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Designing an Outdoor Linear LED Luminaire with Gore-Tex Filters

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Abstract

We introduce a novel outdoor linear LED luminaire enhanced with Gore-Tex filters, designed to overcome the challenges of moisture and thermal management in harsh environments. This luminaire integrates expanded polytetrafluoroethylene (ePTFE)—commercially known as Gore-Tex—achieving superior waterproofing and dustproof qualities while maintaining breathability to prevent internal condensation. The design process, from conceptualization through prototyping and testing, is detailed, highlighting the luminaire's improved durability and stability under varying conditions. Experimental results demonstrate that our design significantly extends the operational lifespan and reliability of outdoor LED lighting systems by mitigating thermal and moisture-related degradation. This study not only advances ePTFE's application in lighting technologies but also offers a scalable model for enhancing the performance of LED luminaires in outdoor settings.

Keywords: *LED, Lighting, Luminaire, Gore-tex, Outdoor, ePTFE, Waterproof*

1. Introduction

Lighting in outdoor spaces has been the cornerstone of architectural engineering, enhancing safety, aesthetics, and functionality. For years, waterproof lighting fixtures designed for fluorescent lamps have dominated outdoor environments, providing economical solutions [1]. However, the advent of LED technology has radically changed the lighting landscape, offering increased energy efficiency, longer lifespans, and improved reliability [2]. Despite these advantages, general LED outdoor lighting fixtures, excluding high-end street and security lights, still face significant challenges to optimize performance and versatility across diverse spaces [3, 4].

Among these challenges, thermal management issues that can reduce the lifespan of LEDs, and the need for waterproof and dustproof capabilities to maintain function in the face of environmental factors, are of paramount importance [5]. Until now, solutions for waterproof and dustproof outdoor lighting fixtures for

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fluorescent lamps have involved securing the lamps within bulky and robust housings, covered and fixed with acrylic. This approach has remained largely unchanged after transitioning to LED lighting, resulting in similar designs for LED fluorescent lamps or dedicated LED fixtures that are aesthetically displeasing. Over time, they are also subject to wear and performance degradation due to UV exposure, temperature variations, and physical impacts [6, 7].

We propose a new design for outdoor linear lighting fixtures incorporating Gore-Tex material filters, known for their waterproof and breathable properties. By integrating Gore-Tex technology into lighting fixtures, the design aims to effectively control moisture and regulate temperature, addressing these two critical challenges [8]. The proposed design ensures consistent and improved thermal management without impacting the functionality or light output of the fixtures while providing exceptional protection from condensation and foreign matter, thus extending the functional lifespan of outdoor LED lighting fixtures.

Moreover, this design initiative is not solely focused on reliability improvement but also aims to offer solutions for product designs that are aesthetically pleasing, functionally easy to install, and feature a simple structure adaptable for various uses and environments. The linear form factor offers a sleek, modern appearance, and the application of Gore-Tex filters supports maintenance cost reduction while ensuring high reliability.

Therefore, this study seeks to contribute to the field of outdoor LED lighting by presenting an enhanced design approach that, through new design and experimental validation, proves the effectiveness of Gore-Tex filters in applications for outdoor LED lighting fixtures. This includes enhanced thermal and moisture management, improved durability against environmental stresses, and maintaining optimal lighting quality over extended periods, ultimately redefining the standards of reliability and efficiency for linear outdoor LED lighting fixtures.

2. Theoretical Background and Structure Design

2.1 Theoretical Background on Expanded Polytetrafluoroethylene

Microstructure Analysis: Expanded polytetrafluoroethylene (ePTFE), commercially known as Gore-Tex, is distinguished by its unique microporous structure. The pores within ePTFE are approximately 20,000 times smaller than a water droplet, approximately 0.1 to 10 microns in diameter, which imparts the material with exceptional waterproof capabilities. Conversely, these pores are about 700 times larger than a molecule of water vapor, facilitating a high degree of breathability. This dual characteristic of being both impervious to liquid water and permeable to water vapor underpins the material's utility in various high-performance applications.

Hydrophobic and Oleophobic Properties: The intrinsic hydrophobicity and oleophobicity of ePTFE are critical for its performance in protective applications. These properties ensure that while water and oil-based substances are repelled, gas and water vapor can pass through, thus supporting the prevention of condensation and maintaining internal atmospheric balance within enclosures.

Durability and Mechanical Stability: The robustness of ePTFE is evident in its high tensile strength and ability to withstand environmental stress, making it suitable for applications ranging from outdoor apparel to industrial and medical applications. The polymer structure of ePTFE remains stable and maintains its mechanical properties over a broad range of temperatures and physical conditions.

Chemical Inertness: An essential characteristic of ePTFE is its chemical inertness. ePTFE does not react with most chemicals, which makes it an ideal choice for applications in chemically aggressive environments. This property is particularly beneficial in industrial filtration systems, where exposure to corrosive substances is common.

Thermal Stability: ePTFE exhibits remarkable thermal stability, maintaining its physical and chemical properties across a wide temperature range. This stability is crucial for applications in both high and low-temperature environments, where material consistency and reliability are paramount [9-11].

Utilizing the key characteristics of ePTFE, when applied to outdoor LED lighting fixtures, we can expect waterproof and dustproof performance while maintaining breathability within a sealed fixture structure. This leads to improved reliability due to enhanced heat dissipation and protection of internal components from various outdoor environments and weather changes. Furthermore, it is anticipated that the prevention of internal condensation due to external temperature differences caused by daily temperature fluctuations or the turning on and off of the fixtures will prevent corrosion of the LEDs and degradation of the diffuser plate's surface quality, thus averting a reduction in light efficiency.

2.2 Structure Design of the Fixture

Based on the analysis, the structural design of the product is depicted in Figure 1. The housing is made of a double structure of Polypropylene (PP) material, with the light-emitting surface being white diffusing material and the body set in gray to anticipate contamination. The overall structure of the fixture is designed to be easily detachable through ceiling attachment brackets made of elastic clip material. Since the long power cord emerges from one end, the design aims to ensure easy and concealable wire management.

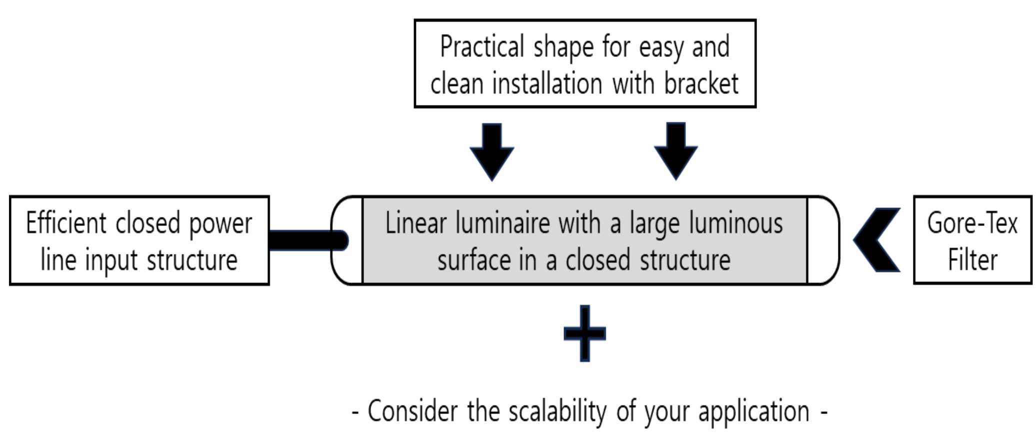

Figure 1. Structural design of the proposed fixture

The side cover parts that finish both ends are designed to be structurally different from each other. One side will be designed to accommodate the core component of this product, the Gore-Tex filter, while the opposite side where the power cord enters will be designed to incorporate part of the Cable gland for sealing, as a single unit with the side cover to improve economic and assembly efficiency, as shown in Figure 2.

Figure 2. Structure of cable gland parts for the AC power cord

Internally, the heatsink where the LED module is mounted is designed out of aluminum, and the LED module is inserted through the frame's rails without the need for attachment screws, allowing it to be secured against movement in the side cover. Similarly, the converter supplying power to the LED Module is designed to be fixed without the use of attachment screws within the heatsink structure.

Lastly, in consideration of the product's future expandability, space for additional components is allocated, and the design contemplates a structure that can accommodate PIR or Doppler sensors in the middle or edges of the product. After the entire assembly and silicone gap sealing, the product aims for a waterproof and dustproof rating of IP66.

2.3 Structure Modeling

Using SolidWorks 3D CAD software, the design and modeling for sample production were carried out. As depicted in Figure 3, the external housing of the fixture was inspired by the structure of traditional outdoor fixtures originally designed for two 55 W fluorescent lamps. Unlike the typically narrower widths of 60 to 80 mm found in common linear type LED fixtures, this design features an expansive light-emitting face measuring 105 mm. This broader surface not only enhances the aesthetic appeal but also increases the coverage area, making it highly suitable for outdoor environments where a wide distribution of light is preferred.

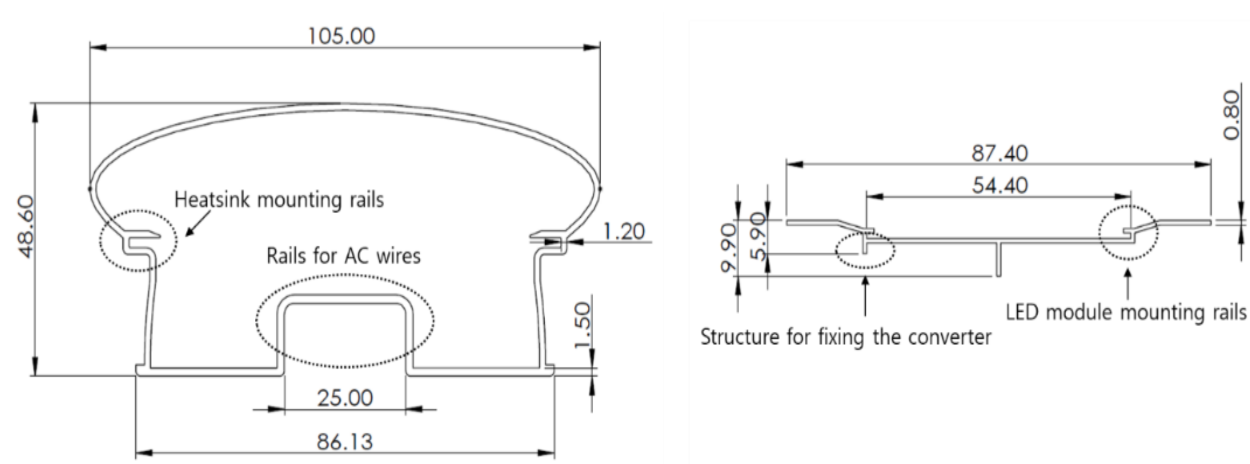

Figure 3. Design of the external housing(left) and internal heatsink(right)

The internal heatsink is designed to attach via the housing's rails, facilitating the mounting of the LED module through the heatsink's rails without the need for screw fittings. The design incorporates a middle rail structure within the housing to ensure that when the product is installed against the ceiling, the AC power cord is concealed, promoting a cleaner installation. The lower sides of the housing are designed to accommodate two spaces; one for housing the LED converter, secured by an asymmetrical converter fixing structure on the heatsink, and the opposite side is reserved for future enhancements, such as the installation of sensor control modules.

Figure 4 illustrates the side cover modeling where the Gore-Tex filter will be installed. The filter chosen is the Gore Screw-In Vent hexagon model, which exceeds IP68 waterproof ratings. To enhance its longevity, additional design features were incorporated to prevent direct rainwater ingress and facilitate drainage of accumulated water. The lower part of the cover includes a breakable structure, designed to allow for easy extension of the AC power line in the field by removing this section for a seamless connection to the next fixture.

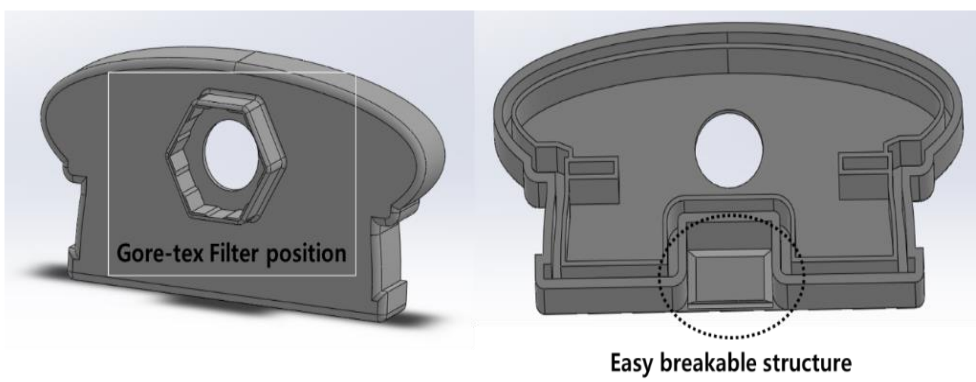

Figure 4. Modeling of the side cover considering the installation of a Gore-Tex filter

The side cover for the AC cable entry, as shown in Figure 5, integrates the Cable gland's screw and nut parts into the side cover, fulfilling the initial design objectives. Once the AC power cable is passed through, sealing is completed by securing the rubber seal and sealing nut, ensuring a fully waterproof configuration without the need for separate assembly with main claws and washer nuts. A designed through-hole at the bottom of the housing enables the AC wire to pass through the rail without lifting when attached to the ceiling, ensuring a tidier installation.

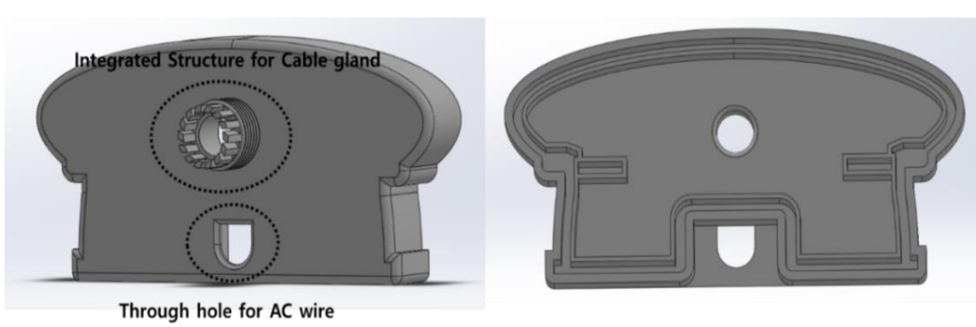

Figure 5. Efficient and economical AC wire entry side cover modeling

The overall assembly and design strategy aim to maximize ease of installation and maintenance while aligning with the aesthetic and functional requirements of modern outdoor lighting fixtures.

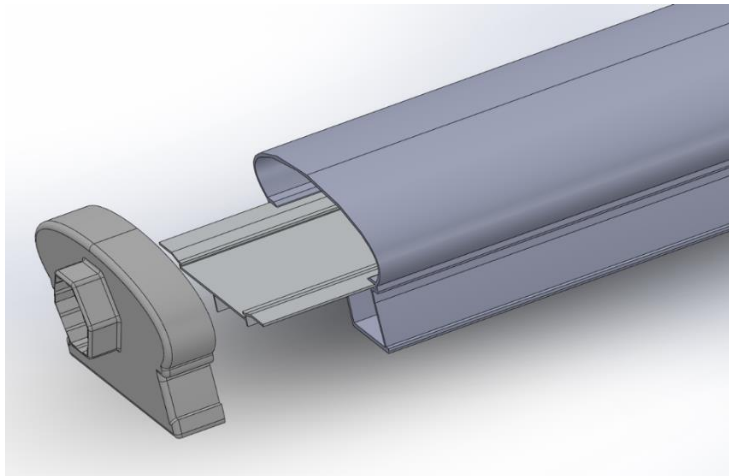

Figure 6. View of assembled parts

2.4 LED Module Design

The power consumption of the lamp was set with a goal of achieving high-efficiency certification, established at 40 watts. A stable and commonly used insulated constant current converter was selected to power the LED module, specified at 36V and 1.0A. Due to the wide light-emitting face, the LEDs were arranged in three rows, totaling 180 LEDs configured in 12 series of 15 parallel circuits. Each LED has a capacity of 3V, 160 mA, and 0.5 watts. Consequently, the current per LED is approximately 67 mA, operating below 50% of the rated current, which is expected to result in minimal heat generation.

The LED module, depicted in Figure 7, is mounted on an aluminum heatsink, designed to facilitate attachment without screws via the heatsink's rails. This ensures a secure fit while allowing movement within the side covers. Moreover, the design of the converter mounting also employs a screwless fixture within the heatsink structure, enhancing overall thermal management and assembly efficiency.

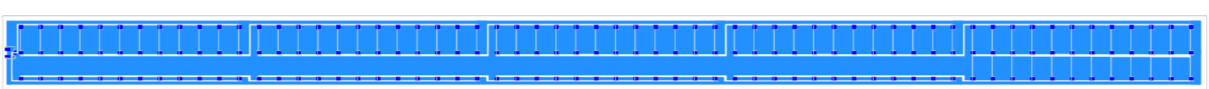

Figure 7. Designed LED module

3. Result and Discussion

3.1 Prototype Production and Analysis

After sample production, the appearance of the Gore-Tex filter mounted within the fixture and the disassembled view of the filter's internal structure can be seen in Figure 8. The filter features a polyamide exterior and an internal membrane made of expanded ePTFE. It is mounted within a specially designed structure that prevents direct rainwater from entering the filter, enhancing productivity by facilitating easier assembly and securing components during manufacturing.

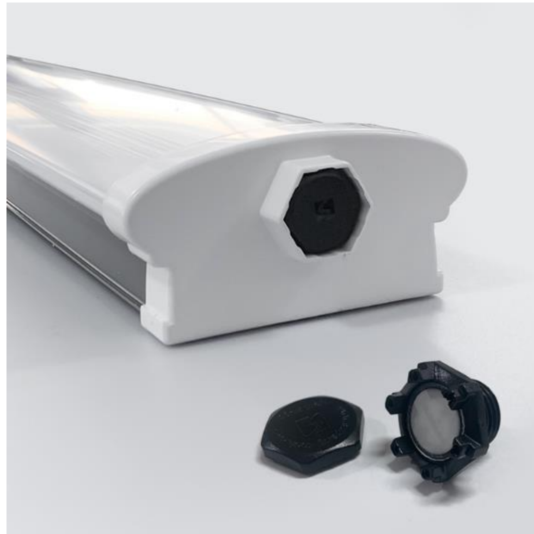

Figure 8. Mounted Gore-Tex filter and internal structure

The overall appearance of the completed fixture sample is shown in Figure 9. The curved structure with a wide light-emitting face is judged to blend well even in varied outdoor environments. The ceiling attachment brackets are robustly fixed, and the concealed AC power line structure functions as intended, showing minimal exposure after installation, thus alleviating any inconvenience due to wiring during installation. The arrangement of LEDs across the wide light-emitting surface ensured that no shadowing occurred at the edges, indicating successful LED array configuration.

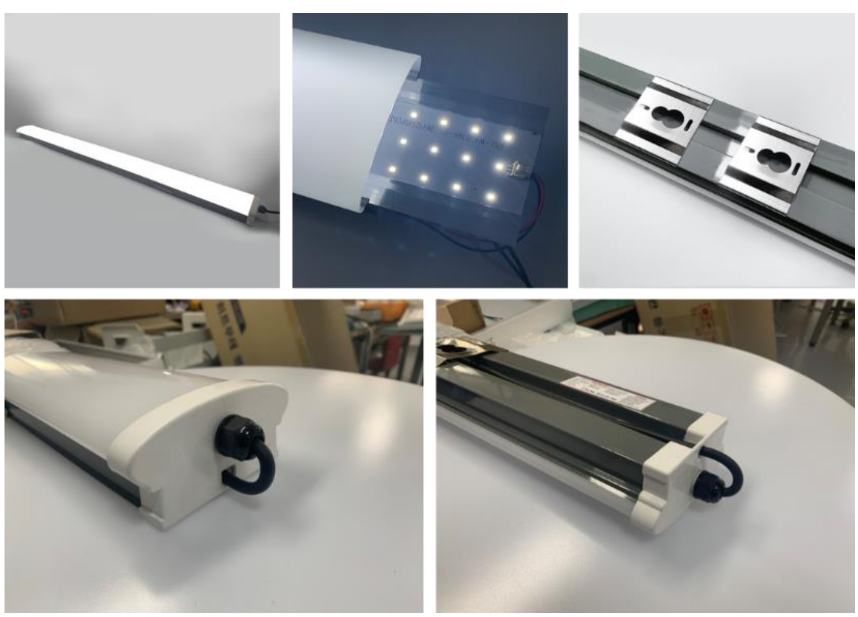

Figure 8. Overall view of the fabricated sample

3.2 Heat Dissipation Characteristics Test

A temperature characteristic test before and after the installation of the Gore-Tex filter was conducted. The top surface of the LED module and the converter housing, known to generate the most heat, were measured using a contact thermometer. Measurements were taken in an ambient environment of 26°C after a stabilization period of one hour. The methodology and results are shown in Figure 9.

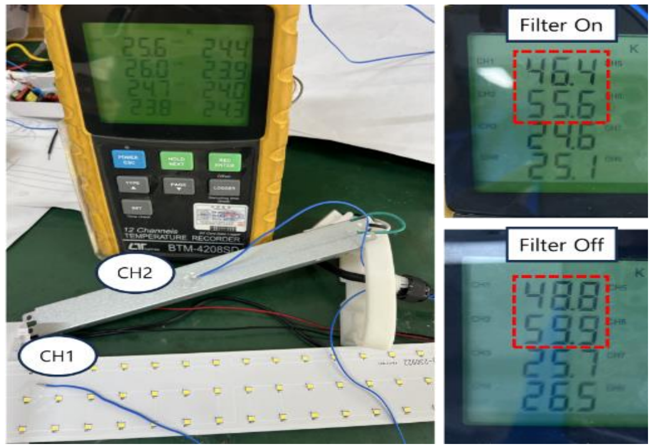

Figure 9. Temperature characteristics measurement

Upon the removal of the Gore-Tex filter, a noticeable increase in temperatures was recorded. Specifically, the LED module's temperature rose from 46.4°C to 48.8°C, an increase of approximately 2.4°C or 5.1%. In parallel, the external casing of the converter saw its temperature increase from 55.6°C to 59.9°C, an elevation of 4.3°C or 7.2%. These findings substantiate the effectiveness of the Gore-Tex filter in facilitating air exchange between the sealed luminaire’s interior and the external environment, significantly enhancing internal component cooling. Furthermore, the data suggests that ambient air temperature variations are more pronounced with the filter’s removal, indicating that the filter’s impact is more substantial at lower external temperatures and for components generating higher levels of heat.

To determine the presence of condensation due to temperature differences between indoor and outdoor environments, the sample was placed in a constant temperature and humidity chamber as shown in Figure 10. The temperature was varied between -35°C and 40°C, with the cycle consisting of 10 minutes of lighting on and 60 minutes off repeated over the course of one week to observe any condensation formation. The experiment showed no occurrence of condensation, which can be attributed to the Gore-Tex filter's ability to quickly equalize the temperature inside and outside the luminaire by facilitating rapid bidirectional air exchange. This effectively reduces the stress and condensation caused by sealing, as the filter manages the pressure differences resulting from temperature changes.

Figure 10. Test for condensation formation inside

3.3 Waterproof and Dustproof Tests

Waterproof and dustproof tests were conducted at the KIEL Institute, an accredited testing facility. The test results, outlined in Table 1, confirm that the product meets the IP66 waterproof and dustproof standard.

Table 1. Waterproof and dustproof test (IP66)

<table>
<tr><th colspan="2">Test Item</th><th>Test Content</th><th>Test Result</th></tr>
<tr><td rowspan="2">Ensure that the product meets the IP66 waterproof and dustproof standard</td><td>First-stage test (6)</td><td>Immersion in 1.0 mm of water is not allowed, and there should be no harmful effects on the product after the test
· Specific gravity of talc: 2 kg/m³
· Test duration: 8 hours</td><td>Pass</td></tr>
<tr><td>Second-stage test (6)</td><td>Water sprayed outward from the perimeter in all directions is unlikely to have a will have no harmful effect
· Nozzle inner diameter: 12.5 mm
· Water flow rate: 100 L/min ± 5%
· Test distance: (2.5 ~ 3) meters
· Test duration: 3 minutes</td><td>Pass</td></tr>
</table>

The design aimed for an IP66 rating. The first-stage dustproof performance was targeted to completely protect against dust to prevent a decrease in light efficiency due to contamination inside the diffuser plate. The second-stage waterproof rating was targeted to withstand strong jets of water since it is designed for outdoor use and not as a submersible light. The results demonstrate that the ePTFE membrane of the Gore-Tex filter allows for the passage of air and water vapor while blocking dust and droplets, thus providing perfect waterproof and dustproof characteristics. This foundation enables the use of various types of Gore-Tex filters such as Vents Screw-In, Snap-in Vents, or Adhesive Vents in the designed fixtures, making them adaptable for different structures and uses of outdoor LED lighting fixtures.

4. Conclusion

We have successfully demonstrated how the integration of Gore-Tex filters can significantly enhance the reliability and maintenance ease of outdoor LED lighting fixtures, which are increasingly utilized across diverse environments. Our innovative approach not only ensures the IP66 standard for waterproof and dustproof qualities but also optimizes air circulation within the sealed luminaire. This advancement crucially mitigates heat accumulation and prevents internal condensation caused by temperature differentials, thereby protecting the internal components from corrosion. Furthermore, it shields the fixtures from external contaminants such as dust and insects, preserving the luminaire's original light characteristics over prolonged use.

Our design introduces a practical and efficient structure that incorporates Gore-Tex filters, setting a new benchmark for outdoor LED lighting. This study not only underscores the potential of enhanced Gore-Tex application in lighting technologies but also provides a scalable model for improving the performance of LED luminaires in outdoor conditions. Through rigorous testing and detailed analysis, we confirm that our proposed design significantly extends the operational lifespan and reliability of these lighting systems, paving the way for their broader application in enhancing urban and architectural environments.

Acknowledgement

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