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

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