spectrum to distribute output more broadly across the visible range.

ADDITIVE MIXING

RGB white



Three narrow emitters can converge on white appearance without filling the wavelengths between their individual peaks.

These are not merely different colors of white. They are different source architectures that happen to produce a similar visual category.

USEFUL QUESTION

Do not stop at “what color is this light?” Ask what physical mechanism produced it, and what spectral structure that mechanism leaves behind.

CIRCADIAN LIGHTING

Spectrum is read by more than one system.

The retina does not send one report to the brain. It sends a visual report and a biological timing report.

THE HIDDEN READER

The same photons carry two meanings.

Beyond rods and cones, the retina contains intrinsically photosensitive retinal ganglion cells, or ipRGCs. These cells project through the retinohypothalamic tract to the suprachiasmatic nucleus, the brain's master circadian clock, and to pathways involved in pupil constriction, alertness, morning cortisol release, and melatonin suppression.

VISUAL SYSTEM

Photopic – V(λ)

Peaks near 555 nm. It is the basis for lux, footcandles, and luminous efficacy – the quantities that tell a lighting designer how bright the room appears.

NON-VISUAL SYSTEM

Melanopic – ipRGC

Peaks near 480–490 nm. It is produced by melanopsin in intrinsically photosensitive retinal ganglion cells and is quantified in melanopic EDI.

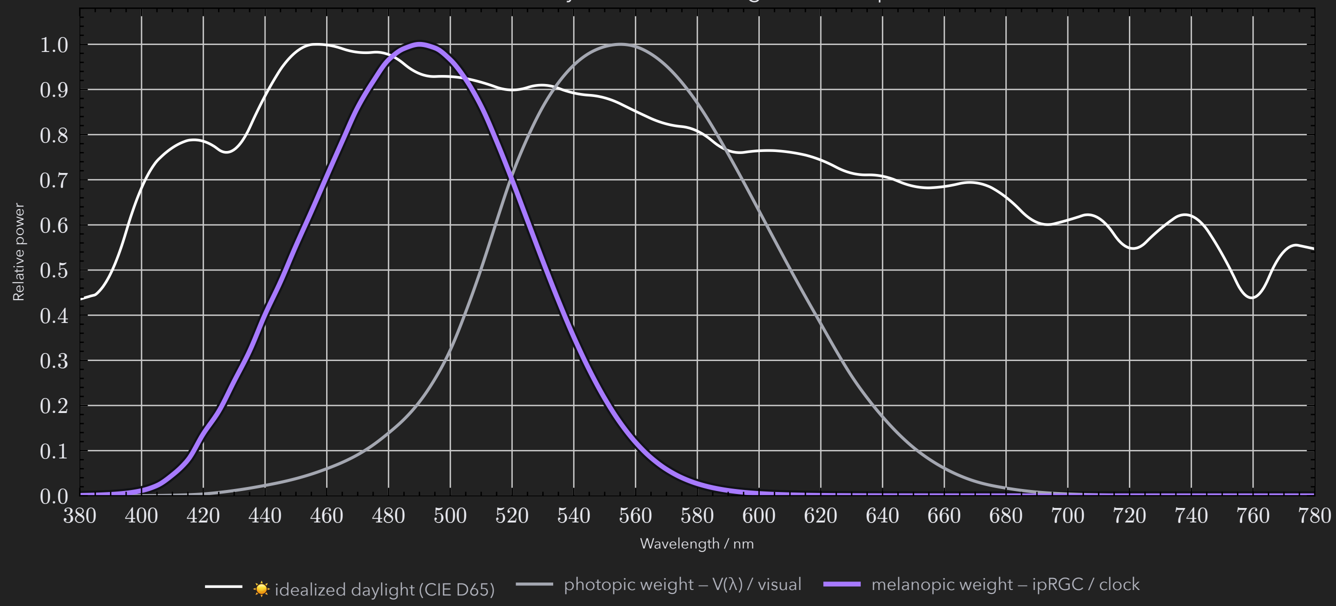
READING THE NUMBER

What the pill numbers on the right mean.

Each modeled source is evaluated by melanopic DER: its melanopic response is compared with its photopic response, then referenced to D65 daylight, which has a DER of 1.0. Higher DER means more melanopic stimulus for the same amount of visual light.

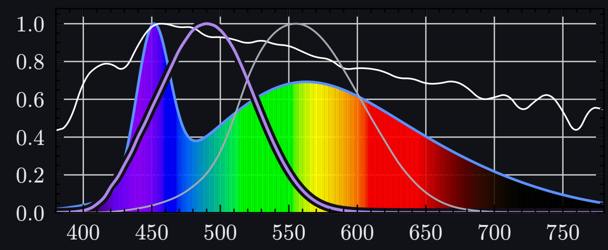
FIRST RULE

Brightness, warmth, CCT, and CRI describe the visual layer. They do not prove what the source does biologically. The circadian layer requires reading the spectrum itself.



SAME VISUAL TARGET

Cheap blue-pump LED

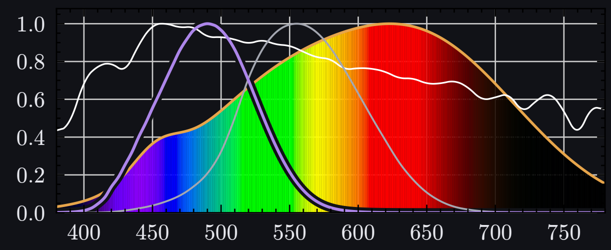


≈ 0.82 melanopic DER

Ordinary white light, but the pump peak sits inside the ipRGC window: a strong clock signal riding on an unremarkable-looking lamp.

SAME VISUAL TARGET

Warm phosphor LED



≈ 0.56 melanopic DER

Comparable brightness, warmer appearance, and a somewhat lower melanopic DER: a modest reduction in clock drive, not an escape from it.

Both lamps can look reasonably white and pass ordinary lux, CCT, and CRI checks – the two curves above are what actually distinguish them biologically.

IMPLEMENTATION TARGETS

Specify the light that reaches the eye.

Circadian lighting is not specified by CCT, fixture wattage, or horizontal lux alone. The practical design quantity is melanopic equivalent daylight illuminance at the observer's eye, evaluated in time as well as space.

THE DESIGN QUANTITY

Melanopic EDI is the scene target.

CIE S 026 expresses melanopsin-weighted exposure as melanopic equivalent daylight illuminance: the illuminance of standard D65 daylight that would produce the same melanopic stimulus. For implementation, this is the quantity to calculate or measure at the eye.

MEASUREMENT PLANE

Measure vertically, where the eye is looking.

Conventional horizontal workplane lux does not describe retinal exposure. Evaluate melanopic EDI on a vertical plane at representative eye position and facing the expected direction of gaze.

IMPORTANT DISTINCTION

DER tells you the engine. EDI tells you the delivered signal.

Melanopic DER describes the spectral efficiency of a source relative to D65 daylight. Melanopic EDI combines that spectral property with the actual photopic illuminance reaching the eye.

DAYTIME

≥ 250 lx

melanopic EDI at the eye

Target throughout the normal waking day for healthy day-active adults. Daylight is the preferred way to reach or exceed the target where practical.

EVENING

≤ 10 lx

during the 3 h before bedtime

Reduce retinal melanopic exposure substantially before sleep. This is a scene-level limit, so displays, windows, decorative light, and task lighting all contribute.

SLEEP

≤ 1 lx

through the sleep period

Darkness is the design condition during sleep. If nighttime visual activity is necessary, provide only the visibility required while keeping melanopic exposure very low.

HOW THE QUANTITIES FIT TOGETHER

spectral power distribution — what wavelengths the source emits → **melanopic DER** — melanopic efficiency relative to D65 → **melanopic EDI** — delivered melanopic exposure at the eye

PHOTOPIC ILLUMINANCE visual quantity	LX	Ordinary illuminance weighted by V(λ). It remains the conventional quantity for visibility, tasks, glare assessment, and ordinary lighting design.
MELANOPIC DER source property	RATIO	The melanopic daylight efficacy ratio. It indicates how much melanopic stimulus a spectrum produces per unit of photopic illuminance relative to D65. D65 has a DER of 1.
MELANOPIC EDI scene exposure	LX	The primary circadian implementation quantity: the D65-equivalent illuminance producing the same melanopic stimulus as the actual light reaching the observer's eye.

WORKING RELATIONSHIP

Melanopic EDI ≈ vertical photopic lux × melanopic DER.

For a source or scene whose spectrum is appropriately characterized:

PHOTOPIC		MELANOPIC DER		MELANOPIC EDI
500 lx	×	0.55	=	275 lx

The same spectral engine at only 20 vertical photopic lux produces approximately 11 lx melanopic EDI. Spectrum determines conversion efficiency; intensity determines how much signal is delivered.

COMMISSIONING

Verify the occupied eye position.

Do not sign off a circadian scene from fixture data alone. Measure or model the complete scene at representative eye locations and gaze directions, including daylight and reflected light.

CONTROL SEQUENCE

Targets belong to time states.

A fixture does not have one universally healthy setting. Commission daytime, evening, and nighttime scenes separately and verify melanopic EDI in each state.

IMPLEMENTATION RULE

Specify melanopic EDI at the eye by time of day: aim for at least 250 lx during the normal daytime, no more than 10 lx during the three hours before sleep, and no more than 1 lx during sleep. Use melanopic DER to understand the spectral engine, but commission the delivered scene using melanopic EDI alongside ordinary visual-lighting requirements.

FROM SPECTRUM TO BIOLOGICAL SIGNAL

DER connects photopic illuminance to melanopic exposure.

Once the spectrum's DER is known, the same relationship can answer two opposite design questions: how much light is required by day, and how much can remain in the evening.

ONE EQUATION, TWO QUESTIONS

The arithmetic stays the same. The unknown changes.

For daytime, start with a melanopic target and solve for the photopic illuminance required to reach it. For evening, start with a melanopic ceiling and solve for the photopic illuminance that can remain beneath it.

SAME 100 LX, DIFFERENT SPECTRUM

DER 1.0

100 lx ⟶ 100 lx melanopic EDI

A daylight-like ratio: melanopic EDI tracks photopic illuminance one-for-one.

DER 0.5

100 lx ⟶ 50 lx melanopic EDI

The same visual-light level carries half as much melanopic exposure.

DER 0.2

100 lx ⟶ 20 lx melanopic EDI

Much less melanopic exposure remains for the same photopic illuminance.

THE REVERSAL

The desirable direction depends on time.

Higher DER is useful when the goal is to build melanopic exposure efficiently. Lower DER is useful when the goal is to preserve visual light while constraining melanopic exposure.

THE WORKING RELATIONSHIP

FROM VISUAL LIGHT TO MELANOPIC EXPOSURE

photopic lx × melanopic DER melanopic EDI

Change the photopic level and the total exposure changes. Change DER and the melanopic content of each photopic lux changes.

SOLVE FOR THE UNKNOWN

BIOLOGICAL DAY

How much light is required?

Suppose the daytime target is 250 lx melanopic EDI.

250 ÷ DER = required photopic lx

At DER 1.0, the target requires 250 photopic lx.
At DER 0.5, it requires 500 photopic lx.
Higher DER therefore reaches the same melanopic target with less photopic illuminance.

BIOLOGICAL EVENING

How much light can remain?

Suppose melanopic EDI must stay at or below 10 lx.

10 ÷ DER = maximum photopic lx

At DER 1.0, only 10 photopic lx can remain.
At DER 0.5, 20 photopic lx can remain.
Lower DER therefore preserves more visual light beneath the same melanopic ceiling.

HIGHER DER ⟶ MORE EDI PER LX ⟷ LOWER DER ⟶ LESS EDI PER LX

THE TARGET CHANGES WITH TIME

NORMAL WAKING DAY

≥ 250 lx melanopic EDI

Establish a strong daytime signal.

⟶

3 H BEFORE BED

≤ 10 lx melanopic EDI

Reduce melanopic exposure while retaining useful light.

⟶

SLEEP PERIOD

≤ 1 lx melanopic EDI

Keep necessary nighttime exposure tightly constrained.

The equation does not reverse between day and evening. The design objective does: first use the spectrum to build melanopic exposure, then use it to limit that exposure without discarding more visual light than necessary.

DESIGN RULE Set the biological target first. Then choose illuminance and spectrum together to reach it.

SPECTRUM STRATEGY

The target is not one perfect spectrum.

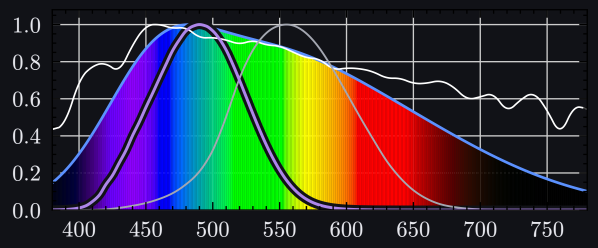
A circadian lighting system should change its spectral engine as the biological objective changes. Day calls for a strong melanopic signal; evening calls for withdrawal; biological night calls for protection.

THREE SPECTRAL STATES

BIOLOGICAL DAY

Broad white

build the daytime signal



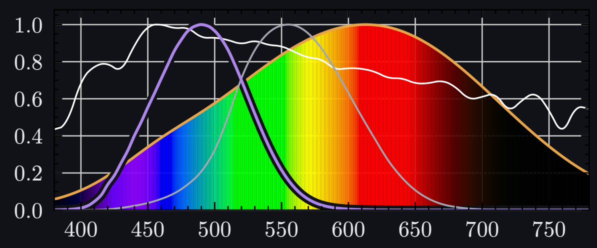
DER high Use melanopically efficient light when the clock needs a strong daytime anchor.

→

BIOLOGICAL EVENING

Reduced-blue white

taper the signal



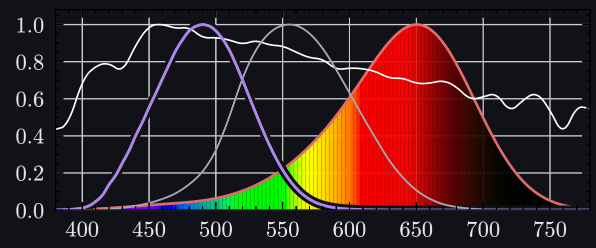
DER moderate Shift visual work toward longer wavelengths while reducing melanopic efficiency.

→

BIOLOGICAL NIGHT

Low-blue layer

protect biological darkness



DER low Keep both melanopic efficiency and total output tightly constrained.

The spectra above are illustrative control states rather than product specifications. Actual DER depends on the emitted spectral power distribution.

IMPORTANT DISTINCTION

Low DER is not the same as low exposure.

DER changes the conversion between visible light and melanopic signal. Illuminance still determines how much light is actually delivered.

20 lx ×	DER 1.0	20 lx EDI

High-DER light can still produce modest melanopic exposure when the illuminance is low.

50 lx ×	DER 0.2	10 lx EDI

Lower DER permits more visible light for the same melanopic budget, but it does not make high output biologically irrelevant.

THREE CONTROL LEVERS

SPECTRUM

DER

Which wavelengths are present, and how efficiently does the spectrum generate melanopic stimulus per unit of visual light?

INTENSITY

Photopic illuminance

How much visible light reaches the eye? DER only becomes exposure when it is multiplied by actual illuminance.

TIME

Schedule

When is the signal delivered? The same melanopic exposure can be appropriate during biological day and disruptive near sleep.

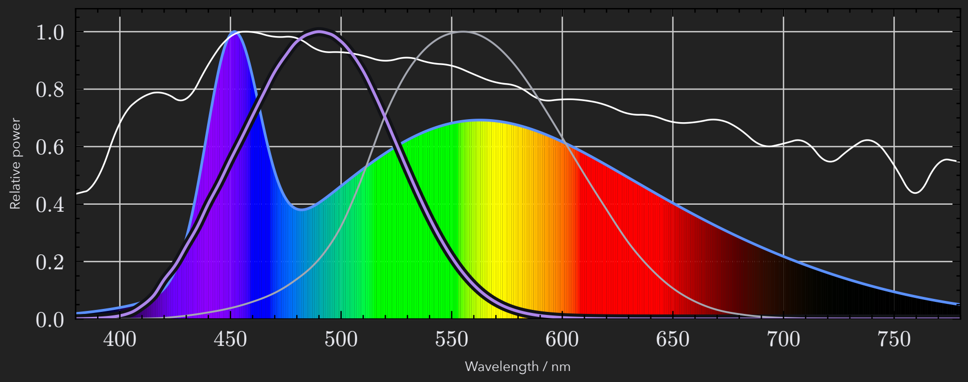
READING A LIGHT SOURCE

Read the spectrum, not just the label.

A lamp can look warm, score well on color rendering, and still deliver substantial melanopic stimulus. Read a source in sequence: spectrum, melanopic DER, illuminance at the eye, then time of use.

START WITH THE SPECTRUM

The shape contains information the package cannot.



Example: a conventional blue-pump white LED. The visible appearance collapses this spectrum into a single impression of "white," while the spectral plot exposes the short-wavelength pump and broad phosphor output.

1 SPECTRUM

What wavelengths are emitted?

Look for the spectral power distribution. Similar-looking whites can distribute their energy very differently across the visible range.

2 MELANOPIC DER

How efficient is the spectrum?

DER expresses melanopic response per unit of photopic illumination relative to D65 daylight, whose DER is 1.

3 ILLUMINANCE

How much reaches the eye?

Measure or model vertical photopic illuminance at the observer. Spectrum alone does not determine delivered exposure.

4 TIME

When is the signal delivered?

High melanopic exposure may support biological day while the same exposure near bedtime may oppose the intended transition to night.

WORKING SEQUENCE

Spectrum → DER → illuminance → EDI → time

DER converts the spectral question into a useful ratio. Photopic illuminance determines how much of that spectral engine reaches the eye. Their combination gives melanopic EDI; timing determines how that exposure should be interpreted.

FROM SOURCE TO EXPOSURE

Keep the quantities separate.

Each quantity answers a different question. Confusion starts when one is used as a substitute for another.

SPECTRUM
SPD
Which wavelengths does the source emit?

→

EFFICIENCY
DER
How strongly does that spectrum drive melanopic response per visual lux?

→

EXPOSURE
EDI
How much melanopic signal actually reaches the observer?

COMMON SHORTCUTS

Useful specifications, different questions.

These values matter. They simply do not replace spectral or melanopic measurements.

CCT	APPEARANCE	Describes chromaticity and the warm-cool appearance of white light. It does not uniquely determine the spectral power distribution.
CRI	COLOR	Describes aspects of color rendering. A high CRI value does not by itself establish high or low melanopic efficiency.
lumens	VISUAL OUTPUT	Describe photopically weighted luminous output, not the melanopic composition of that output.
wattage	ELECTRICAL INPUT	Describes power consumption. It says little about either spectral distribution or retinal exposure.

THE USEFUL QUESTION

What signal reaches the eye, and when?

Do not reduce a source to "warm," "cool," "healthy," or "circadian." Read its spectrum, use melanopic DER to understand its spectral efficiency, combine that with illuminance to determine melanopic EDI, and interpret the result within the biological schedule.

SOURCE COMPARISON

White light has different engines.

Common sources that all appear white do not feed the visual and melanopic readers the same way.

READING THE NUMBER

Melanopic efficiency relative to daylight.

Each modeled source is evaluated by melanopic DER: melanopic response per unit of photopic illumination, referenced to D65 daylight, which has a DER of 1.0. The values are illustrative because the source spectra are representative models rather than measured product spectra.

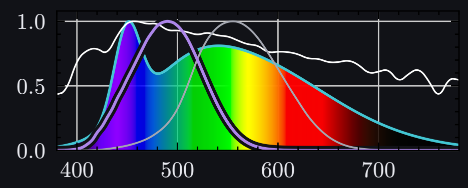
idealized daylight (CIE D65) — photopic weight (V(λ)) — melanopic weight (ipRGC)

DESIGN CONSEQUENCE

The same visual target can be reached by different spectral engines.

Future interior lighting should specify which engine is active in each scene: broad alerting white by day, warm reduced-blue white in the evening, and narrow long-wavelength light only when biological night must be protected.

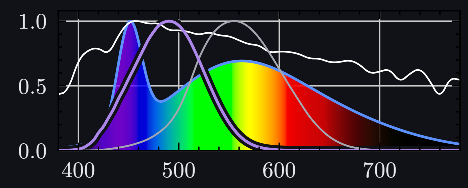
COOL DAYLIGHT LED



≈ 0.9 melanopic DER

high-CCT blue-pump white, strong cyan region

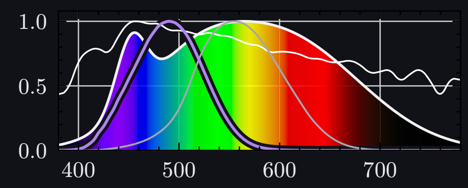
CHEAP BLUE-PUMP LED



≈ 0.82 melanopic DER

narrow blue spike at 450 nm + broad phosphor

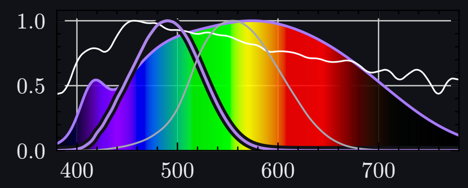
NEUTRAL PHOSPHOR LED



≈ 0.78 melanopic DER

common balanced white

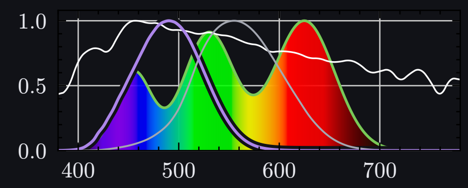
VIOLET-PUMP / FULL-SPECTRUM LED



≈ 0.76 melanopic DER

pump at 415 nm, engineered broad spectrum

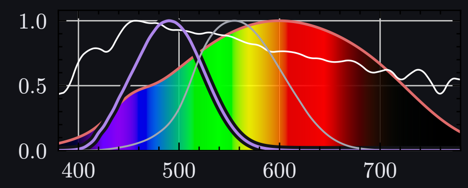
RGB MIXED WHITE



≈ 0.73 melanopic DER

three narrow emitters mixed to appear white

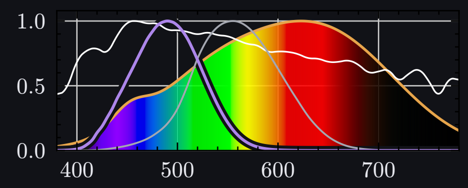
HIGH-CRI WARM LED



≈ 0.61 melanopic DER

warm phosphor blend with added red content

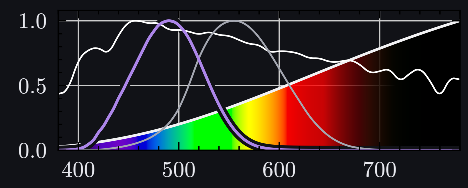
WARM PHOSPHOR LED



≈ 0.56 melanopic DER

shifted toward amber and red, pump reduced

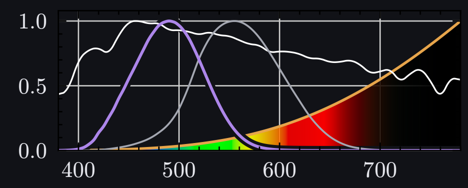
INCANDESCENT 2700 K



≈ 0.46 melanopic DER

continuous thermal spectrum, red-heavy

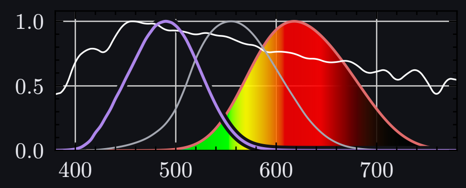
CANDLE / VERY WARM FLAME



≈ 0.25 melanopic DER

low-temperature thermal spectrum

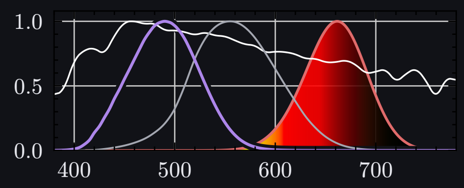
AMBER NIGHT SOURCE



≈ 0.08 melanopic DER

narrow amber/red task and path lighting

DEEP RED NIGHT SOURCE



≈ 0.01 melanopic DER

long-wavelength protection state

NIGHT LAYER

Night lighting should be designed as a separate operating layer.

Biological night places a different requirement on the lighting system. The objective is no longer general illumination, but enough light for safe movement and essential tasks with minimal melanopic exposure.

SOURCE-SIDE CONTROL

Control the spectrum before the light enters the room.

Dimming reduces exposure, but it does not fundamentally change the spectral proportions of an ordinary white source. A dedicated night source reduces both output and the short-wavelength content that contributes strongly to melanopic response.

THE BOUNDARY

Warm-white is useful in the evening – but it is still white light.

A 2200-2700 K phosphor LED can substantially improve an evening scene, yet still retain a short-wavelength pump. Biological-night lighting begins where spectral restraint becomes an explicit source requirement, rather than a consequence of warm appearance.

APPLICATION

Use the night layer where limited visibility is sufficient.

Typical locations include bedside lighting, bathrooms, corridors, stairs, nurseries, toe-kick lighting, closet edges, and low-level kitchen paths. These are local orientation and task functions rather than room-filling scenes.

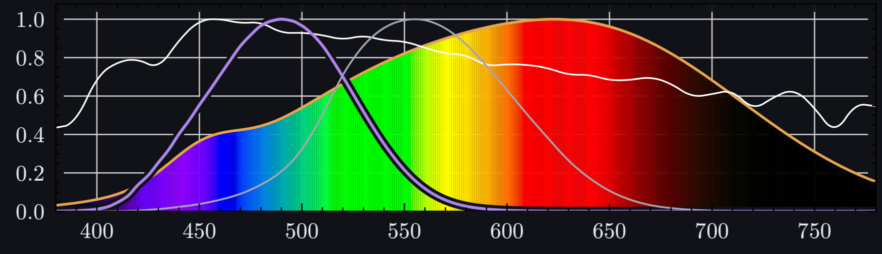
FROM EVENING WHITE TO BIOLOGICAL NIGHT

BOUNDARY CASE

Warm phosphor LED

Appropriate for evening transition, but not equivalent to a dedicated biological-night source.

≈ 0.56 melanopic DER



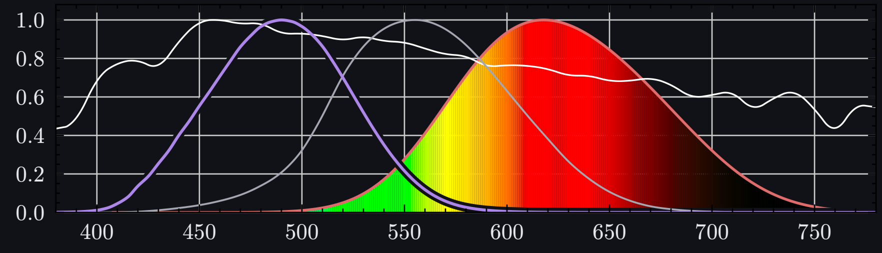
Warm phosphor LEDs move more visual work into longer wavelengths, which lowers melanopic efficiency somewhat compared with cool sources – but the reduction is modest, not a large drop. Warm-white is a better evening candidate than daylight LEDs, but it is still far from biological night protection.

NIGHT SOURCE

Amber night source

A dedicated long-wavelength source preserves basic visibility while sharply reducing melanopic efficiency.

≈ 0.08 melanopic DER



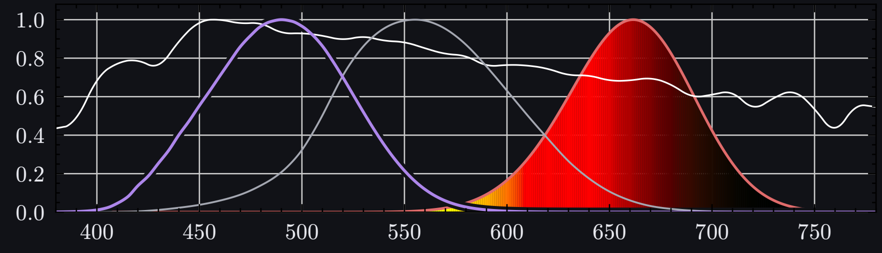
Amber night lighting is not merely warm-looking white. It deliberately avoids the blue-cyan channel and uses the long-wavelength region for orientation, pathfinding, and minimal tasks.

MAXIMUM RESTRAINT

Deep-red night source

An extreme low-melanopic state for situations where color rendering and general illumination are secondary to biological-night protection.

≈ 0.01 melanopic DER



Deep red is the extreme case: little useful color rendering, low general visibility, but extremely low melanopic efficiency. It belongs to night protection, not ordinary room lighting.

SAME REQUIREMENT, INCREASING SPECTRAL RESTRAINT

idealized daylight (CIE D65) — photopic weight (V(λ)) — melanopic weight (ipRGC)

The transition is not simply from brighter to dimmer light. The emitted spectrum itself moves away from the short-wavelength region receiving the strongest melanopic weighting. Warm-white remains a useful transition state; amber and deep-red sources establish a distinct biological-night layer.

TWO CONSTRAINTS

Low melanopic efficiency does not authorize high output.

Spectral control reduces melanopic stimulus per unit of photopic light. Total exposure still increases with illuminance. Biological-night lighting therefore requires both a constrained spectrum and a constrained light level.

DESIGN RULE

Treat the night layer as its own source class: low output, low melanopic efficiency, limited spatial distribution, and reserved for locations where illumination remains operationally necessary.

PRODUCT SPECIFICATION

Specify performance, not the color name on the box.

A night-lighting product should be selected by what it emits, where it places that light, and how it behaves in the control system. Marketing terms such as amber, warm, or sleep light are not sufficient.

SPECTRAL EVIDENCE

Ask for the emitted spectrum.

The useful evidence is the spectral power distribution and a melanopic metric derived from it. CCT alone cannot show whether a nominally warm product retains a substantial short-wavelength component.

USABLE OUTPUT

The fixture must work at genuinely low levels.

A suitable source should remain stable and controllable at the low outputs required for nighttime circulation. A low-DER lamp that cannot operate gracefully at low illuminance is still a poor night-layer product.

OPTICAL CONTROL

Place the light where the task occurs.

Distribution matters alongside spectrum. Shielding, low mounting, directional optics, and small illuminated areas can provide useful visibility without raising the ambient exposure of the entire room.

CONTROL BEHAVIOR

The night source should be independently addressable.

A nighttime action should recall the dedicated night layer rather than simply dim an ordinary white scene. Separate scene behavior allows the system to change source, output, and distribution together.

FOUR SPECIFICATION DIMENSIONS

01 SPECTRUM

Verify what the source emits.

Record the spectral power distribution, melanopic DER, and relevant photometric operating condition. Do not infer low melanopic performance from CCT or appearance alone.

02 OUTPUT

Verify the low end of the operating range.

Establish the minimum stable output and the actual illuminance delivered at the eye or task plane. Night performance depends on usable low output, not merely rated maximum output.

03 DISTRIBUTION

Constrain where the light goes.

Prefer low-level, shielded, and task-specific distribution. Orientation lighting should illuminate the path or working surface without unnecessarily increasing room-wide ambient exposure.

04 CONTROL

Make the night state explicit.

The source should participate in a dedicated nighttime scene, schedule, or control state so that an ordinary interaction does not restore a higher-output white-light condition.

SELECTION SEQUENCE

SOURCE

Choose the spectrum

Establish the spectral class appropriate to the nighttime task.

→

FIXTURE

Control the distribution

Put light only where visibility is required.

→

SYSTEM

Commission the scene

Set the low output and ensure the night layer is recalled reliably.

RECORD AT COMMISSIONING

SOURCE DATA

Keep the spectral record with the fixture schedule.

Record the product identity, spectral data used for selection, melanopic DER, nominal operating state, and any assumptions used to establish the night scene.

FIELD CONDITION

Verify the installed result, not only the catalog value.

Final performance also depends on output setting, mounting, distribution, surface reflection, and viewing geometry. Commission the installed scene at the level at which it will actually operate.

Product selection establishes the capability of the night layer; commissioning determines whether that capability survives in the actual space. A spectrally appropriate source can still be undermined by excessive output, poor distribution, or incorrect scene behavior.

SELECTION RULE A credible night product is not defined by one favorable number. Spectrum, minimum usable output, optical distribution, and control behavior must work together.

DAY STRUCTURE

Lighting should change as its biological role changes.

A circadian lighting system is not defined by one preferred spectrum. It is defined by how light changes across the day as visual and biological requirements change.

TWO CONTROL DIMENSIONS

Intensity and spectrum solve different problems.

Dimming changes the amount of light reaching the eye. Spectral control changes how that light is distributed by wavelength. Effective circadian lighting uses both rather than treating brightness as the only control variable.

DAY

Support the biological daytime signal.

During normal waking hours, lighting should provide adequate visual illumination together with a deliberate melanopic contribution. Short-wavelength energy is useful here rather than something to avoid.

EVENING

Reduce melanopic exposure before removing useful light.

As bedtime approaches, the objective changes. The system should retain enough illumination for ordinary activity while progressively reducing both overall exposure and melanopic efficiency.

NIGHT

Treat illumination as an exception.

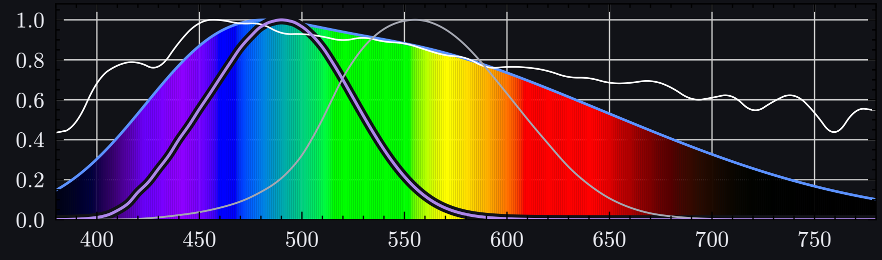
During the sleep period, general room lighting is no longer the design target. Necessary light should be limited to navigation, safety, and essential tasks, with both intensity and short-wavelength content kept low.

THREE OPERATING STATES

STATE 01

Active daytime

Provide useful visual illumination together with a strong daytime melanopic signal.



VISUAL TASK

Broad white light supports work, movement, color discrimination, and normal daytime visual tasks.

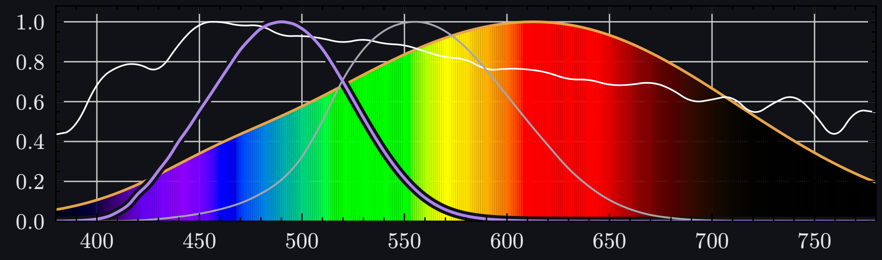
MELANOPIC TASK

Short- and middle-wavelength content remains substantial, producing melanopic exposure appropriate to the biological day.

STATE 02

Evening transition

Preserve visual utility while deliberately reducing melanopic exposure.



VISUAL TASK

Warm, comfortable illumination remains available for faces, circulation, social activity, and routine evening tasks.

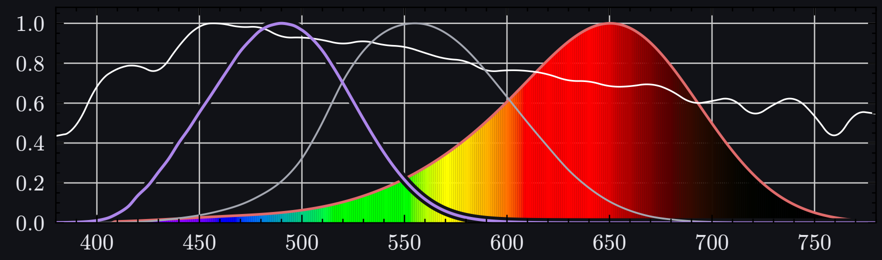
MELANOPIC TASK

Short-wavelength output is reduced so melanopic stimulus declines as the lighting environment approaches biological night.

STATE 03

Biological night

Minimize exposure when artificial light is still operationally required.



VISUAL TASK

Light is limited to navigation, orientation, safety, and essential low-demand tasks rather than general illumination.

MELANOPIC TASK

Blue-cyan content is strongly constrained so necessary visibility produces as little melanopic stimulus as practical.

FIXED REFERENCES, CHANGING SOURCE

DESIGN PRINCIPLE The transition from day to night is not simply a dimming curve. It is a change in both the required quantity of light and the spectral character of that light.

— idealized daylight (CIE D65) — photopic weight (V(λ)) — melanopic weight (ipRGC)

The reference curves remain unchanged across all three states. What changes is the source spectrum: broad daytime output gives way to progressively lower short-wavelength content as the lighting system moves toward biological night.

Dimming Is Not Just "Less Power"

DIMMING

The same visible level can come from different electrical signals.

For LEDs, "less light" does not identify the mechanism. One driver lowers current. Another keeps peak current high and shortens on-time. A hybrid driver may reduce current first, then switch to pulses at the bottom of the range.

READ LEFT TO RIGHT

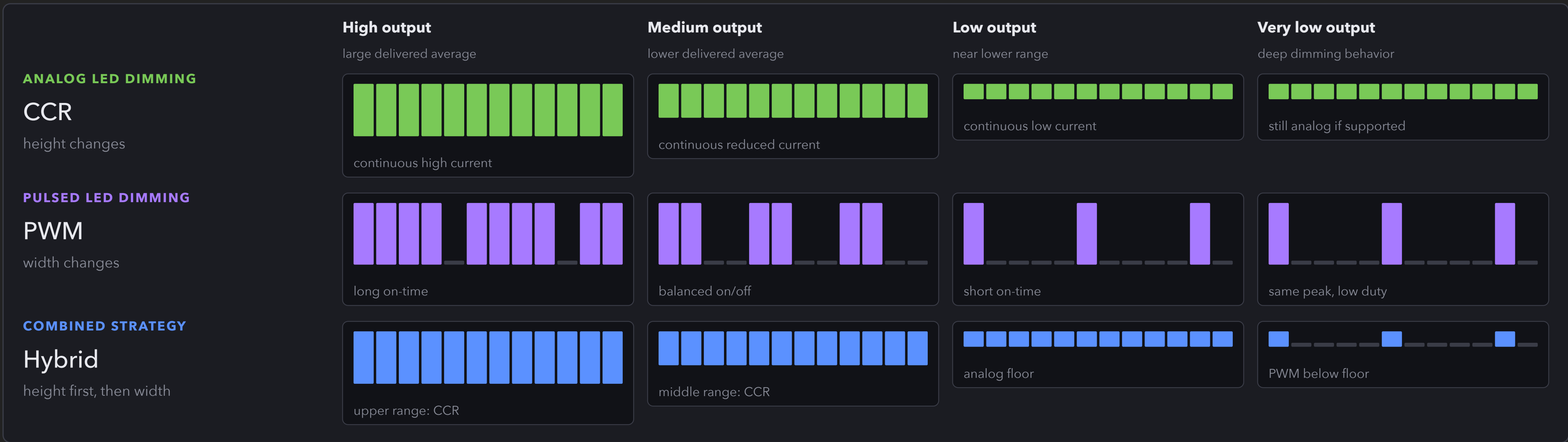
Each strip is current over time. Bar height is current. Muted bars are off-time.

CCR

Dimming changes height: same time profile, lower current level.

PWM

Dimming changes width: same peak current, shorter on-time.



CURRENT → LIGHT

Current is the control signal. Light is the result.

LED dimming begins electrically, but electrical current, optical output, heat, and time structure are not interchangeable quantities. The driver determines the current waveform; the LED package determines what that waveform becomes.

ELECTRICAL INPUT

Current does not become light one-to-one.

A driver controls current. The LED package converts part of that electrical input into photons and sheds the rest as heat. Higher drive current increases output, but the useful fraction does not stay fixed.

LOW DRIVE	photons	heat	efficient region
NOMINAL DRIVE	photons	heat	normal working point
HARD DRIVE	photons	heat	more heat penalty

DRIVE RESPONSE

More current gives more light, then more penalty.

The important curve bends. At ordinary currents, extra current mostly buys more output. Near the upper range, heat and efficiency droop take a larger share of the electrical input.

SOFT DRIVE

current
light
heat

Low current is often efficient, but absolute output is small.

RATED DRIVE

current
light
heat

The normal operating region balances output, efficacy, and lifetime.

OVERDRIVE

current
light
heat

Current keeps rising; useful light rises less cleanly than heat.

SAME AVERAGE

Equal visible average can hide unequal peak stress.

Two dimming methods can deliver a similar time-average output. The diode, camera, driver, and thermal stack still experience different instantaneous conditions.

CCR at 50%

lower continuous current

PEAK CURRENT

Lower peak; lower instantaneous stress.

TIME STRUCTURE

Continuous emission; no off-gaps in the signal.

PWM at 50%

full current half the time

PEAK CURRENT

Full peak remains; only duty cycle changes.

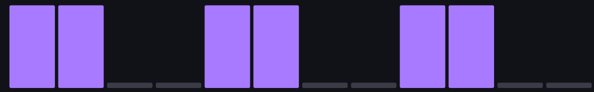
TIME STRUCTURE

Emission arrives in bursts; the average is visual.

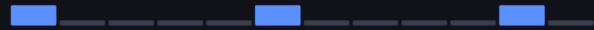
AREA RULE

For a simplified teaching model, delivered light follows the area under the current-time signal.

lower height × full time



full height × half time



low height × short time

SOURCE BEHAVIOR

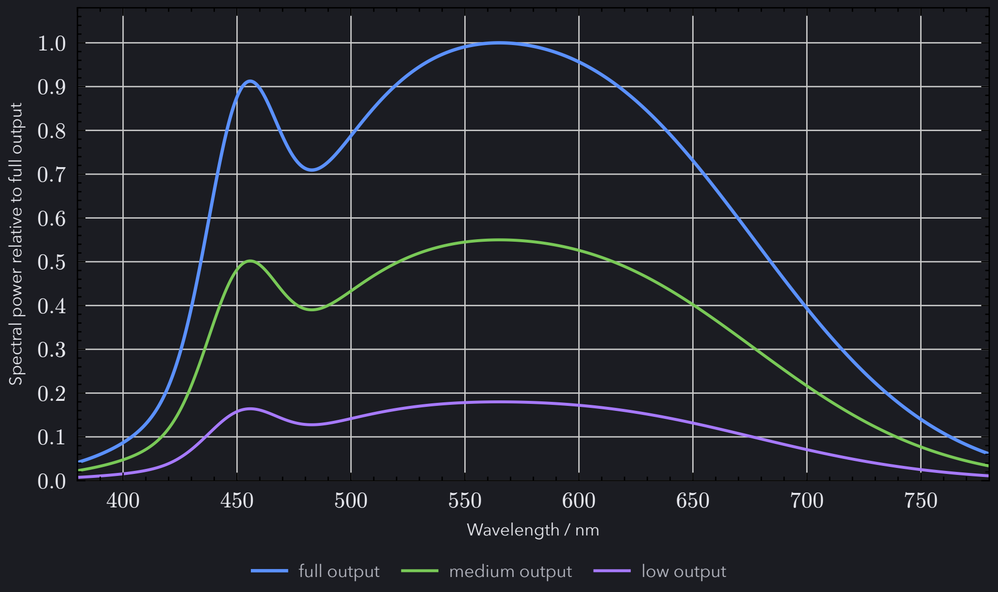
Dimming does not mean the same thing for every light source.

“Less light” sounds like a simple quantity change, but the source physics matter. A white LED usually keeps roughly the same spectral recipe and emits less of it. An incandescent lamp does not. As it dims, it also gets warmer and shifts its spectral balance toward longer wavelengths.

WHITE LED

Dimming mostly changes intensity.

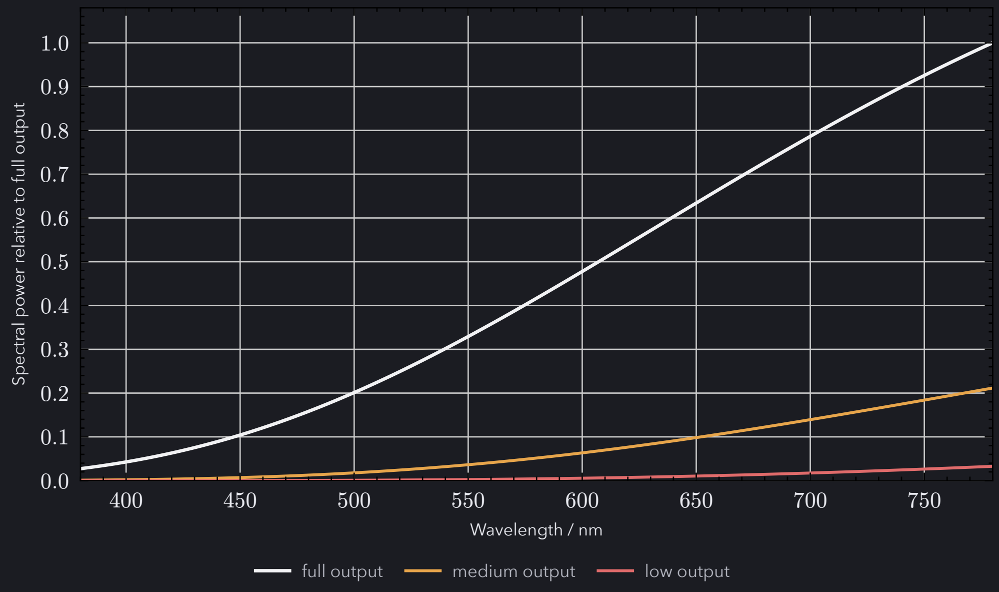
In an LED system—especially with PWM, and often in well-behaved CCR—the emitted spectrum is substantially the same shape. The output falls, but the spectral construction is broadly stable.



INCANDESCENT / RESISTIVE LAMP

Dimming changes intensity and color.

A thermal source dims by cooling. As temperature falls, short wavelengths collapse faster, the light appears warmer, and the spectral emphasis moves further toward longer wavelengths.



LED + PWM

Same instantaneous SPD; lower time-averaged output.

LED + CCR

Nearly same SPD shape; lower continuous output.

INCANDESCENT

Lower output and warmer spectrum because the filament cools.

LED TAKEAWAY

The main change is amplitude. The source is usually “the same light, less of it.”

INCANDESCENT TAKEAWAY

The change is not only amplitude. The source itself gets warmer as it dims.

AXIS MATTERS

The Y axis uses one shared full-output reference. Curves are not normalized independently.

VISUAL THESIS

LED dimming is mostly a quantity story. Incandescent dimming is a quantity-and-spectrum story. That is why “dimming” should not be treated as one universal behavior across source types.