Enclosures and Weatherproofing

How to select, seal, and maintain outdoor enclosures for LoRa mesh nodes.

- Choosing an Outdoor Enclosure
- Cable Glands and Penetrations
- Condensation Management
- Thermal Management for Outdoor Enclosures
- Practical Sealing Techniques

Choosing an Outdoor Enclosure

Picking the right enclosure is one of the most consequential decisions in any outdoor LoRa build. A node that works flawlessly on your workbench can fail within weeks if rain, dust, or condensation reaches the electronics. This page walks through IP ratings, common product lines, material choices, sizing rules, and the real-world tradeoffs in the $5 - $50 price range.

IP Ratings Explained

The **Ingress Protection (IP)** rating system (IEC 60529) uses two digits to describe a enclosure's resistance to solids and liquids. For outdoor electronics you primarily care about the second digit (liquid protection). **This table is the canonical IP-selection reference for the DIY Build Guides — other weatherproofing and enclosure pages should defer to it rather than restate different thresholds:**

Rating	Protection level	Typical test	Use case
IP65	Dust-tight + water jet resistant	Water jets from any direction at 12.5 L/min, 3 m distance, 1 min per m²	Covered outdoor installation - under eaves, inside a vent enclosure, mounted on a wall with overhang
IP66	Dust-tight + powerful water jet	100 L/min jets, 3 m distance, 1 min per m²	Exposed outdoor with heavy rain, areas prone to power washing
IP67	Dust-tight + temporary immersion to 1 m	30 minutes at 1 m depth	Exposed outdoor - rooftop, pole-mount, anywhere water can pool on the lid
IP68	Dust-tight + continuous submersion beyond 1 m	Manufacturer-specified depth and duration (often 1.5 - 3 m for 30 - 60 min)	Marine installations, flood-prone areas, below-grade deployments

Practical rule of thumb:

- Sheltered / covered outdoor (under a roof, inside a weatherproof cabinet): **IP65 minimum**. IP54 is not recommended for any unattended outdoor node, even a sheltered one.
- Fully exposed outdoor (rooftop, field, ridge line): **IP66 or IP67 minimum**

- Marine, tidal, or flood-zone: **IP68 required**

Note that IP ratings are tested on a new, undamaged enclosure with its original gasket. A used enclosure with a compressed or cracked gasket may no longer meet its rated IP level. Inspect and replace gaskets annually.

Common Enclosure Options for LoRa Nodes

Polycase WC Series (Popular for Small Nodes)

The **Polycase WC-21** is a common choice in the hobbyist LoRa community. It is an IP65-rated polycarbonate enclosure measuring approximately 115 × 65 × 40 mm externally (interior roughly 107 × 57 × 35 mm) - large enough for a Heltec V3 or T-Beam with an 18650 battery. Key features:

- Impact-resistant polycarbonate body (gray) with clear or gray lid options, designed for outdoor use
- Stainless lid screws and a gasket-sealed lid
- Molded-on flanges available for surface mounting (the flanged "F" variants)
- DIN rail mounting clip available as an add-on
- Price: roughly $10 USD per unit direct from Polycase (Polycase sells direct rather than through Digi-Key/Mouser; verify current pricing at polycase.com). *Pricing as of 2026-06-08.*

For larger boards (T-Beam Supreme, RAK WisBlock with many modules) step up to the **WC-22** (external 115 × 65 × 55 mm) or **WC-27** (external 171 × 121 × 80 mm).

Hammond 1554 Series

Hammond Manufacturing's **1554** series (and the sealed-lid 1555 of the same footprints) is a step up in build quality with thicker walls and a more robust gasket track. The **polycarbonate** versions are independently tested to IP66, IP67, and IP68 (NEMA Type 4, 4X, 6, 6P) — the suffix letters (A, B, C, …) denote *size*, not an IP grade, so there is no "1554 = IP65 vs 1554N = IP67" split. (The ABS versions of the 1554 are rated to about IP66 and are intended for indoor use.) Common sizes for small-to-medium LoRa builds (lid footprint; box depth varies by box height):

- **1554A**: 52 × 50 mm - good for a bare LoRa module without display

- **1554B**: 65 × 65 mm - fits most single-board LoRa nodes
- **1554C**: 120 × 65 mm - solar builds with a battery management board

Hammond polycarbonate enclosures are available with gray, clear, or smoked lids; a clear or smoked lid allows LED status visibility without opening. Price range: roughly $15 - $30 depending on size (verify at a distributor such as Digi-Key or Mouser).

Bud Industries PTS and PN Series

Bud Industries offers a wide range of NEMA 4X (IP66 equivalent) polycarbonate enclosures at competitive prices, including compact options in roughly the 115 × 65 × 40 mm class. Bud enclosures typically include a captive lid with stainless hardware. Available from Digi-Key, Mouser, and Amazon; roughly $8 - $25. Confirm the exact model number and dimensions against the Bud datasheet at budind.com before ordering.

Weatherproof Outdoor Electrical Boxes (Home Depot / Lowe's)

For ultra-budget builds, standard weatherproof PVC electrical boxes (the gray or white boxes designed for exterior receptacles) are surprisingly capable. A 1-gang or 2-gang deep weatherproof box with a gasket cover runs **$3 - $8** at any hardware store and is rated IP44 - IP55 depending on the specific cover. Limitations: no clear lid option, cable entries require separate cable glands or conduit fittings, and most are only IP55 (not IP65). Acceptable for covered-outdoor deployments; not recommended for fully exposed installations.

Material Choices and UV Resistance

Material	UV resistance	Impact resistance	Notes
Standard ABS	Poor - yellows and becomes brittle after a few years (roughly 2 - 5) of direct sun	Good	Avoid for exposed outdoor unless painted with UV-blocking paint
UV-stabilized ABS	Good - manufacturers typically rate it for many years (often 10+) outdoors	Good	Look for "UV-stabilized" or "UV-resistant" explicitly in the spec sheet
Polycarbonate (PC)	Excellent when UV-coated	Excellent - near-unbreakable	Most premium outdoor enclosures; naturally clear (can be tinted)

Material	UV resistance	Impact resistance	Notes
Glass-filled polyester (GRP)	Excellent	Excellent	Industrial standard; heavier and more expensive; overkill for most LoRa nodes
Aluminum	Excellent (anodized)	Excellent	Best thermal conductivity (useful as heatsink), poor RF transparency - a metal enclosure blocks/detunes RF, so do not mount the antenna inside

Recommendation: For any build that will see direct sunlight, use polycarbonate or explicitly UV-stabilized ABS. Do not use generic black ABS - it absorbs more solar radiation and degrades rapidly. (A dark enclosure is only worth considering for extreme-cold, unheated deployments that never see strong summer sun — see the Cold Weather Operation page.)

Sizing Your Enclosure

Measure your components in their final configuration (board + battery + cables routed) and follow this rule: **add 30% to each dimension for wiring clearance**. Cramming components into a too-small enclosure leads to pinched wires, forced cable bends that crack insulation, and difficulty accessing connectors during maintenance.

Worked example for a Heltec V3 build:

- Heltec WiFi LoRa 32 V3 board: 50.2 × 25.5 mm
- 18650 battery holder (single): approximately 78 × 22 × 20 mm (varies by maker)
- Combined footprint with standoffs and JST connectors: approximately 80 × 55 mm
- Add 30% → target enclosure interior: 104 × 72 mm minimum
- Good match: a Polycase WC-21 (internal ~107 × 57 mm - slightly narrow but workable) or a larger Hammond polycarbonate box such as the 1554C (120 × 65 mm footprint); check the internal dimensions on each manufacturer's datasheet before buying.

Gray vs. Clear Lids

Many polycarbonate enclosures are available with either an opaque gray lid or a clear (transparent) polycarbonate lid. The tradeoffs:

- **Clear lid advantages:** You can see LED status indicators, check battery indicator lights, and visually confirm the node is running without opening the enclosure and breaking the seal. This is especially valuable for hard-to-reach installations.

- **Clear lid disadvantages:** Slightly less UV resistance on the lid surface (though most reputable clear PC lids are UV-coated); greater solar heat gain through the transparent lid compared to a reflective gray lid.
- **Recommendation:** Use a clear lid when the node is hard to access; use an opaque white or light gray lid when the enclosure is in direct sun and thermal management is a concern.

Mounting Tabs and Options

Most IP-rated enclosures include integrated mounting flanges or tabs. Common configurations:

- **Flat wall tabs / flanges** (most common): drill through the tab and use an appropriately sized screw (M5 or M6 is typical) with stainless washers. Use stainless or galvanized hardware outdoors - standard zinc-plated steel screws rust quickly.
- **DIN rail clips**: available as accessories for many enclosure lines (Polycase, Hammond). Mount inside electrical panels or control cabinets.
- **Pipe/conduit clamps**: use a stainless hose clamp around a pole with the enclosure attached via its mounting tabs. Effective for antenna mast mounting.
- **Self-tapping screws into wood**: acceptable for temporary mounts; use stainless screws and pre-drill to avoid splitting.

Price vs. Quality Tradeoffs ($5 - $50)

Price tier	What you get	Suitable for
$3 - $8 (hardware store electrical box)	IP44 - IP55, PVC or ABS, no clear option, requires extra work for glands	Covered outdoor, short-term or prototype builds
$8 - $15 (Polycase WC, Bud PN)	IP65, polycarbonate, clear lid option, proper gasket track	Most covered and semi-exposed outdoor builds
$15 - $30 (Hammond 1554, quality PE boxes)	Polycarbonate tested to IP66/IP67/IP68, thicker walls, superior gasket, often IP-tested at the manufacturer	Fully exposed outdoor, IP67-required environments
$30 - $50 (larger Hammond 1554 sizes, specialty PC boxes)	IP67 - IP68, stainless hardware throughout, rated for industrial use	Marine, mountain-top, or critical infrastructure nodes

Do not cheap out on enclosures for permanent installations. A $5 savings on the enclosure is meaningless compared to the cost of re-climbing a pole or rooftop to replace water-damaged electronics.

Cable Glands and Penetrations

The gasket between the lid and body of your enclosure gets all the attention, but **cable penetrations are among the most common ingress failure points in outdoor electronics**. Cable penetrations are a more common water-ingress path than a properly maintained lid seal - water tends to enter through poorly installed or incorrect cable glands, or through cables that enter the enclosure without any gland at all. This page covers everything you need to seal cable entries correctly.

Why Cable Glands Matter

A cable gland (also called a cable strain-relief fitting or PG fitting) serves three functions simultaneously:

1. **Sealing:** It forms a watertight seal around the cable jacket, preventing liquid ingress at the point where the cable crosses the enclosure wall.
2. **Strain relief:** It clamps the cable so that tension on the external cable cannot be transmitted to the internal solder joints or connectors.
3. **Anti-rotation:** It prevents the cable from twisting inside the enclosure as it moves in wind or is pulled during servicing.

A common mistake is to drill a hole, pass the cable through, and seal around it with silicone RTV. This is not reliable long-term: silicone can shrink and crack, adhesion to polycarbonate is poor, and the seal is permanently destroyed the first time you need to reroute the cable. Use proper cable glands.

IP68-Rated vs IP65-Rated Cable Glands

Cable glands carry their own IP rating, independent of the enclosure:

- **IP65-rated glands:** Suitable for covered outdoor use and most exposed outdoor installations with rain. Acceptable for IP65/IP67 sheltered builds. Less expensive and

widely available. Typically a simple rubber cone insert that compresses around the cable.
- **IP68-rated glands:** Required for marine, submersion, or mission-critical outdoor nodes (use only where the enclosure itself is IP68 or for marine). These use a clamping insert with a labyrinth seal or a multi-piece compression fitting. Cost approximately $1 - $3 more per gland (cost delta is approximate). Brands: Icotek, Jacob GmbH, and generic metric cable glands from Digi-Key. (Roxtec makes cable-transit systems for sealing multiple cables through a frame rather than standard single-cable glands.)

Rule (gland IP must meet or exceed enclosure IP): Every cable gland must be rated at least equal to the enclosure's IP rating. IP65 glands are acceptable for IP65/IP67 sheltered builds; reserve IP68 glands for IP68 or marine enclosures. Installing a gland rated lower than the enclosure brings the system rating down to the gland's rating. This is the same rule used on the weatherproofing pages - see Weatherproofing Enclosures for the canonical convention.

Gland Sizing by Cable Type

Cable glands are sized to match both the thread entry in the enclosure wall and the diameter range of the cable passing through. Metric thread sizes (M-series) are standard for most IP-rated enclosures. Knockout-style enclosures (Hammond, Polycase) ship with blanked holes sized for common gland threads. This page is the canonical gland-sizing reference for the build pages; other pages should link here rather than restate sizes.

Thread size	Cable diameter range	Common use in LoRa builds
M12	3 - 6.5 mm OD	Thin antenna coax (RG-174, LMR-100), RG-58, USB cables, small 2-conductor power leads
M16	5 - 10 mm OD	Standard antenna coax (RG-58, LMR-195), FTDI/serial cables, 3-conductor leads
M20	8 - 13 mm OD (ranges vary by maker, roughly 6 - 13.5 mm)	LMR-400 coax, multi-conductor power cables, heavier solar charge cable
M25	10 - 17 mm OD	Multi-conductor shielded cable bundles, large solar panel leads

PG-to-Metric Cross-Reference

Some builds and suppliers specify glands in PG (Panzergewinde) thread sizes rather than metric M. Use this crosswalk so every gland-mentioning page can reference one canonical sizing reference. PG sizes refer to the cable OD range each accepts:

PG size	Cable OD range	Closest metric equivalent

PG7	3 - 6.5 mm	~M12
PG9	4 - 8 mm	~M16
PG11	5 - 10 mm	~M16 / M18
PG13.5	6 - 12 mm	~M20
PG16	10 - 14 mm	~M20 / M22
PG21	13 - 18 mm	~M25

Always measure your cable's actual outer diameter with calipers before ordering glands. Cable labeling often specifies conductor gauge, not OD. An RG-58 coax, for example, is approximately 5.0 mm OD - it fits both an M12 gland (3 - 6.5 mm) and an M16 gland; M16 is often preferred for easier strain relief. Note that RG-58 is lossy at 915 MHz (~0.5 dB/m), so use it only for very short jumpers; prefer LMR-195/LMR-240 or better for any run longer than about 0.3 m.

Material Selection

Material	Environment	Notes
Nylon (PA66)	General outdoor, UV exposure, fresh water	Best choice for most LoRa builds; lightweight, inexpensive, good chemical resistance; can become brittle in direct UV without UV stabilization (an often-cited estimate is 5 - 10 years, but this depends heavily on UV exposure and stabilization) - buy UV-stabilized (black) nylon glands for direct sun
Polypropylene (PP)	Chemical environments, fuel/oil exposure	Better chemical resistance than nylon; slightly more flexible at low temperatures. Note: unstabilized PP degrades faster than nylon under UV - reserve PP for shaded or chemical-exposure use
Stainless steel (316L)	Marine, saltwater, coastal	Required for saltwater environments - nylon and PP glands corrode and seize in marine conditions; more expensive (~$3 - $8 per gland) but the only correct choice within 5 km of saltwater
Brass (nickel-plated)	Industrial, high-vibration	Strong and resistant to vibration-induced loosening; avoid in saltwater (galvanic corrosion with aluminum enclosures)

Sealing Technique: Getting It Right

A cable gland is only as good as its installation. Follow this procedure:

1. **Drill the correct hole size** for the gland thread. Metric M-glands thread into a hole of approximately their nominal thread diameter plus a little clearance: M12 needs about a 12.5 mm hole, M16 about 16.5 mm, M20 about 20.5 mm, and M25 about 25.5 mm. Use a step drill bit to reach the gland's nominal thread diameter for clean holes in polycarbonate - standard twist bits can crack PC. **Wear eye protection when drilling enclosures; deburred plastic chips can injure eyes.**
2. **Apply PTFE (Teflon) thread tape** to the gland's male threads before insertion. Two or three wraps is sufficient. This improves the seal between the gland body and the enclosure wall, especially if the knockout hole is slightly oversized.
3. **Insert the gland body from outside the enclosure** and thread the locknut on the inside. Hand-tighten, then add 1/4 turn with a wrench - no more. Over-tightening cracks the nylon nut and defeats the seal.
4. **Pass the cable through the open gland** (with the compression nut backed off) and route it to its termination point inside the enclosure.
5. **Tighten the compression nut** hand-tight plus 1/4 turn until the cable is firmly gripped and cannot be pulled through. Test by tugging the cable - it should not move.

Over-tightening warning: Nylon glands crack at the compression nut if overtorqued. If you feel significant resistance before the cable is gripped, stop and check that you have the correct gland size for your cable diameter. A gland that is too large for the cable cannot seal properly regardless of torque.

Potting Compound: Permanently Sealed Entries

For entries that will never need to be reopened - a permanently-installed power cable or antenna coax - potting compound (also called cable entry seal or cable fill) provides a superior seal to a mechanical gland. Two-part polyurethane or silicone potting kits are available from RS Components and Digi-Key. The procedure:

1. Pass the cable through the entry hole.
2. Build a small dam around the hole with tape or a temporary form.
3. Mix and pour the potting compound, ensuring it wets the cable jacket and enclosure wall.
4. Allow to cure fully before installation - follow the product datasheet; full cure is often around 24 hours at room temperature but varies by product.

Do not use potting compound on entries that might ever need cable replacement or service access.

Self-Amalgamating Tape on External Antenna Connectors

Every antenna connector that is exposed to weather outside the enclosure must be weatherproofed with **self-amalgamating (self-fusing) tape**. This applies to N-connectors, SMA connectors, and any PL-259 connector on your antenna feedline junction:

1. Wipe the connector with isopropyl alcohol and allow to dry.
2. Stretch the self-amalgamating tape to approximately twice its resting length as you wrap - this activates the self-fusing adhesive.
3. Begin wrapping 2 cm below the connector junction and end 2 cm above it, overlapping each wrap by 50%.
4. Apply at least two layers for exposed outdoor connectors; four layers for marine environments.
5. Optionally apply a layer of standard black vinyl electrical tape over the self-amalgamating tape as UV protection (self-amalgamating tape degrades in UV faster than vinyl).

Drip Loops

A **drip loop** is the practice of routing every cable entering the enclosure so that it hangs below the entry point before rising to its termination - forming a low point where water drips off rather than running into the enclosure along the cable jacket.

Install drip loops on every cable entering the enclosure, including the antenna feedline, power cables, and any USB or serial connections. A drip loop requires only 10 - 15 cm of extra cable length and is one of the most effective low-cost passive measures against water ingress through cable entries.

Conduit Entry vs. Direct Cable Gland

For fixed permanent installations where cables run long distances from the enclosure to a power source or antenna base, conduit is preferable to direct cable glands:

- Conduit protects the cable from UV, abrasion, and rodent damage over its entire run.
- Conduit entries use a weatherproof conduit connector at the enclosure wall rather than a cable gland - these are available in liquidtight flexible conduit (LFMC) versions for IP65+ use.
- Use **Schedule 40 PVC conduit** for buried runs and UV-rated gray PVC or LFMC for exposed above-ground runs.
- The conduit entry at the enclosure must still be sealed - use a conduit-to-enclosure seal or conduit hub with an integrated gasket.
- Direct cable glands are preferable when the cable run is short (under 1 m) or when flexibility is needed at the enclosure end (e.g., an antenna cable that may be repositioned).

Condensation Management

A perfectly sealed enclosure with no cable gland defects can still suffer moisture damage from condensation. This page explains why condensation occurs in sealed enclosures and the proven methods to prevent it.

Why Condensation Happens

When you seal an enclosure, you trap whatever air is inside at that moment. Outdoor air contains water vapor. As the enclosure temperature drops overnight, the air inside cools and its relative humidity rises. When the dew point is reached, water vapor condenses on the coldest surfaces inside the enclosure - typically the metal components (battery terminals, solder joints, board ground planes) - exactly the surfaces most susceptible to corrosion.

The temperature swing needed to cause condensation is modest. On a warm day (30°C, 60% RH), the dew point is approximately 21°C. If the enclosure cools to 20°C overnight, condensation forms. In many climates, this cycle occurs nightly.

The Wrong Approach: Perfect Sealing Alone

A common misconception is that a perfectly sealed IP68 enclosure eliminates condensation. It does not - it just eliminates the mechanism by which fresh dry air can replace the humid air inside. A 100% sealed enclosure with no desiccant or membrane vent will accumulate moisture over time from the air that was trapped at sealing, and from any residual moisture in the components or wiring insulation.

There is also a subtler problem: rapid temperature drops create a slight pressure differential between the inside and outside of the enclosure. This differential can **draw air (and vapor) inward through any microscopic gap** - a slightly imperfect gasket, a hairline crack in the plastic, or a cable gland that is marginally undertorqued. A vapor-permeable **breather vent** (see Solution 2) prevents this by equilibrating pressure passively. Note this breather/membrane vent is a different feature from a thermal *convection* vent (an open, insect-meshed hole used for airflow cooling on rain-sheltered enclosures) - do not confuse the two.

Solution 1: Silica Gel Desiccant

Silica gel desiccant packs absorb water vapor from the air inside the enclosure, keeping relative humidity low enough to prevent condensation. This is the simplest, lowest-cost solution:

- **Sizing** (starting heuristics only - actual desiccant demand depends on how well the enclosure is sealed and its moisture load, not volume alone; for critical builds use a desiccant-unit sizing reference such as MIL-STD-3010):
  - Small enclosures (under 0.5 L internal volume, e.g., a small Polycase/Bud field box): 1 - 2 standard 5-gram silica gel packets
  - Medium enclosures (0.5 - 2 L internal volume): 3 - 5 packets or one 10-gram unit
  - Large enclosures (over 2 L, e.g., full solar build): 5 - 10 packets or one 25-gram canister
- **Placement:** Place desiccant at the lowest point in the enclosure where condensation would otherwise collect, and away from direct contact with the PCB.
- **Service interval:** Silica gel packs a finite adsorption capacity and must be replaced or regenerated. In humid climates, replace annually. In very humid or coastal environments, check every six months.

Color-Indicating Silica Gel

Standard white silica gel gives no visual indication of saturation. **Color-indicating silica gel** (also called "self-indicating") changes color when it approaches saturation. Two common indicator chemistries are sold, so don't assume your gel is defective if it isn't blue:

- Traditional orange-to-green formulation (cobalt-chloride free): orange when dry, green when saturated
- Classic blue-to-pink formulation: blue when dry, pink when saturated (contains cobalt chloride - not recommended for food-adjacent applications but fine for electronics)

Color-indicating desiccant is visible through a clear enclosure lid, allowing you to check desiccant status without opening the enclosure - ideal for hard-to-access installations. The price premium over standard silica gel is minimal ($0.50 - $1 per pack).

Regenerating Desiccant

Regeneration temperature depends on the desiccant type. **Loose indicating silica gel beads/pellets** are regenerated by heating at **120°C (248°F) for 2 - 3 hours** in a conventional oven - do not exceed about 125°C, which can damage the indicating dye. Spread the pellets in a single layer on a baking sheet. Allow to cool in a dry, sealed environment before returning them to the enclosure; color-indicating gel returns to its dry color on successful regeneration. **Sealed**

rechargeable canister units (e.g., the Eva-Dry E-333) are different: they have a built-in heater and are regenerated by plugging them into a wall outlet for 10 - 12 hours per the manufacturer's instructions - **never bake a plug-in canister unit in an oven.**

Solution 2: Vapor-Permeable Membrane Vents

A **Gore-Tex IP68-rated membrane breather vent** (or equivalent PTFE membrane vent) is a small screw-in or snap-in fitting that installs in a hole in the enclosure wall. It passes water vapor and equalizes pressure, but blocks liquid water in both directions. This is a pressure-equalizing breather vent, not an open airflow/convection vent.

How it works: the expanded PTFE membrane has a very fine sub-micron pore structure (manufacturer figures are typically on the order of 0.2 microns) - small enough to block liquid water droplets while letting air and water vapor pass freely; liquid water (even under pressure) cannot penetrate. Confirm the exact pore size and pressure rating against the specific vent's datasheet.

- **Popular products:** Gore GORE-TEX Protective Vents (available from Digi-Key, Mouser), Parker Hannifin breather vents, generic PTFE membrane vents from Chinese suppliers (quality varies - buy from reputable distributors for critical builds)
- **Thread sizes:** M12 and M16 metric and 1/4 NPT are common vent thread sizes; M12 is the most widely stocked for small enclosures and NPT shows up on larger ones. Check the vendor's catalog for the exact range.
- **IP rating:** A properly-rated, correctly-installed Gore (or equivalent) vent will maintain the enclosure's IP rating - but only the vent and installation themselves are rated. A generic, unrated vent or a poorly-sealed thread can compromise the enclosure's IP rating, so use a vent whose own datasheet states the IP rating you need.
- **Installation:** Install the breather vent on a vertical wall or the underside of the enclosure, never on the top - pooled water on the vent face can block vapor permeability
- **Cost:** $3 - $8 per vent depending on size and brand

Combining Both Solutions

For the most reliable long-term moisture control, use both a membrane vent and a desiccant pack. The membrane vent handles pressure equalization and provides a path for vapor escape; the desiccant acts as a backup, absorbing any moisture that enters during initial assembly or through marginal gland seals. This combination is used in commercial outdoor electronics (traffic sensors, cellular base station equipment, utility meters) for exactly this reason.

Summary: Condensation Management Checklist

- Include at least one silica gel desiccant pack sized for the enclosure volume
- Use color-indicating desiccant when the enclosure is accessible for visual inspection
- Install a PTFE membrane breather vent in a vertical or downward-facing position
- Seal the enclosure in dry conditions (low ambient humidity), not on rainy days
- Allow components to reach ambient temperature before sealing (cold components carry condensed moisture on their surfaces)
- Service desiccant annually (or more frequently in humid climates); regenerate loose silica at 120°C for 2-3 hours, and recharge plug-in canister units per their label - never bake them

Thermal Management for Outdoor Enclosures

Heat is the silent killer of outdoor electronics. A node that operates flawlessly through rain and vibration can fail within months if it repeatedly reaches thermal extremes inside its enclosure. This page covers the mechanisms of solar heating, its effects on components, and practical solutions in order of effectiveness.

The Solar Heating Problem

A sealed enclosure in direct sun acts as a greenhouse. Solar radiation penetrates the polycarbonate walls and is absorbed by the PCB, wiring, and battery inside. The resulting heat cannot convect away (no airflow) and cannot easily conduct through the plastic walls (low thermal conductivity). The enclosure interior temperature rises well above ambient.

Approximate, illustrative interior temperatures for LoRa node enclosures (estimates, not from a controlled study - real temperatures vary widely with sun intensity, enclosure size, orientation, and mounting). The relative ordering (darker = hotter) is the reliable takeaway; treat the absolute numbers and deltas as rough estimates:

Enclosure color	Ambient temperature	Interior temperature (direct sun, estimated)	Difference (estimated)
Black	30°C (86°F)	70 - 80°C (158 - 176°F)	+40 - 50°C
Dark gray	30°C (86°F)	60 - 70°C (140 - 158°F)	+30 - 40°C
Light gray	30°C (86°F)	45 - 55°C (113 - 131°F)	+15 - 25°C
White	30°C (86°F)	38 - 45°C (100 - 113°F)	+8 - 15°C

Black enclosures in direct sun can easily exceed 70°C internally on a 30°C day - well into the danger zone for LiPo batteries and some IC packages. **Sustained high enclosure temperatures are not only a longevity problem: a lithium cell that is overheated - and especially one being charged while hot - can vent, swell, or enter thermal runaway and catch fire. Treat 60°C+ internal temperatures as a fire-safety limit, not just a degradation limit, and stop charging a hot cell.** This is an additional reason to prefer LiFePO4, which is far more resistant to thermal runaway.

Component Temperature Ratings

Component	Max operating temperature	Permanent degradation begins at	Notes
LoRa radio (SX1276/SX1262)	85°C	~85°C (gradual)	Both SX1276 and SX1262 are rated to +85°C per Semtech datasheets. The radio is usually not the thermal weak point
ESP32 microcontroller	85°C (commercial), 105°C (industrial grade)	~85°C for commercial grade	Industrial-grade modules (rare in hobbyist hardware) rate to 105°C
nRF52840 microcontroller	85°C	~85°C	Used in RAK WisBlock, T-Echo
LiPo (Li-ion polymer) battery	~45°C (charging), ~60°C (discharge/storage)	**Permanent capacity loss begins above 45°C during charging**	The thermal weak point in most builds; charge limit is typically lower (~45°C) than discharge (~60°C) - check your cell's datasheet, figures vary by manufacturer. Cycle life drops dramatically above 45°C
LiFePO4 battery	~45 - 55°C (charging), ~60°C (operating)	~60°C	Significantly more heat-tolerant than LiPo; preferred for direct-sun deployments. Confirm charge/operating limits on your specific LiFePO4 cell datasheet
Polycarbonate enclosure body	115 - 125°C	~115°C	The enclosure itself rarely fails thermally; the battery fails first

Solutions in Order of Effectiveness

1. Enclosure Color (Most Impactful, Zero Cost)

Choose a **white or light gray enclosure** as the default for any deployment that will see direct sun or in a hot climate. This single choice can reduce interior temperature substantially (roughly 25

- 40°C compared to a black enclosure, based on the estimated color table above) at no additional cost. Most enclosure manufacturers offer the same model in multiple colors. *The opposite advice applies only in a narrow case: a darker enclosure can help slightly at an unheated, extreme-cold site that never sees strong summer sun - see the cold-weather / winter-operation page, which is scoped for that scenario. White/light is the default everywhere else.*

If you already have a dark enclosure: a coat of high-reflectance white exterior paint (Rust-Oleum Flat White, or similar) applied to the exterior reduces temperatures almost as much as a white enclosure, at the cost of a few minutes of prep work.

2. Radiation Shield (High Impact, Low Cost)

Install a **radiation shield** - a second reflective surface positioned 4 - 6 cm above the enclosure to intercept direct solar radiation before it reaches the enclosure surface. Options:

- A second identical enclosure lid mounted above the main enclosure on standoffs
- A piece of aluminum flashing cut to size and bent into a shallow roof profile
- A purpose-built aluminum sun shade (commonly available from industrial enclosure suppliers; small shades often run roughly $5 - $20, but price is volatile - check a current vendor listing, as of 2026-06-08; larger shields can cost more)

A well-designed radiation shield with a ~5 cm air gap can reduce enclosure surface temperature appreciably (an estimated 15 - 20°C in favorable conditions) by allowing convective cooling in the gap between the shield and the enclosure surface. Treat that figure as an estimate; actual benefit depends on airflow and sun angle.

3. Ventilated Enclosures with Filtered Vents

For nodes installed in locations that are **not exposed to direct rain** (inside a larger weatherproof cabinet, under a substantial roof overhang, inside a NEMA-rated outdoor panel), an enclosure with filtered ventilation slots can eliminate the thermal problem almost entirely. Filtered vents use a hydrophobic membrane that keeps insects and dust out while allowing free airflow. **Book-wide venting rule:** a node directly exposed to rain must stay fully sealed - use a hydrophobic membrane (Gore-type) pressure-equalization vent only, never an open or merely screened hole. Only a sheltered, rain-protected node may use screened open vents. Do not use open ventilation on any rain-exposed outdoor enclosure.

4. Thermal Mass (Moderate Impact, Passive)

A larger battery acts as a thermal mass, moderating temperature swings by absorbing heat energy during peak solar hours and releasing it at night. A 10,000 mAh LiFePO4 pack will heat up more slowly than a 2,000 mAh LiPo under the same solar load. This is not a substitute for radiation shielding, but it meaningfully extends the time before dangerous temperatures are reached.

5. Temperature-Rated Component Selection

If your deployment is in a severe climate (Middle East, Arizona summer, south-facing rooftop in a subtropical region), explicitly select components rated for higher temperatures:

- Prefer **LiFePO4 batteries** over LiPo for their superior thermal tolerance and thermal runaway resistance
- Consider industrial-grade ESP32 or dedicated LoRa modules (RAK811, Ebyte E22) over consumer boards for high-temperature environments
- Verify that electrolytic capacitors on your board are rated for at least 85°C (check the cap markings - cheap boards sometimes use 85°C caps where 105°C would be more appropriate)
- As a margin/robustness choice (not strictly required, since enclosure wiring rarely approaches PVC's limit), consider silicone-insulated wire inside the enclosure rather than standard PVC insulation - silicone hookup wire is commonly rated to ~200°C per its datasheet, versus ~80 - 105°C for typical PVC, so it will not soften or off-gas at LoRa enclosure temperatures

Monitoring Enclosure Temperature

Adding a cheap temperature sensor (DS18B20, SHT31, or a spare ADC connected to a thermistor) inside the enclosure allows your node to report internal temperature as part of its telemetry. Meshtastic supports environmental telemetry modules; MeshCore can be extended similarly. Setting an alert threshold at 55°C gives you advance warning before LiPo degradation begins, allowing you to add shielding or relocate the node before batteries are damaged.

Practical Sealing Techniques

This page consolidates the step-by-step procedures for assembling and commissioning a sealed outdoor enclosure, along with a maintenance checklist to keep your nodes running reliably year after year.

Step-by-Step Enclosure Assembly

Step 1: Dry-Fit All Components Before Final Assembly

Before you drill a single hole or apply any sealant, place all components inside the enclosure in their intended positions. Verify:

- The board, battery, and any ancillary modules fit without forcing
- Cable routing is achievable without sharp bends or kinks
- The lid closes fully with all components in place
- Cable gland positions are accessible and do not interfere with internal components
- The antenna connector exit point makes sense for the intended antenna direction

Adjusting the layout at this stage costs nothing. Adjusting it after drilling and gland installation costs time and may require a new enclosure.

Step 2: Clean All Sealing Surfaces with Isopropyl Alcohol

Before any gasket or sealant work, wipe down:

- The lid gasket track and the mating surface on the enclosure body
- The outer surface of the enclosure around each cable gland hole
- The gland body surfaces that will contact the enclosure wall

Use 90%+ isopropyl alcohol (IPA) on a lint-free cloth. Allow to dry for 2 - 3 minutes before proceeding. Oils from handling - even fingerprints - reduce adhesion and gasket compression. Never use acetone on polycarbonate; it crazes the surface. **Note:** IPA can promote stress cracking

on highly-stressed polycarbonate, so do not flood loaded/stressed areas with it - clean *around* (not into) loaded screw bosses. A heptane-based cleaner is a safer alternative for cleaning near stressed PC.

Step 3: Install Cable Glands Before Mounting Electronics

Install all cable glands into the enclosure walls before mounting the PCB or battery. This is much easier when the enclosure interior is clear:

1. Drill holes to the correct diameter for each gland thread (see Cable Glands page for sizes)
2. Use a step drill bit for polycarbonate - standard twist bits can crack PC on the exit side
3. Deburr the holes with a countersink bit or small file to remove any plastic burr that would prevent the gland body from seating flush
4. Apply 2 - 3 wraps of PTFE thread tape to each gland's male thread
5. Insert gland body from outside and thread the locknut from inside: hand-tight + 1/4 turn
6. Leave the cable compression nuts backed off - you will tighten them after routing cables

Step 4: Use Thread Sealant or PTFE Tape on Threaded Entries

Use one consistent gland-sealing procedure (the same one referenced across all the build pages): **PTFE (polytetrafluoroethylene) thread tape on the thread**, a **neutral-cure RTV bead at the gland-to-wall interface**, and a drop of **medium-strength thread-locker** on the locknut to prevent vibration back-off. PTFE tape is chemically inert, resists all weather conditions, and - unlike RTV silicone on the thread - does not require cure time and can be disassembled and reassembled without re-application.

Apply PTFE tape by stretching it slightly as you wrap clockwise (viewed from the gland nose), so the tape tightens as the fitting is screwed in. Two to three wraps is standard for M12 - M20 gland threads.

Step 5: Inspect the Enclosure Gasket

Before mounting electronics, inspect the lid gasket carefully:

- **Cracks or cuts:** Any visible crack in the gasket requires replacement. Even a small crack allows water ingress under pressure.
- **Permanent compression set:** If the gasket has a flat, shiny surface where it previously contacted the lid (indicating it has been permanently compressed and is no longer

resilient), replace it. A gasket that does not spring back when the lid is removed cannot seal.
- **Missing sections:** Gaskets can slip out of their groove during shipping or storage. Verify the gasket is continuous and fully seated in its track.

Replacement gaskets for common enclosure brands are available from the manufacturer or as generic cord gasket (foam or EPDM rubber) sold by the meter - cut to length and join with RTV silicone at the splice.

Step 6: Mount Electronics on Standoffs

Mount the PCB and battery on plastic or nylon standoffs (M3 or M4 × 8 - 12 mm) that raise the board off the enclosure floor. Benefits:

- Air gap under the board allows any condensation that does form to drain away from solder joints
- Vibration isolation between the enclosure floor and the PCB
- Access to bottom-side components and connectors during servicing

Use insulating (nylon) standoffs rather than metal. Their purpose is to prevent unintended electrical connections between PCB nets and any conductive parts, and to avoid corrosion at metal-to-metal contacts. (In an all-plastic enclosure the walls are insulating, so the real benefit is avoiding accidental shorts and galvanic corrosion at fastener contacts, not "bridging" to the walls; in a metal enclosure, insulating standoffs also keep PCB grounds from tying to the chassis unintentionally.)

Step 7: Route Cables with Drip Loops

Before tightening cable gland compression nuts, route each cable so it forms a drip loop - the cable exits the enclosure, drops below the gland entry point by at least 10 cm, then rises to its destination. This ensures any water running down the cable exterior reaches the lowest point of the loop and drips off rather than continuing into the gland.

After routing, tighten each cable gland compression nut: hand-tight plus 1/4 turn. Test by tugging the cable firmly - it should not move through the gland.

Step 8: Add Desiccant and Membrane Vent

Place the desiccant packet(s) inside the enclosure at the lowest point, away from direct contact with the PCB or battery. If installing a membrane vent, it should already be installed in the enclosure wall (treat it like a cable gland - install it in Step 3). Verify the vent is positioned on a

vertical wall or underside, not on the top face where water can pool.

Step 9: Close and Torque Lid Screws to Specification

Tighten the lid screws in a cross-pattern (like tightening lug nuts on a wheel) to ensure even gasket compression. **For most builders without a torque driver, use the feel test:** the screw should be snug with the gasket *visibly compressed but not crushed* - stop as soon as the gasket seats; do not keep turning, or you will crack the boss. Defer to the enclosure manufacturer's published torque spec where one is available. The figures below are rough starting guidance, not a formal standard, and **assume the screw threads into a plastic boss** (not a metal-to-metal joint); reduce them further for small or fragile bosses. Full-torque values for stainless screws in metal are much higher and would split a plastic enclosure.

Screw size	Material	Starting torque (plastic boss / gasketed lid)
M3	Nylon or stainless	~0.3 - 0.4 Nm
M4	Nylon or stainless	~0.5 - 0.8 Nm
M5	Stainless	~1.0 - 1.5 Nm

If you do not have a torque driver, calibrate by feel: the screw should be snug with the gasket visibly compressed, but not so tight that the screw head is pulling into the plastic or the enclosure body is deflecting. Over-torquing a polycarbonate enclosure cracks it around the screw bosses.

Step 10: Label the Enclosure

Apply a permanent label (laser-printed on weather-resistant label stock, or engraved with a label maker using polyester tape) on the outside of the enclosure with:

- **Install date** (month and year)
- **Node name or ID** (as configured in firmware)
- **Contact information** (your callsign, email, or phone number)
- Optional: next scheduled maintenance date

This information is invaluable when someone else encounters your node, when you forget which node is which, or when first responders need to contact the network owner.

Annual Maintenance Checklist

Outdoor electronics require periodic maintenance to maintain weatherproofing integrity. Perform the following checks annually, or following any severe weather event:

Item	What to check	Action if degraded
Lid gasket	Visual inspection for cracks, cuts, compression set, and gaps in the gasket track	Replace the gasket; clean the gasket track before installing the new one
Desiccant	Color-indicating: check color. Non-indicating: replace on a fixed annual schedule	Replace or regenerate per procedure on the Condensation Management page
Cable gland tightness	Attempt to pull each cable through its gland by hand - cables must not move	Re-tighten compression nut; if nut is cracked, replace the entire gland
Cable jacket condition	Inspect the cable jacket at the gland entry point for abrasion, cracking, or UV degradation	Replace cable if jacket is compromised; re-seal gland entry
Antenna connector weatherproofing	Inspect self-amalgamating tape for peeling, cracking, or UV degradation	Remove old tape (it will tear off in strips), clean with IPA, reapply fresh tape
Enclosure mounting hardware	Check for rust on mounting screws; verify the enclosure has not shifted on its mount	Replace with stainless hardware; re-tighten mounting fasteners
Internal inspection	Look for moisture droplets, corrosion on PCB or battery terminals, loose connectors	Address moisture source (new gasket or gland); treat any corrosion with contact cleaner; re-seat connectors
Enclosure body	Inspect for UV yellowing, cracks, or impact damage	Minor UV yellowing is cosmetic only; cracks or physical damage require enclosure replacement

Quick Reference: Common Mistakes to Avoid

- **Do not** seal cable entries with silicone RTV alone - use proper cable glands
- **Do not** over-tighten cable gland compression nuts - hand-tight plus 1/4 turn is correct
- **Do not** use standard zinc-plated hardware for mounting outdoors - use stainless
- **Do not** install the enclosure with a cable entering from the top without a drip loop
- **Do not** use black enclosures in direct sun without a radiation shield
- **Do not** close an enclosure in high-humidity conditions without a desiccant inside
- **Do not** skip the annual gasket inspection - gaskets silently fail between visits