

TECHNICAL WHITE PAPER

Industrial LED Selection Handbook

PLC / EV Charging / Instrumentation Application Guide

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Rev. v1.3 | September 2026 | www.hc-led168.com

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Revision: v1.3 | September 2026

Application notes and parameter recommendations in this handbook reflect industry common practice and our application engineering experience. Verify critical parameters through project-specific qualification testing.

EXECUTIVE SUMMARY

Industrial LEDs are not consumer LEDs with a wider temperature label slapped on them. The difference runs through every layer of the stack: die attach material, wire bond metallurgy, encapsulant chemistry, and leadframe plating. Over the years, we have seen too many designers grab a cheap 0805 LED from a distributor catalog, drop it into a PLC front panel or EV charging station display, and then wonder why 15% of the units are dead after two winters.

This handbook is written for the engineer who needs to make a selection decision on Monday morning and does not have time to become an LED PhD. We cover three application verticals that represent the bulk of our industrial business: programmable logic controllers (PLCs), electric vehicle (EV) charging infrastructure, and process instrumentation. For each, we explain the environmental stressors, the relevant industry standards, and the specific LED parameters that actually matter—versus the ones that just look good on a datasheet.

We will also be blunt about cost. Yes, an industrial-grade LED costs 2× to 4× more than a toy-grade part. But the alternative is a service truck rolling at 2 AM to replace a failed HMI in a paper mill, or a charging station going dark because the status LEDs faded below legibility. The math is not hard.

CHAPTER 1: THE INDUSTRIAL ENVIRONMENT — WHAT KILLS LEDS

1.1 Temperature Extremes and Thermal Cycling

Industrial equipment does not live in a living room. PLCs in foundries see ambient air at 55°C. EV chargers in Phoenix sit in black enclosures at 70°C internal temperature. Instrumentation in arctic pipelines must survive -40°C cold starts. The LED package has to handle all of this without cracking, delaminating, or losing brightness.

More damaging than steady-state heat is thermal cycling. A PLC in a steel mill might cycle from 20°C to 60°C twice per shift as furnaces turn on and off. Over five years, that is 3,000+ cycles. The CTE mismatch between the PCB (FR-4: ~14 ppm/°C), solder (SAC305: ~21 ppm/°C), LED leadframe (copper: 17 ppm/°C), and die (GaN: ~5.6 ppm/°C) creates shear stress at every interface. Eventually something gives—usually the wire bond heel or the solder joint.

Design rule: Specify LEDs qualified to at least 1,000 cycles of -40°C to +125°C per JEDEC JESD22-A104. If your application sees frequent thermal cycling (more than once per day), demand 1,500+ cycles or consider moving to heavier-gauge gold wire bonds (20-25µm) and enhanced leadframe designs.

1.2 Humidity and Condensation

Outdoor EV chargers and coastal instrumentation face 100% RH regularly. Worse, they face condensation—liquid water forming on the PCB when the enclosure cools at night. Water plus bias equals electrolysis, which drives ionic migration, corrosion, and dendritic growth.

Standard consumer LEDs are tested at 85°C/85%RH for 168 hours and call it done. That is not enough for industrial. We recommend demanding 1,000 hours of 85°C/85%RH bias testing (JEDEC JESD22-A101) as a baseline, and 96 hours HAST (130°C/85%RH, JESD22-A110) as an accelerated screen. If the LED cannot survive HAST, it will not survive five years in a Florida parking garage.

1.3 Vibration and Mechanical Shock

PLCs mounted on stamping presses. Instrumentation on compressor skids. EV chargers in parking lots where trucks back into them. The LED must survive vibration per IEC 60068-2-6 (sinusoidal, 10-500 Hz, 5G) and shock per IEC 60068-2-27 (50G, 11 ms half-sine). Through-hole LEDs with long leads are particularly vulnerable to fatigue; SMD packages with short leads and low center of gravity perform better.

1.4 Chemical Exposure

We covered sulfuration in detail in [White Paper 1: LED Indicator Failure Analysis](#), but industrial LEDs also face salt fog (coastal and road-salt environments), oils, cutting fluids, and cleaning solvents. Salt fog testing per ASTM B117 (5% NaCl, 35°C, 96 hours) is a good screen for coastal EV chargers. For oil exposure, we have seen standard epoxy encapsulants swell and soften when soaked in hydraulic fluid at 60°C for 500 hours. Silicone and PCT-based packages resist this far better.

CHAPTER 2: PLC APPLICATIONS — RELIABILITY OVER BRIGHTNESS

2.1 The Real Requirements

PLC status indicators have a simple job: tell a maintenance tech whether the relay is on. They do not need 1,000 mcd. They do need to survive for 10+ years in a cabinet that might be 55°C and full of ozone from motor drives.

The most common mistake we see is over-specifying brightness and under-specifying reliability. A 200 mcd red LED is plenty visible in a dim cabinet. A 1,000 mcd LED running at 20 mA just generates more heat and dies faster. Our recommendation: size for 100-300 mcd at 10 mA, which gives you a 2× derating margin on current and keeps junction

temperature low.

2.2 Color Coding and Wavelength Stability

Industrial HMIs rely on color coding: red = fault, green = run, yellow = warn. If the red LED drifts toward orange because of phosphor degradation, or the green LED shifts toward cyan because of die wavelength shift, operators get confused. This is a safety issue, not just an aesthetic one.

Specify tight binning: ± 2 nm for monochromatic LEDs (red, green, yellow), and 3-step MacAdam ellipse for white. Demand that the supplier guarantees bin stability over temperature—some cheap LEDs shift 5 nm when the junction warms from 25°C to 85°C. That is enough to turn a "stop" red into a "caution" orange.

2.3 Electrical Isolation and EMI

PLCs live next to VFDs and contactors that generate serious EMI. The LED leads can act as antennas, picking up noise and causing false indications or flicker. Keep LED traces short, use twisted pairs if running off-PCB, and place a 100 nF ceramic capacitor across the LED terminals at the PCB. If the LED cable runs more than 30 cm, shield it.

For 24V PLC logic, do not drive the LED directly from the logic rail without a series resistor. A 24V LED module with built-in current limiting is better—it protects against transient overvoltage when inductive loads switch nearby.

2.4 Recommended PLC LED Specification

Parameter	Minimum Spec	Preferred Spec	Notes
Package	3mm round or 0805 SMD	3mm round with stand-off	Stand-off aids cleaning and reduces solder stress
Luminous intensity	100 mcd @ 10 mA	200 mcd @ 10 mA	Do not over-drive for brightness
Viewing angle	60°	30° (narrow)	Narrow angle improves visibility in bright cabinets
Operating temp	-25°C to +85°C	-40°C to +105°C	Upper end matters more than lower
ESD HBM	2,000V	4,000V	Essential for hand-assembly repair
Encapsulant	Silicone	Silicone	Epoxy will yellow before the PLC is obsolete
Leadframe	PPA or EMC	PPA or EMC	Avoid Ag plating in industrial atmospheres
TCT qualification	500 cycles	1,000 cycles	-40°C / +125°C
HAST	96 hours	168 hours	130°C / 85%RH

CHAPTER 3: EV CHARGING STATIONS — OUTDOOR TORTURE

3.1 The Thermal Problem

EV chargers are essentially ovens with electronics inside. The power modules dump heat into the enclosure, and solar loading on a black steel cabinet in summer can push internal air to 70°C. The LED display and status indicators sit in this air, often with minimal airflow.

Worse, the LEDs are on 24/7. A "charging" indicator that runs continuously for 8 hours while a vehicle charges accumulates serious thermal stress. If the LED junction reaches 120°C, lumen depreciation accelerates by an order of magnitude compared to 80°C.

Thermal design rules:

- Use high-brightness LEDs driven at low current (5–10 mA) rather than standard LEDs at 20 mA. You get the same perceived brightness with half the heat.
- If using white LEDs for a backlit logo or display, keep junction temperature below 85°C at all times. This usually means adding thermal vias under the LED and possibly a small aluminum heatsink on the PCB backside.
- For 7-segment displays, choose ones with low current per segment (2 mA) and multiplex them rather than running DC. Multiplexing at 100 Hz with 1:4 duty cycle reduces average power by 75% with no visible flicker.

3.2 UV Resistance

Outdoor LEDs face direct sunlight. UV-B (280–315 nm) and UV-A (315–400 nm) photons have enough energy to break chemical bonds in standard epoxy encapsulants, accelerating yellowing and surface crazing. Silicone encapsulants with UV stabilizers (hindered amine light stabilizers, or HALS) perform far better. We have also seen good results with adding a separate UV-filtering polycarbonate lens in front of the LED, though this adds cost and optical loss.

3.3 Ingress Protection (IP Rating)

EV chargers need at least IP54 (dust protected, water splashing) and often IP65 (dust tight, water jets). The LED itself is not the sealing problem—the problem is the interface between the LED lens and the front panel. Gasket design matters enormously.

We recommend using panel-mount LED holders with integrated silicone gaskets (e.g., VCC CNX series or equivalent) rather than relying on the LED leads to seal against a hole. The holder provides mechanical retention, seals the panel cutout, and allows the LED to be replaced without disassembling the charger.

3.4 Surge Immunity

EV chargers are connected to the grid, and grid transients are brutal. A lightning strike two miles away can induce 2 kV transients on the AC line, which couple through the power supply to the 12V or 5V LED rail. Entire banks of status LEDs have been destroyed by a single surge event when designers assumed the switch-mode power supply would absorb

everything.

Protection strategy:

- Use a TVS diode (e.g., SMAJ15A) on the LED supply rail, as close to the connector as possible.
- Add a 100Ω series resistor to each LED string. This limits surge current and costs almost nothing.
- If the LED indicators are on a separate PCB from the main controller, use an optocoupler to drive them. This provides galvanic isolation and prevents ground loops.

CHAPTER 4: PROCESS INSTRUMENTATION — PRECISION AND LONGEVITY

4.1 The Calibration Problem

Process instruments—flow meters, pressure transmitters, analytical probes—often have a 15–20 year service life. The LED indicators on these devices must remain legible for the entire life because recalibration and status indication are part of the safety case. You cannot have a "fault" LED that is too dim to see during a midnight turnaround.

This means lumen maintenance is not a "nice to have"; it is a specification. We recommend requiring LM-80 test data and using TM-21 to project L70 (time to 70% lumen maintenance). For an instrument with 20-year life, you need an LED that projects to L70 > 50,000 hours at your operating temperature. Only a handful of silicone-encapsulated, high-grade die products meet this.

4.2 Explosion-Proof and Intrinsically Safe Environments

In oil & gas and chemical plants, LEDs may be used in explosion-proof (Ex d) or intrinsically safe (Ex i) circuits. Ex i circuits limit energy to <1.2W and <30V, which is easy for an LED. But the LED must not become an ignition source if the encapsulant fails and exposes hot die or wire bonds.

Specify LEDs with encapsulants that meet UL 94 V-0 flammability rating. In truly harsh chemical environments, consider hermetically sealed LEDs with glass lenses and metal cans. They cost \$2–\$5 each versus \$0.20 for a standard indicator, but they are the only option when the atmosphere contains hydrogen sulfide, benzene, or other flammable gases.

4.3 Low-Light-Level Reliability

Some analytical instruments use LEDs as light sources (photometers, turbidity sensors) rather than just indicators. Here, intensity stability directly affects measurement accuracy. A 5% drift in LED output creates a 5% error in the analytical result.

For these applications, we recommend:

- Driving the LED with a precision constant-current source, not a simple resistor.

- Using a feedback photodiode to monitor LED output in real time and compensate for aging.
- Selecting LEDs with <1% lumen degradation per 1,000 hours (measured at operating temperature).
- Avoiding white LEDs; monochromatic LEDs (typically 660 nm red or 880 nm IR) have far better long-term stability because there is no phosphor to degrade.

CHAPTER 5: STANDARDS COMPLIANCE CHECKLIST

Standard	Scope	What to Verify
IEC 62717	LED modules for general lighting	Not directly for indicators, but good baseline for lumen maintenance claims
IEC 60068-2-6	Vibration (sinusoidal)	LED and assembly must survive 10–500 Hz, 5G, 2 hours/axis
IEC 60068-2-27	Mechanical shock	50G, 11 ms, half-sine, 3 shocks/direction
IEC 60068-2-78	Damp heat, steady state	40°C / 93%RH, 56 days minimum for outdoor
IEC 61000-4-5	Surge immunity	±1 kV line-line, ±2 kV line-earth on power ports
IEC 61000-4-2	ESD immunity	±8 kV contact, ±15 kV air discharge on enclosure
UL 94	Flammability	V-0 rating for encapsulant in enclosed spaces
AEC-Q102	Automotive	Use for industrial if you want overkill; covers everything above plus more

CHAPTER 6: SUPPLIER QUALIFICATION — WHAT TO ASK

When qualifying an LED supplier for industrial use, go beyond the datasheet. Here is what our application engineering team recommends checking:

1. Die Traceability Can the supplier tell you which epi house the die came from? Can they provide the wafer lot number? If not, you are buying a lottery ticket, not a component.

2. Wire Bonder Calibration Records Ask for the last three months of wire pull test data. First bond pull strength should be >5 gf for 18–20µm Au, >8 gf for 25µm pure Au. If the supplier will not share this, walk away.

3. Encapsulant Certificate of Analysis Get the Tg, CTE, and spectral transmission data for the exact encapsulant batch. We have seen suppliers switch encapsulant formulations mid-production to save money, causing a wave of delamination failures six months later.

4. Reliability Report with Raw Data Do not accept a one-page "pass" summary. Ask for the individual unit data from HTOL, TCT, and HAST. Look for outliers—a few units that barely passed are a warning sign of process drift.

5. Change Notification Agreement Industrial products have long lifecycles. You need a formal PCN (Product Change Notification) agreement guaranteeing 90 days' notice for any material or process change. We recommend 180 days for critical applications.