GORE® Protective Vents
White Paper

HOW TO EXTEND THE SERVICE LIFE OF LED OUTDOOR LIGHTING

By Gary Chan and Henning von Lepel, Application Engineers

Outdoor LED luminaires need strong protection against harsh weather. Their housings act as a barrier, keeping sensitive electronics safe from dust, moisture, and physical damage. The greatest stress on these housings occurs at the seals, which face pressure differences caused by daily temperature changes. If these variations are not equalized, they can lead to condensation, contamination, and premature failure of internal components. To maintain performance and longevity, pressure must be balanced without allowing water or dust to enter. This paper discusses various methods to extend the service life of these enclosures by managing pressure fluctuations, with a focus on smart venting elements—specialized membranes that enable air exchange and pressure equalization while blocking fluids and contaminants, ensuring reliable protection for electronic housings in demanding outdoor environments.

For both commercial and residential applications standard neon tubes and energy-saving lamps are increasingly replaced by LED (light-emitting diodes) luminaires. The advantages of LED lightings are numerous:

- They are fully RoHS-compliant (Restriction of Hazardous Substances).
- They provide up to 85 percent energy savings in comparison to conventional lamps.
- They can generate as much as 50,000 hours of light.
- They are one of the most environmentally friendly and reliable solutions for outdoor lighting applications.

LED Service Life and Environmental Challenges

The lifespan of an LED depends on the reliability of its electronic components and power supply drivers, which together form the lighting system. This is a major challenge for outdoor LED systems, whose housings must withstand harsh environmental conditions. To protect the electronics inside, the housing is sealed against water and contaminants. However, outdoor temperature changes cause air pressure inside the housing to fluctuate. These pressure changes stress the seals, reducing their effectiveness over time. Eventually, water and contaminants can enter the housing, leading to corrosion, electrical shorts, and possible system failure. Condensation inside the luminaire can also affect light quality, further reducing performance.

Causes for Pressure Differentials

Temperature Fluctuations

Changes in outdoor temperature are one of the most common causes of pressure differentials. These changes can be sudden, for instance a strong thunderstorm on a hot summer day, or more gradual over the course of the day or of the year. Either way, they put significant stress on the seals. What is more, direct sunlight can often cause the air inside the LED luminaire to rapidly heat up, with the resulting higher pressure putting positive pressure on the seals. As temperatures drop again at night, the internal air contracts and creates a gentle vacuum, which draws the seals inward. A quick drop in temperature can create a vacuum of up to 150 mbar inside the luminaire, while a 30 °C change in temperature creates approximately 10 percent of volumetric flow of air in or out in a non-hermetically sealed enclosure.

Typical Calculation

Pressure differential in a housing with 5 liters of free air volume caused by a temperature drop from 65 °C to 15 °C in 11 minutes.

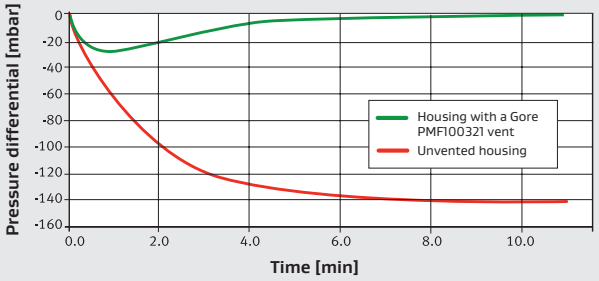


Figure 1: Typical calculation of pressure differentials in a housing

Temperature Changes within LED Luminaires

Although LEDs generate less heat than incandescent lamps, switching a luminaire on and off still causes significant temperature fluctuations. These fluctuations are most intense immediately after switching. Frequent on-off cycles place considerable strain on both the electronics and the seals.

Altitude Changes

When LED luminaires are shipped by air from manufacturing sites, they experience major altitude changes—often multiple times if the shipment includes intermediate stops. This exposes them to pressure differences between slightly over 1,000 mbar at ground level and 800–850 mbar during flight.

Thermal Shock

A thermal shock occurs when a hot LED luminaire is sprayed with cold water from a garden hose, for instance, or when a cold luminaire is washed with hot water. It can also arise when a luminaire encounters snowfall.

Important Consideration: Hydrogen Sulfide

Maintaining constant pressure is not the only factor for ensuring a long service life of an LED luminaire. Hydrogen sulfide can be released, especially from inexpensive EPDM seals manufactured using sulfur vulcanization when not all sulfur atoms are fully cross-linked. Sulfur-vulcanized nitrile butadiene rubber (NBR) or other sulfur-containing components can also emit hydrogen sulfide. This substance causes corrosion in luminaire components such as silver-plated lead frames, which may affect electrical contacts at the wire bond or die bond.

Challenge: How to Vent and Seal Simultaneously?

To maintain constant pressure inside a luminaire, air must be able to flow freely in and out. The challenge is to allow this airflow while at the same time blocking water and contaminants. Common sealing methods have significant drawbacks, as highlighted here:

- Labyrinth seals: Permeable to particles, insects, and water.
- Rugged seals, extra bolts, thicker housings, or potting compounds: Provide hermetic sealing but require non-permeable materials, making them expensive. They also add weight, make opening under negative pressure extremely difficult, and make repairs nearly impossible.
- Felt elements and sintered vents: Help equalize pressure but can easily become blocked by water and contaminants.
- Mechanical valves: Allow one-way airflow from inside to outside, but cannot prevent vacuum formation.

Solution: A Waterproof, Breathable Protective Vent

After understanding the limitations of conventional venting methods, the necessity of a solution that equalizes pressure continuously while blocking liquid and particulate ingress is clear.

Gore's two-way breathable protective membrane vents will steadily equalize pressure inside the luminaire housing while preventing water and contaminant ingress. By stabilizing internal pressure, not only will seal life be extended, but condensation on lenses and reflectors will be minimized. The membrane microstructure is open enough for gas molecules and water vapor to pass through easily, yet the openings are small enough to repel liquids and particulates. Depending on the conditions, the membrane can be coated to provide oleophobicity, if required. Additionally, hydrogen sulfide, a potentially damaging gas, will be expelled through the vent.

Impact of pressure on vented and unvented housings

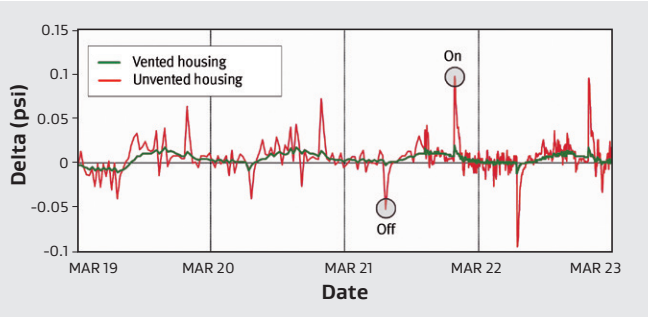


Figure 2: Impact of pressure on vented and unvented housings.

Relative humidity in vented and unvented housings

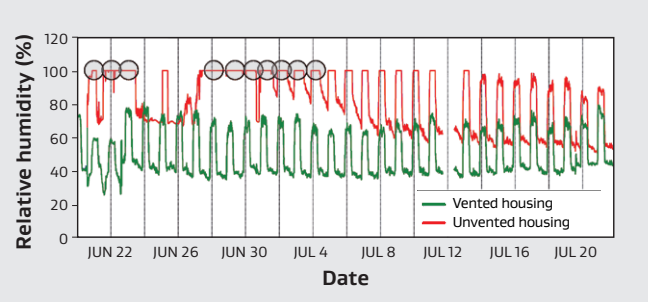


Figure 3: The unvented housing shows relative humidity of 100%, indicating condensation.

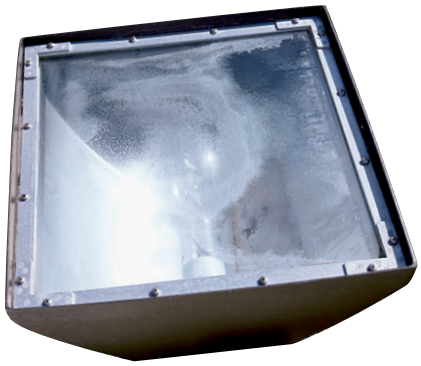
Evaluating the Impact of Pressure on Performance

Proper pressure equalization and water tightness have been demonstrated by thorough testing to compare two commercially available LED luminaires, one conventionally sealed unit and one with a protective membrane vent. Although the on/off cycle of both luminaires caused temperatures to rise and fall, the amount of pressure placed on the seals is significantly different. In the sealed luminaire, the pressure spiked by 6.2 mbar when the light was switched on and dipped -6.9 mbar when switched off. However, the vented luminaire showed a change of only ±0.69 mbar.

Comparing the relative humidity inside the LED luminaires after a standard IPX5 water ingress test demonstrates the significance of pressure differentials. The relative humidity in the sealed luminaire was significantly higher than in the vented luminaire. Over the course of ten days, the relative humidity in the sealed luminaire almost always remained at around 100 percent.

This shows that condensation formed inside the luminaire due to water entering during the test. In contrast, while the relative humidity in the vented luminaire rose immediately after the shock test, it quickly dropped again, and no condensation was observed.

Figure 4: Luminaire with condensation



Field Test Proves Long-Term Protection

Beginning in 2016 and continuing to now, Gore undertook a long term outdoor study, summarized in the white paper titled GORE® Protective Vents Field Study: *Optimizing the performance and durability of outdoor electronics: Field study proves GORE® Protective Vents to be a lasting safeguard*, to demonstrate that vented enclosures deliver longer service life. (Figure 5). The study was published in August 2024.

Study Design:

Fourteen identical aluminum electronic enclosures, rated to IP65 and fitted with neoprene seals were installed in the roof garden of a Gore building south of Munich, Germany.

The enclosures were equipped with various GORE® Protective Vents, while one enclosure was intentionally left unvented for comparison. Data loggers inside each unit continuously monitor humidity, temperature, and pressure, supplemented by an external sensor capturing ambient conditions. Exposed to temperatures from –15°C to +50°C, the unventilated enclosure experienced pressure fluctuations significant enough to stress and potentially damage its seal. The enclosures are inspected regularly, with ongoing analysis of sensor data. Vent performance— including pressure equalization behavior, airflow, and water entry pressure (WEP)—is routinely evaluated to assess seal integrity.

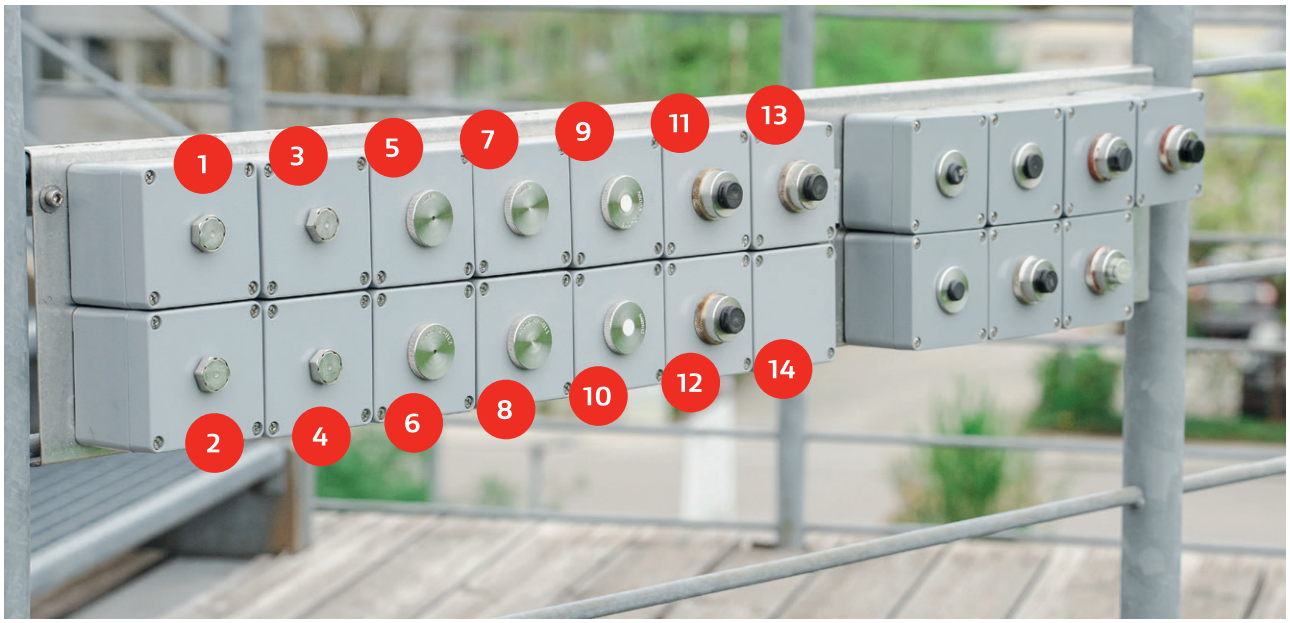


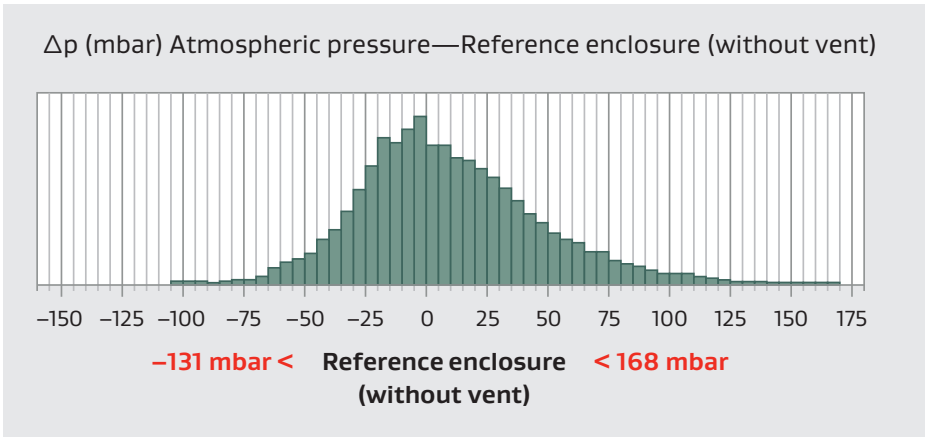
Figure 5: Enclosure equipped with different GORE® Protective Vents

Results:

Since data collection began in 2016, ventilated enclosures have maintained internal pressures that closely follow ambient atmospheric conditions, limiting differential pressures to less than 19 mbar. This controlled pressure environment greatly reduces mechanical stress on the sealing system, slowing seal degradation and preventing the formation of leakage pathways that enable moisture intrusion.

The data in the illustration below (Figure 6), captured in May 2022, shows a comparison of pressure differentials in the ventilated and unventilated enclosures.

Distribution



Distribution

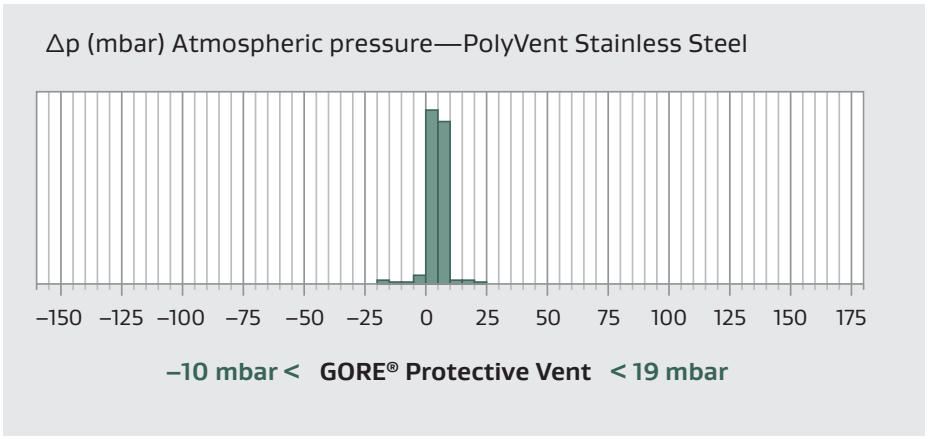


Figure 6: Distribution and extent of differential pressures in the unventilated enclosure (top) and in a ventilated enclosure (bottom) since data logging began (May 2022)

The microporous membrane within GORE® Protective Vents further reinforces this protection by blocking liquid and particulate ingress while permitting moisture vapor to diffuse outward. By continuously releasing internal humidity, the vent helps prevent the enclosure from reaching dew point conditions that lead to condensation.

A comparison of relative humidity provides further evidence of well-functioning moisture management.

Figure 8 compares the relative humidity of an enclosure without a vent to that of an enclosure with a vent. The data shows that with GORE® Protective Vents, relative humidity decreases (red), whereas a high level of humidity (~90%, blue) remains constant inside the enclosure without a vent. In a direct comparison with the unvented enclosure, the relative humidity in enclosures with GORE® Protective Vents falls by as much as 46% (Figure 8).

Comparison of relative humidity

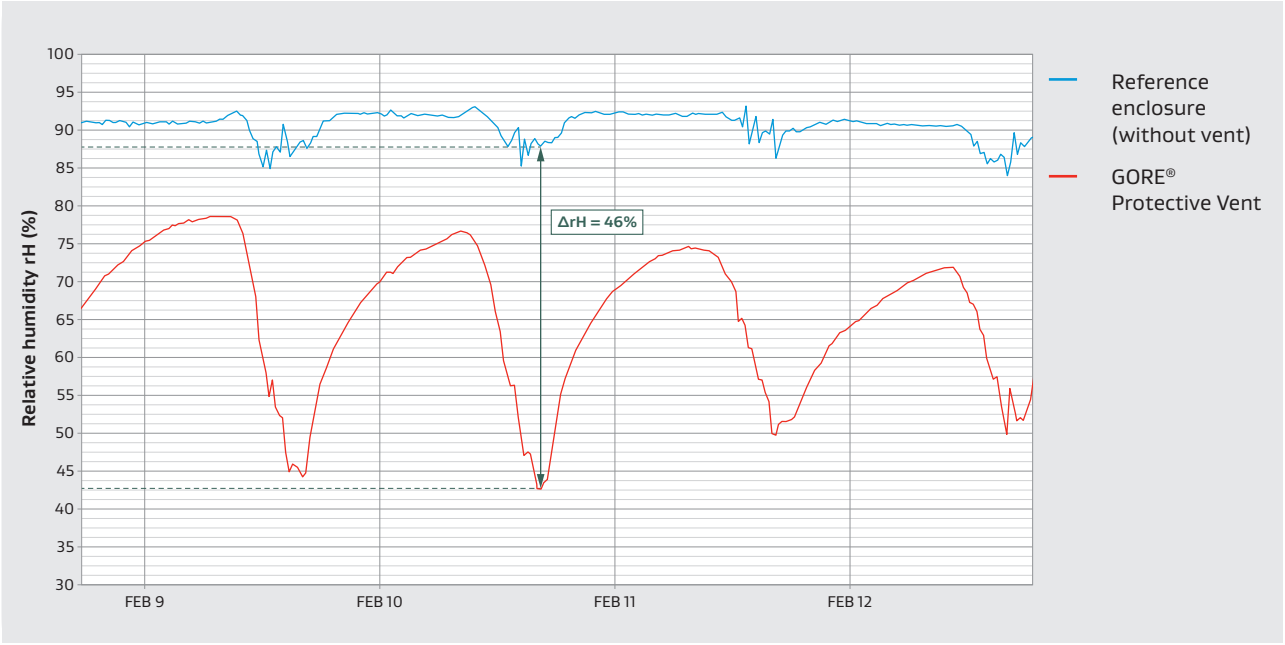


Figure 8: Comparison of relative humidity: enclosure with GORE® Protective Vent and without vent

Together, the pressure equalizing function of the vent and the membrane's vapor permeability create a synergistic moisture management mechanism—minimizing seal stress, suppressing condensation risk, and preserving internal environmental stability essential for long term reliability.

Summary

Outdoor LED luminaires—like many sealed electronic enclosures—must withstand harsh, variable environmental conditions. Their housings protect sensitive components, but daily temperature-driven pressure fluctuations place significant stress on the seals. Without proper pressure equalization, these fluctuations can accelerate seal degradation, allow water ingress, and create condensation that threatens internal electronics.

Various testing shows that adding a microporous membrane vent allows continuous air exchange that keeps internal pressure aligned with ambient conditions while blocking liquids and particulates. Because the membrane also releases moisture vapor before it can condense, the enclosure maintains a drier, more stable internal environment—improving long-term reliability across luminaires and other outdoor electronic systems.

Although demonstrated here using luminaires, the same venting principles apply broadly across outdoor electronic enclosures. Effective pressure equalization combined with controlled vapor transmission enhances seal durability, reduces condensation risk, and supports long-term reliability in a wide range of sealed electronic systems.

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See the White Paper:

8-Year Field Study Shows GORE® Protective Vents as a Lasting Safeguard

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INTERNATIONAL CONTACTS

Europe / Middle East / Africa
W. L. Gore & Associates GmbH (Germany)
T +49 89 4612 2211
E protectivevents@wlgore.com

Asia Pacific
W. L. Gore & Associates (Korea) Ltd.
T +82 2 393 3411
E performancesolutions@wlgore.com

China
W. L. Gore & Associates (Shenzhen) Co., Ltd.
T +86 21 5172 8299
E info_china@wlgore.com

Americas
W. L. Gore & Associates, Inc.
401 Airport Road, Elkton, MD 21914, U.S.
T +1 410 506 7812 (USA) **E** protectivevents@wlgore.com
gore.com

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