



OEM Design-in guide

Philips Fortimo LED Linear Light Module system (LLM) - November 2009

• Philips Fortimo LED LLM1100 & 1800 in 3000 & 4000K



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1. Introduction of Philips Fortimo LED Linear system



Fortimo LLM module



Fortimo LLM driver

Thank you for choosing the Philips Fortimo LED LLM system.

This guide tells you all about this system. If you require any further information or support please consult your local Philips office or visit: www.philips.com/support or www.philips.com/fortimo.

The advantages of LEDs have been known for 40 years:

- Long life – low maintenance cost.
- Robustness – high reliability.
- Saturated colors – maximum visual effect.
- Cool beam – no heating of illuminated products.
- No UV or IR – wide application possibilities.
- Low-voltage operation – more safety, ease of use.
- Mercury-free – care for the environment.

Rapid improvements in high-power LED technology mean that LEDs can now be used for the first time in 'real' lighting applications, providing improvements over traditional lighting systems. The use of LEDs has implications for lighting manufacturers in terms of differences in solid-state lighting usage compared with traditional lamps: for example how to design given the constant improvements in specifications; how to provide the necessary heat sinking and how to deal with variations in flux and/or color. The Philips Fortimo LED LLM system addresses these differences and facilitates easy adoption of LED technology for high lumen packages. The system is designed for integration in luminaires (system). This technical application guide addresses the relevant issues to support and facilitate the work of specifiers and lighting system designers.

Fortimo LED Linear system is primarily designed for luminaires in outdoor use, but can also be used in certain indoor applications as long as this creates no design conflicts with the Fortimo LED Linear system and the European luminaire standards are respected (EN60598). Please consult us if you wish to deviate from the design rules as described in this application guide. Meanwhile also complementary businesses especially for heat sink and reflector design are developing around Fortimo LED LLM systems. In the application guide you will also find references to heatsinking and reflector manufactures.

1.1 Features and benefits

Features	Benefits
Constant Light Output (CLO)	No light depreciation
Linear shaped LED module	Easily creation of uniform and rectangular lightpatterns
Directed light output (batwing distribution)	Reducing light pollution (no sky glow)
Fortimo technology applied (RP film layer)	High efficient, energy saving lighting (>64lm/W at system level)
Fixed form factor (Lumen packages 1000-4500)	Reduced Time To Market (TTM) and related cost for OEMs
Latest LED technology inside ensuring performance and availability	Reduced LED supply chain complexity for OEMS
No mercury	Environmental friendly
Long lifetime (50Khrs)	Reliable (system approach)
CCT 3000K & 4000K / Ra 75 and good color consistency	Comfortable and safe high quality LED light
Easy replacement (not sealed for life)	Upgradeable



Residential area application



City Application



Outdoor Park application

1.2 Applications

Examples are:

- Residential.
- City centre.
- Square.
- Park.
- Wall washing.
- Flood lighting.
- General lighting.

2. LEDs, the heart of the Fortimo Linear module

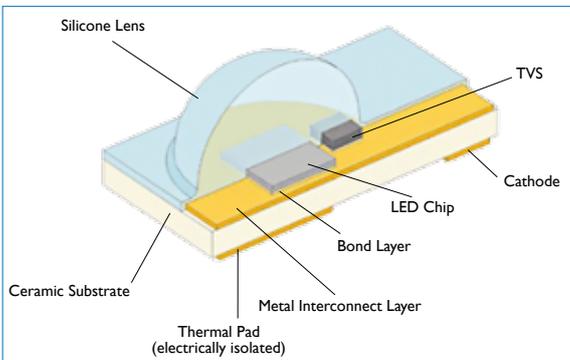
The development of Light Emitting Diodes (LEDs) is progressing at such a pace that they are rapidly gaining importance for lighting applications. To most people, the term LED still only means the small indicator lights that show whether the TV set is switched on. These tiny light sources barely emit enough light to make them selves visible. However, breakthroughs made in the last few years now allow LEDs to be used for 'real' lighting applications that have traditionally been the domain of incandescent lamps and discharge lamps. The Philips/Agilent joint venture Lumileds was the first to bring high power LEDs for lighting applications to the market under the Luxeon trademark. Luxeon emitters are among the highest-performance LEDs in the world, allowing us to offer the brightest solid-state lighting solutions.

2.1 What is a LED?

LEDs are solid-state devices, built up from crystalline layers of semiconductor material. The light generation process makes use of the special electronic properties of crystalline semiconductors in a process called injection luminescence. In brief, this means the injection of charged particles by an electric field from one semiconductor layer into another, where they are able to relax to a lower-energy state by emitting visible light. LEDs produce narrow light spectra. The bandwidth remains limited to a few tens of nanometers, and are therefore perceived by the human eye as a single, deeply saturated color. LEDs are now available in all wavelength regions of the visible spectrum; yellow is the only region in which no high-power LED is currently available. White light can be produced by combining LEDs of different colors (for instance red, green and blue), or by applying phosphor coatings on blue or ultraviolet LEDs. Like many other lamps, LEDs cannot be connected directly to the mains. The LEDs have to be operated at a stabilized low voltage, which is provided by Driver electronics. However, LEDs do not need ignition and can be switched within milliseconds. LEDs do not generate nearly as much heat as many other lamps, but that does not mean that thermal design is not important. LEDs do produce heat when they operate, and are themselves relatively sensitive to temperature. Thermal considerations are therefore very important aspects of LED lighting system design.



LUXEON Rebel LED



Cutoff section LED

2.2 LED packaging

The bare LED die is still a very sensitive and fragile device that must be handled in a clean room environment. Before bringing them outside, they must be packaged. The light flux of conventional LEDs, for example those used as indicator lights on TV sets, is severely limited by the amount of heat generated. In practice, conventional LED packages are limited to about 0.15 W at most, and emit only a few lumens. Their light is too weak to be used for illumination purposes, and they can only be used for luminance applications (i.e. when the light source is intended to be viewed directly). A breakthrough came with a new package design invented by Philips Lumileds, which guides away the heat generated at the diode junction much more efficiently. LEDs based on this package are sold under the trademark Luxeon. Instead of an epoxy cap, the chip is encapsulated in a silicone gel covered by a polymer lens. Using two different materials for encapsulation and for the primary optics allows better optimization of material properties for heat management and lifetime. The slug is a large metal body that takes up the heat from the chip and provides a low-thermal-resistance route to the outside world. This package design now makes high-power LEDs feasible.

2.3 Binning

The subject of binning should be explained because of its importance in LED system design. As in other semiconductor manufacturing processes, in LED production the number of parameters of the epitaxy process is very large and the process window small (for example, the temperature must be controlled to within 0.5 °C (<1 °F) across the wafer at temperatures of ~800 °C/1470 °F). The difficulty of achieving such a high degree of control means that the properties of the LEDs may vary significantly within single production runs and even on the same wafer. To obtain consistency for a given application, binning (= selection in bins) is mandatory. Binning involves characterization of the LEDs by measurement and subsequently categorizing them into several specific bins. To keep the cost per LED down, LED manufacturers must sell the full production distribution. At the same time they cannot guarantee the availability of all bins at all times. There is a trade-off between logistics and cost price on the one hand, and the application requirements on the other. Setting the specification too tightly will increase the cost price and may lead to logistics problems. System design should therefore try to combine LEDs from different bins intelligently to obtain the required system performance at a reasonable price and with reasonable delivery reliability.

2.4 LUXEON Rebel LEDs

LUXEON Rebel is the smallest surface mountable power LED available today. With the industry's best lumens per package, highest light density (lumens per mm²), and the highest packing density, LUXEON Rebel is ideal for both space constrained and conventional solid lighting applications. Due to the small mounting surface we have been able to use multiple LUXEON Rebel within the Fortimo products in order to match required high lumen packages.

2.5 Fortimo addresses the issue of binning

High-quality LED light is achieved by mixing the light of blue LEDs and applying a special Fortimo phosphor technology remote from the LEDs. High-quality white light for outdoor applications is characterized by a color rendering of minimal 70, popular CCTs in general lighting applications of 3000 K and 4000 K and a color consistency comparable with conventional PLL and HID solutions (five to seven SDCM).

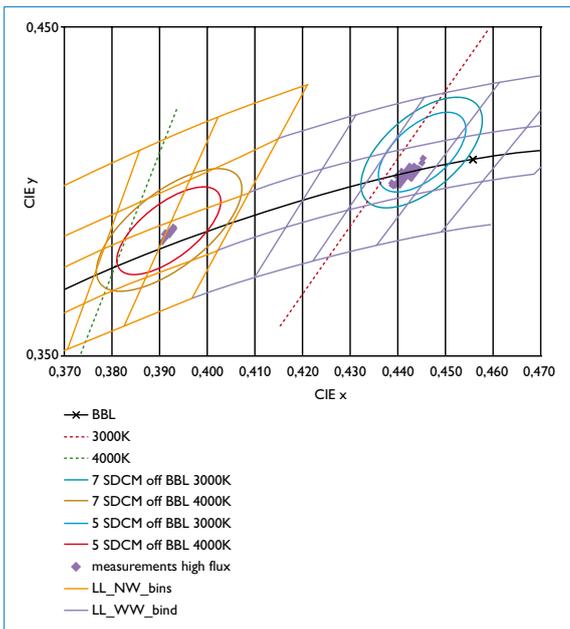
2.6 Color consistency (SDCM)

The target specification of Fortimo LED LLM systems for color consistency is 5 SDCM @ 0-hours and 7 SDCM @ 10K hrs. This is a similar specification as for conventional PLL lamps. SDCM stands for Standard Deviation of Color Matching and the value 5 refers to the size of an ellipse around the black body locus. Staying within this ellipse results in a consistency of light that ensures that from one luminaire to another no difference can be noticed.

In the visual we have plotted > 150 Fortimo LED LLM systems and you can see they all fit within the 5 SDCM ellipse. This really demonstrates the unique quality of the remote phosphor concept. We also plotted these results in a typical bin distribution sheet of Philips Lumileds. As you can see all Fortimo's fit within 1 bin! Typically you can buy 6 to 12 bins combinations, not so precise as the 1-bin result of Fortimo.

2.7 Miniaturization

LEDs are typically much smaller than conventional light sources. Lighting designers and specifiers immediately recognized the fact that LEDs allow dramatically different lighting designs that capitalize on these tiny, unobtrusive light sources. This is understandable, but care must also be taken to deal with the heat produced by power LEDs. Proper heat management places limits on miniaturization.



Color consistency (SDCM)

3. Philips Fortimo LED LLM system



Fortimo LED Linear System

The Fortimo LED LLM portfolio is a complete range. It is primarily designed for luminaires in outdoor use, but can also be used in certain indoor applications. Further extensions of the portfolio will be in high lumen packages and programmable dimming features. The future range extensions will make use of the current form factor to build further on the future proof promise of Fortimo LED systems. As the system is future proof it will be possible to replace and upgrade the system without modifying the luminaire.

3.1 The Fortimo LED LLM system components

- Fortimo LED Linear Light Module.
- Fortimo LLM Driver.
- Fortimo LLM Cable 25 cm.

3.2 Nomenclature

Philips Fortimo LED LLM1800 28W/730 220-240	
Philips	Brandname
Fortimo	Family type
LED	LED system
LLM	Fortimo type descriptor
1800	Light output
28W	Energy consumption System
730	CRI+CCT
220-240	Voltage range

Philips Fortimo LED LLM1800 28W/730 LS-8	
Philips	Brandname
Fortimo	Family type
LED	LED system
LLM	Fortimo type descriptor
1800	Light output
28W	Energy consumption System
730	CRI+CCT
LS-8	Lumistep 8 hrs dimming

Note LS stands for the lumistep dimming protocol. See dedicated chapter (3.8) for details about lumistep.

3.3 Fortimo LED Linear portfolio

3.3.1 3000K

- Fortimo LED LLM**1800** 28W/730 220-240V
- Fortimo LED LLM**1800** 28W/730 LS-6
- Fortimo LED LLM**1800** 28W/730 LS-8
- Fortimo LED LLM**1800** 28W/730 LS-10

- Fortimo LED LLM**1100** 17W/730 220-240V
- Fortimo LED LLM**1100** 17W/730 LS-6
- Fortimo LED LLM**1100** 17W/730 LS-8
- Fortimo LED LLM**1100** 17W/730 LS-10

3.3.2 4000K

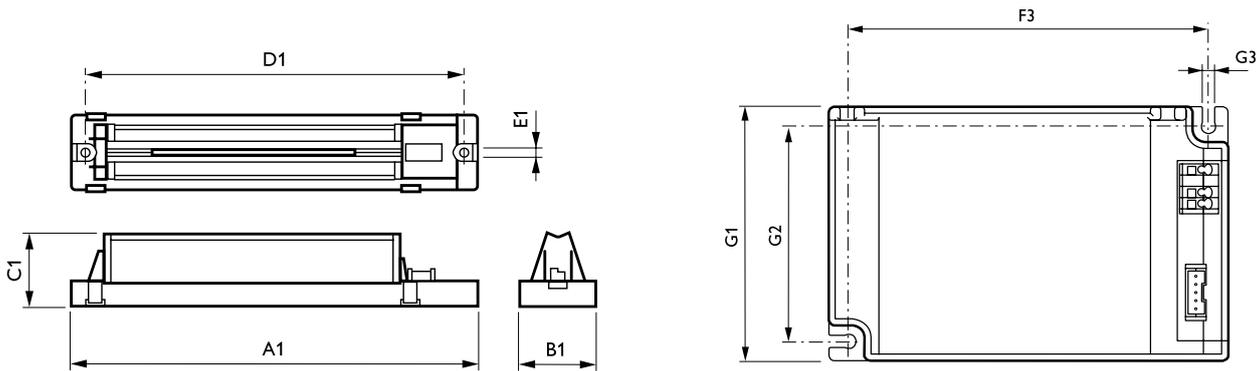
- Fortimo LED LLM**1800** 25W/740 220-240V
- Fortimo LED LLM**1800** 25W/740 LS-6
- Fortimo LED LLM**1800** 25W/740 LS-8
- Fortimo LED LLM**1800** 25W/740 LS-10

- Fortimo LED LLM**1100** 15.5W/740 220-240V
- Fortimo LED LLM**1100** 15.5W/740 LS-6
- Fortimo LED LLM**1100** 15.5W/740 LS-8
- Fortimo LED LLM**1100** 15.5W/740 LS-10

3.3.3 Future range extensions

Fortimo LED Linear with higher lumen packages (3000, 4500 and 8000).
 Fortimo LED Linear with programmable dimming possibilities.
 Fortimo LED Linear with CRI of 80+.

3.4 Dimensions of Fortimo LED Linear system



Fortimo LLM module



Fortimo LLM driver

A1	B1	C1	D1	E1	F1	F3	G1	G2	G3	H1
230.0	45.0	42.0	214.5	4.5	123.0	110	79.0	67.0	4.5	33.0

Dimensions in mm.

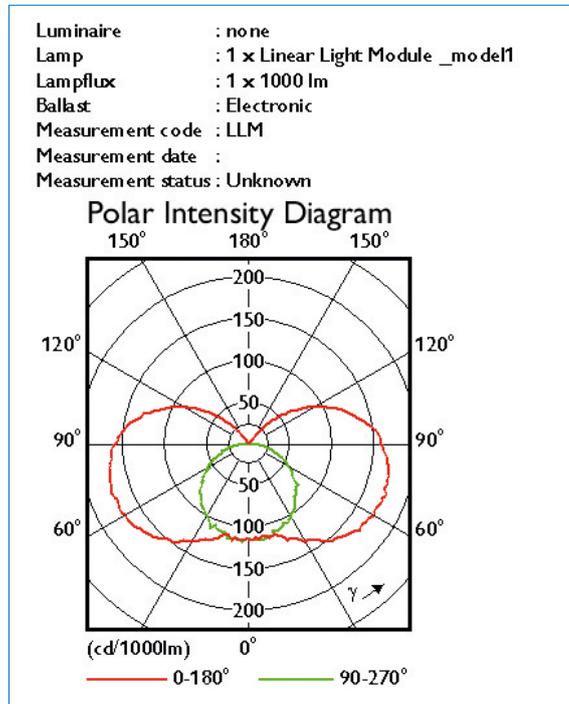
3.5 Fixation (mechanical)

The separate components (Driver and Module) of the Fortimo LED LLM system can be securely fastened by the mounting holes located on the module and driver. Please refer to dimensional drawing for the specific details such a pitch and diameter.

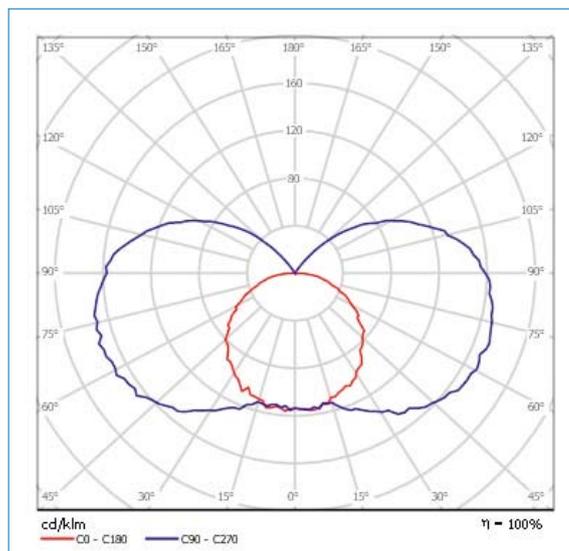
The 3D CAD files will be available for downloading from www.philips.com/fortimo. For fixation of the system we advise to use hexagon socket head cap screw M4 (DIN 912 / ISO 4762) with a spring lock washer for screws with cylindrical heads M4 (DIN 7980) of Stainless steel A2 (DIN 1.4301 / AISI 304).

3.6 Lighting performance characteristics

3.6.1 Photometric diagrams



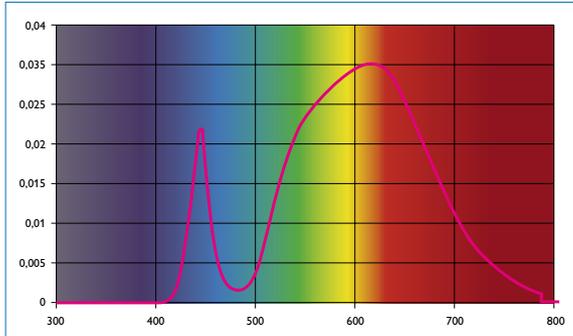
Polar diagrams Fortimo LED Linear



Batwing light distribution

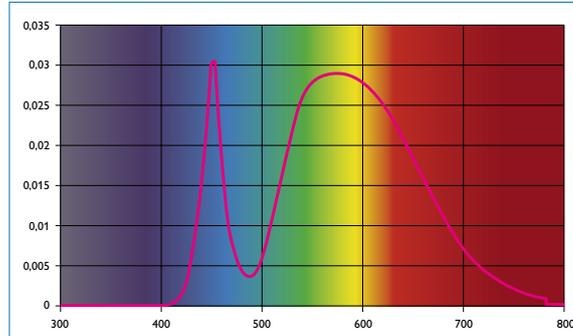
3.6.2 Spectral power distribution Fortimo LLM

Special Power Distribution Fortimo LLM 3000 K



Wavelength (nm)

Special Power Distribution Fortimo LLM 4000 K



Wavelength (nm)

3.6.3 UV and other hazards

PET value >100 hrs./Klux (zero UV)

Damage factor 0.08 @ 4100 K

IR (infrared) radiation As well as being free of UV radiation, the LED modules are also free of infrared radiation in the beam.

3.6.4 Photobiological safety aspects

As of March 2007, LEDs and LED-based products for general lighting are no longer included in the scope of the Eye Safety standard for lasers, IEC 60825-1 'Safety of laser products'. The new lamp standard, IEC 62471 'Photobiological safety of lamps and lamp systems', covering incoherent light sources, is now applicable. This international standard gives guidance for evaluating the photobiological safety of lamps and lamp systems including luminaires. Specifically it specifies the exposure limits, reference measurement technique and classification scheme for the evaluation and control of photobiological hazards from all electrically powered incoherent broadband sources of optical radiation, including LEDs but excluding lasers, in the wavelength range from 200 nm through 3000 nm. In the photobiological safety standard, hazard categories are defined as follows:

Radiance-based:

- Blue Light LB 300 – 700 nm
- Retinal Thermal LR 380 – 1400 nm
- Retinal Thermal Weak Stimulus LIR 780 – 1400 nm

Irradiance-based:

- Actinic UV Skin & Eye ES 200 – 400 nm
- Eye UVA EUVA 315 – 400 nm
- Blue Light Small Sources EB 300 – 700 nm
- Eye IR EIR 780 – 3000 nm

Hazard Category	Emission Limit
LB	Low (Risk Group 1)
LR	Exempt*
LIR	Exempt
ES	Exempt
EUVA	Exempt
EB	Exempt
EIR	Exempt

Emission limit

* Exempt means 'no risk'.

3.6.5 Measurements on the Fortimo LED LLM

The following should be taken into account: The effective radiance measurement for Blue Light (LB) modules is 'Low', meaning that the LED modules are categorized in Risk Group 1. For the 1800 lumen version, the permitted exposure time for Blue Light radiance (relevant when looking into the source) is limited to 1.5 hours, while for the 1100 lumen version it is 3 hours. Because of the Law of Conservation of Radiance, integrating the LED module into a luminaire results in either the same radiance or a reduced radiance. Final assessment of the luminaire is recommended.

- The measured irradiance-based values (E) for the categorized hazards are all within the exempt group (both 1100 and 1800 lumen versions).
- In general the permitted exposure time for irradiance is limited when in the 'low', 'moderate' or 'high' risk group. Limiting the exposure time and/or the distance to the source can reduce the hazard level. However, for the measured LED modules there are no special precautions necessary since they are ranked in the exempt group. Final assessment of the luminaire (including e.g. secondary optics) is recommended.



Photobiological safety is not assured if the Fortimo LED module is lit up without the cover. Direct exposure to the blue LED light is dangerous for the eyes.

3.7 Starting characteristics

The system can be switched on in milliseconds, which is a general characteristic of LEDs. It is planned to have a programmable outdoor driver, making it possible to switch in milliseconds to any dimming level for any length of time.

3.8 Luminous flux during start period

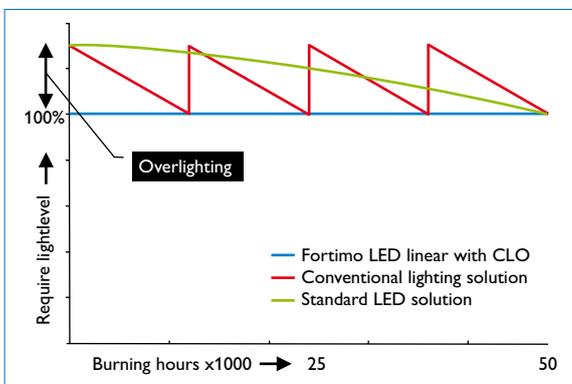
In contrast to other light sources, LEDs can be switched on at full power (or at any other dimmed level) instantaneously. The Fortimo LED LLM system requires an initial burning-in time of 100 hours to reach the listed specifications because of the combination of the LEDs and the remote phosphor used in the modules.

3.9 Constant Light Output (lumen maintenance)

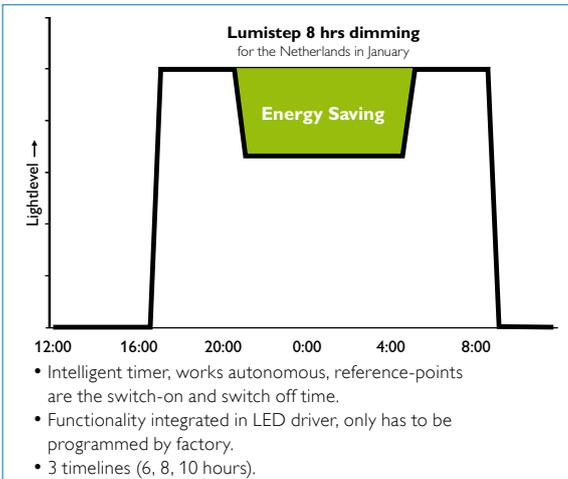
The Fortimo Led Linear system has been equipped with a special feature CLO (Constant Light Output), when used within specification a lumen maintenance of 100% is expected at 50,000 hours (average lifetime specification).

3.9.1 The main benefits of a CLO system are the optimized energy consumption and improved system reliability

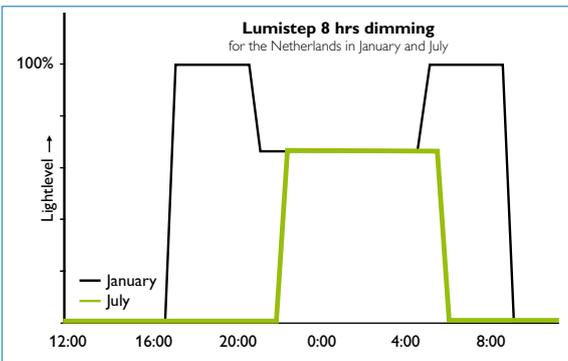
The main difference between a CLO system and a conventional system or standard LED light system is that with CLO the end-user always has the required light level; there is no overlighting (see picture Overlighting CLO). The CLO feature uses a predictive algorithm to increase the current to the LED over the specified lifetime of 50Khrs. As the current increases also the energy consumption increases with about 20%. Compared to a conventional PLL 36W (40W system level) an energy saving of 23% for warm white and 31% for neutral white can be achieved. These savings can even be increased to respectively 42% and 48% when the lumistep (8 hrs) version is used.



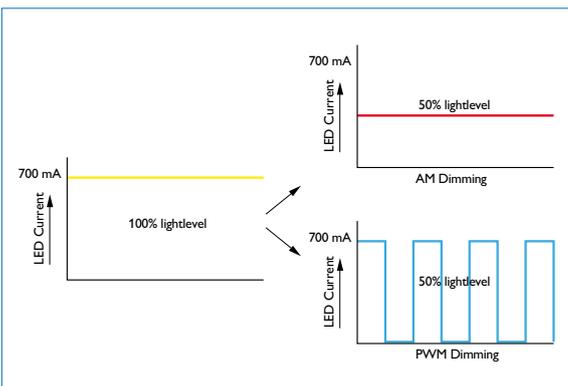
Overlighting versus CLO



Lumistep dimming



Example differences dim period January and July



3.10 Lumistep dimming

To enable even further energy savings a special feature has been integrated in the Fortimo LED LLM system based on the lumistep protocol. This is a stand alone feature, which will dim the light level for a pre-determined period (6, 8 or 10 hrs) per night.

- Intelligent times, works autonomous, reference-points are the switch-on and switch-off time.
- The functionality integrated in LED driver has to be programmed by factory.
- 3 time lines (6, 8, 10 hours).

The intelligent software which makes up the Lumistep protocol counts the time between the switch on and off point for three days in a row and determines the middle point on this data. As most lighting installations make use of the sun rise and sun set times the mid point of the program is around the same point during a year. From this point the software calculates at which point the dimming should start and stop. So in the summer the standard dimming period can be as long as the period between switching on and off (the night period). This is illustrated in picture: Example differences dim period January and July.

The dimming characteristics of the Fortimo LED LLM makes use of a so called amplitude (AM) dimming protocol. Most LED systems use PWM (pulse width modulation), which means that the current is switched on/off at high frequency. When dimming the time between the on and off switching increases. AM dimming reduces the current through the LEDs to achieve lower light levels and another advantage is that there is no:

- No audible noise during dimming.
- No visual interference with other lighting or video sources.

3.11 Electromagnetic compatibility

Electromagnetic compatibility, EMC, is the ability of a device or system to operate satisfactorily in its electromagnetic environment without causing unacceptable interference in practical situations. When connecting the Functional Earth (FE) of the driver the system will always be compliant to the electromagnetic compatibility requirements as laid down in European Norms EN 55022, EN 61000-3-2 and EN 61547. However, in some applications it can be that the system will also be compliant to the EMC norms even without connecting the Functional Earth. When there is no possibility to connect the FE the EMC behavior of the system might be improved by connecting the driver FE to the aluminum base of the light module.

3.12 Exposure to direct sunlight

Exposure to direct sunlight during operation may have severe temperature or UV effects. Where this situation is likely, extensive temperature testing is recommended. The Fortimo LED LLM systems are build-in systems, so this is expected to be negligible.

3.13 Vibration and shocks

Shock resistance: 50 g @ 6 ms semi-sinusoidal.

Vibration resistance: sweep 50-150 Hz, one hour at resonance frequency (all 3 axes) without failure.

3.14 Standards and approvals

Philips Fortimo LED LLM systems comply with the following international rules and regulations, including:

Safety EN/IEC 60598-1 & 2-2, EN 61347-1, 2-13

Approvals ENEC 05

Philips Fortimo LED LLM systems carry the CE marking. CE is the abbreviation of Conformité Européenne. It expresses conformity of products to mandatory requirements of the European Community Directives. The CE mark acts as a 'passport' that allows goods to circulate freely throughout the European Union. Furthermore, it simplifies inspection by Market Controlling Bodies. Two European directives cover lighting products: the Electromagnetic Compatibility (EMC) Directive and the Low Voltage Directive (LVD). The Philips Fortimo LED LLM system carries the CE marking on the basis of compliance with the following standards: EN 61547, EN 61000-3-2, EN 55015 and EN 55022

3.15 IP codes, dust and moisture protection

The Fortimo LED LLM modules and LLM drivers are build-in systems and have therefore no IP classification. The Fortimo LED system is not designed for operation in free air. The OEM is responsible for proper IP classification and approbation of the luminaire.

3.16 Glow-wire test

Philips Fortimo LED LLM systems conform to the 960 degree glow-wire test.

Reference test: according to additional national deviations for clause 13.3 (Annex 2c of EN 60598-1). An exception is made for France, where local regulations are more strict.

3.17 End-of-life behavior

Unlike typical conventional light sources, LEDs are not subject to sudden failure or burnout. There is no time at which the light source will cease to function. Instead, the performance of LEDs shows gradual degradation over time.

When used according to specification, Fortimo LED LLM modules are predicted to deliver an average of 100% of their initial intensity after 50,000 hours operation. This is achieved via the CLO (Constant Light Output) feature. To compensate for the gradual degradation of the LEDs a predictive algorithm is used.

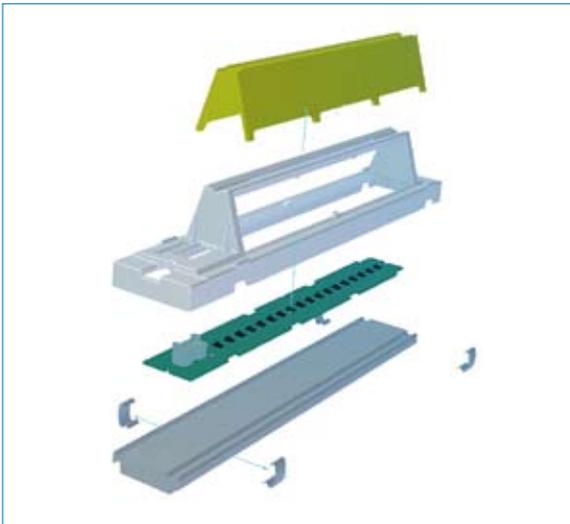
The lifetime of the system is therefore more dependent on the other electronic system components and soldering methods. The LEDs in the Fortimo LED LLM module are connected in series. If one LED fails, this may be due to an internal short-circuit (character of blue LEDs). In this case it will still conduct current, so that the other LEDs will still operate.

3.18 About the Fortimo LED Linear Light module

The LED module consists basically of four main components:

- PCB with LEDs.
- Mixing chamber.
- Heat spreader.
- Diffuser with remote phosphor technology.

High-quality white light with high efficiencies is achieved with a plain PCB with LEDs and a remote phosphor film layer. The mixing chamber ensures perfectly mixed light, resulting in uniform colors and good color consistency. The heat spreader facilitates optimal heat transfer and helps luminaire manufacturers to design their own heat sink system. The heat spreader is equipped with a hole on either side of the module for fixing. The function of the diffuser is to shape the light output, resulting in a batwing distribution. In this manner the luminaire manufacturer has the freedom to design its own secondary optics. The overall dimensions of the LED module, i.e. the combination of heat spreader and mixing chamber, is optimized for lumen packages varying from 1100 lumen to 4500 lumen.



Exploded view Fortimo Light module

3.19 About the Fortimo LLM driver

The highly efficient Fortimo LLM driver is specially designed to operate the Fortimo LED Linear Light Module. It is designed to operate high-power LEDs.

- Maximum current settings of 700mA.
- Max. 80V enables operation of many LEDs in series.
- High efficiency: .90% at full load (220-240 V).
- Tcase life = 55 °C.
- Safety Class 2 system.



Fortimo LLM Driver

3.20 About the Fortimo LLM cable

For connecting a Fortimo LLM driver to a Fortimo LED Linear Light module a specific cable has been developed. The standard Fortimo LED LLM cable is 250 mm. We advise to use the Fortimo LED LLM cable, if an OEM prefers to use a cable with a different length it has to organize this itself.

The cable specification should meet UL & IEC/EN requirements. However, approval of the Fortimo LED LLM module and LED driver is based on a reference luminaire with the standard 250 mm cable length. In any case, any luminaire design needs its own approval, organized by the responsible OEM, irrespective of the length of cable used. If an OEM prefers to have a cable with a different length it can use the following cable/connector specifications:

JST connector:

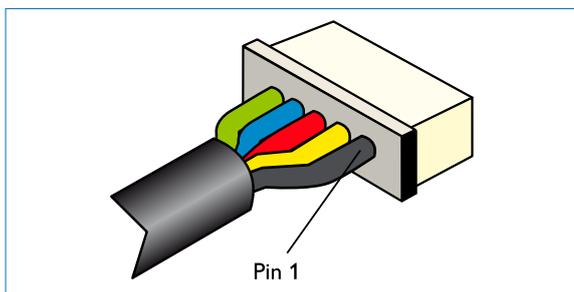
Housing JST XAP-05V-1

Contact JST SXA-001T-P0.6

Cable:

5x Wire 24 AWG UL style 1569 (green, blue, red, yellow, black)

Heat shrink tube



Fortimo LLM Cable details

Pin 5: Wire 24 AWG UL style 1569 green	= Signal ground
Pin 4: Wire 24 AWG UL style 1569 Blue	= LED module setting
Pin 3: Wire 24 AWG UL style 1569 Red	= NTC (thermal control)
Pin 2: Wire 24 AWG UL style 1569 Yellow	= Power ground
Pin 1: Wire 24 AWG UL style 1569 Black	= Current (power output)

3.21 Fortimo LED LLM System disposal

At the end of their (economic) lifetime, appropriate disposal of the Fortimo LED LLM or its components is recommended. The modules are basically normal pieces of electronic equipment containing components that at present are not considered to be harmful to the environment, or which can be disposed of with normal care. It is therefore recommended to dispose of these parts as normal electronic waste, according to local regulations.

4. Designing a luminaire

4.1 Introduction

The Fortimo LED Linear system is designed as a LED breakthrough in energy efficacy, comfortable and high quality light. To facilitate the integration of Fortimo LED Linear in existing luminaires and/or developing new luminaires the interface points of the system are put down, together with recommendation.

4.2 IEC recommendations

The general recommendations for luminaire design by IEC and the national safety regulations (ENEC, CE, ANSI etc.) are also applicable to Fortimo LED LLM systems. The luminaire manufacturer is advised to conform to the international standards of luminaire design (IEC 60598-Luminaires).

4.3 Electrostatic device (ESD) measures

The Fortimo LED LLM systems do not require special ESD measures in a production environment.



Fortimo LLM driver & connection layout mains

4.4 Wiring

The sticker on the power supply shows the connections layout for the connection to mains. The minimum diameter for the main cables is 0,2 mm and the maximum diameter is 1.5 mm². The system should not be serviced when mains voltage is connected; this includes connecting or disconnecting the Fortimo LLM cable!

4.5 Optical design (Secondary optics)

The Fortimo LED LLM module generates a batwing beam shape, which is a pragmatic starting point for secondary optic design by OEMs. Secondary optics are not part of the Fortimo LED LLM system offering as this is an added value area for OEMs. Meanwhile a complementary reflector business around the Fortimo LED LLM is developing by several companies like Alux Luxar and Jordan. A Ray-set will become available upon request.

4.6 Thermal management

For optimal performance the Fortimo LED LLM system must operate within specified temperature limits. Depending on the application and luminaire design a suitable solution for the thermal management should be applied.

4.6.1 Test requirements

Temperature measurements should only be performed when the luminaire is thermally stable, which may take 0.5 to 2 hours depending on the thermal capacity of the luminaire (see also the relevant clauses in IEC 60598). For all measurements such as temperature, luminous flux and power, a stabilization period of at least half an hour must be allowed before any reliable data can be obtained. Measurements must be performed by means of thermocouples that are firmly glued to the surface (and not, for example, secured with adhesive tape).

4.6.2 Temperature range

Because LEDs are temperature-sensitive, LED modules require a different approach with respect to thermal management. The system has been designed to operate between -20 °C and 75 °C at T_{case}.

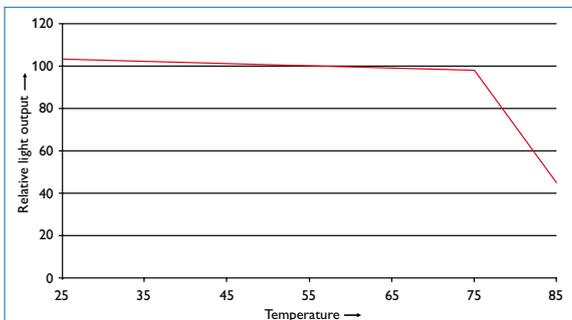
The lower and upper limit has been determined by the application and by the components used in direct relation to the performance and reliability of the system.



Tc point light module

4.6.3 Critical temperature points (T_c)

For LEDs the junction temperature is the critical factor for operation. Since there is a direct relation between the case temperature and the LED junction temperature it is sufficient to measure the aluminum casing of the LED module at its critical point (T_c). The T_c point is located on the back surface of the LED module and for the driver it is noted on the label of the driver. If the case temperature at the T_c point exceeds the recommended T_c life of 55 °C the performance of the LEDs and the Fortimo LED system will be adversely affected, in terms of light output, lifetime and lumen maintenance.



Relative light output

If due to insufficient thermal management or other circumstances the T_c point reaches 75 °C, a thermal circuit* will be engaged. This circuit will start dimming the LED module. The thermal circuit is only a fail save in order to protect the module against overheating.

The optimum performance is only achieved if T_c point stays below 55 °C. The graph shows the effect on the relative flux as a function of T_c temperature.

Note:

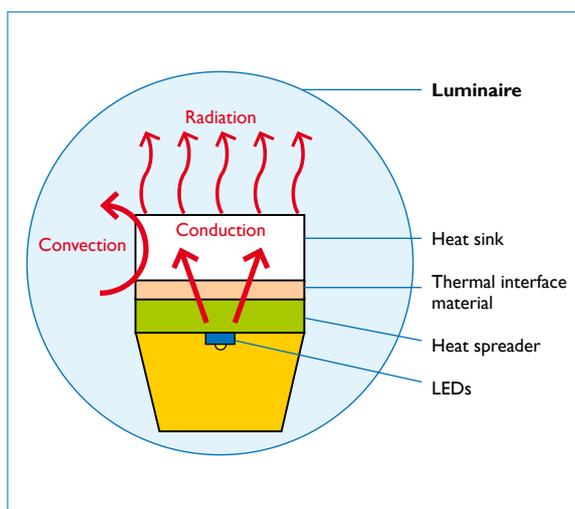
The thermal circuit is applied in all Fortimo LED Linear versions.

4.6.4 Operation under built-in conditions

The heat produced by the LED driver and LED module in the luminaire (or similar housing) must be dissipated to the surroundings, if this is not taken care of it will have an adverse effect on system performance and lifetime.

4.6.5 Heat sink design

To ensure performance it is essential that the critical temperature of module and driver stays below 55 °C. The thermal management can be done in 3 ways conduction, radiation and convection or a combination of these. The figure explains the 3 terms.



3 types of heat transport

Note:

The objective of this chapter is not to indicate exactly how to calculate a heat sink, but to give some guidelines on how to improve its performance.

4.6.6 Heatsink material

The type of material used has a relatively large influence on the final result. For example, a comparison of the thermal conductivity (k) of copper with that of corrosion-resistant steel (see table left) shows that a substantially smaller heat sink can be made with copper. In practice the best material for heat sinks is (soft) aluminum. The thickness (H) of the heat sink is also of major importance. Assuming that we would use the same heat sinks but made from different material a similar effect would be archived with 1 mm copper, 2 mm aluminum, 4 mm brass, 8 mm steel or 26 mm corrosion-resistant steel.

Material	W/mK
Copper	400
Aluminum	200
Brass	100
Steel	50
Corrosion-resistant steel	15

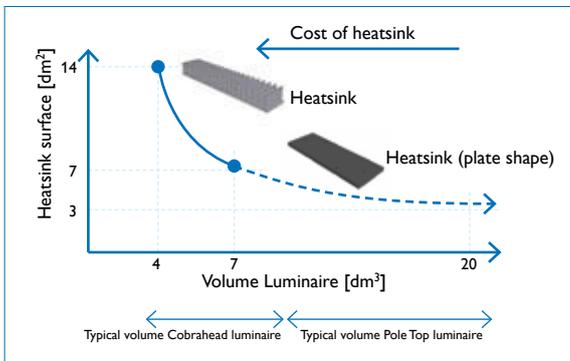
Thermal conductivity

4.6.7 Thermal radiation and emission coefficient

Thermal radiation can also form a substantial part of the total heat transfer, and is of the same order as for convection. This depends strongly on the emission coefficient (see table) of the surface, which lies between 0 and 1. For example, a polished aluminum surface has a very low emission coefficient, while that of a painted surface is very high.

Material	W/mK	Emission coefficient
Aluminium	new/polished	0.04 - 0.06
	oxidized	0.2 - 0.3
	anodized	0.8
Steel	painted	0.8 - 0.95
	new/polished	0.03 - 0.07
	heavily oxidized	0.7 - 0.8

Emission coefficients



Indication of luminaire volume vs heatsink surface and cost (Fortimo LED Linear 1800 lm)

4.6.8 Surface area

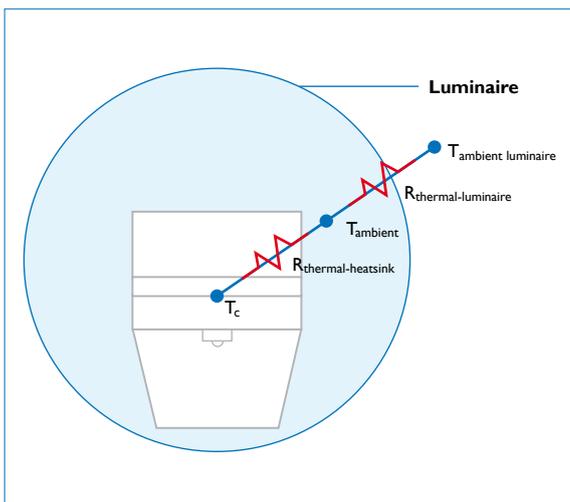
Although a heat sink can have many (complex) shapes the design will depend on several parameters. Depending on application of the luminaire the required surface area, cost, thermal resistance and volume inside of the luminaire can be determined. Here is a differentiation opportunity for luminaire manufacturers.

The first generation Fortimo LED LLM products have an initial energy consumption of 28 W for the 1800 lm version and 17 Watt for the 1100 lm warm white version. The amount of heat (energy) that needs to be taken from the module is about 14 W for the 1800 lm and 9 W for the 1100 version. The heat spreader at the back side of the module is the contact area for the external heat sink. The external heatsink transports the heat away from the module.

By improving the thermal management, in other words lowering the T_c point of the LED module, the system will perform better (lifetime and light output). Here is another differentiation opportunity for luminaire manufacturers. The size of the heat sink depends on the power rating of the module the design and volume of the luminaire.

A typical surface area of a heat sink, when passively cooled, for a 1800 lm system is 10,40 dm² whilst the 1100 Lm module requires a heat sink with a surface area of 6,30 dm² this is based on a “standard” heat sink of aluminium with outer dimensions of 250x40x50 mm (LxHxB) and a inside volume of the luminaire of 7 dm³.

Once LED efficiency upgrades become available, power rating will be reduced and required heat sink size can also be reduced.



Thermal model

4.6.9 Thermal design

If one wants to calculate the required surface area of the heatsink a relatively simple model can be used as shown in the thermal model graph.

4.6.10 Calculation of thermal resistance

The total thermal resistance (R_{th_tot}) of the system is equal to the thermal resistance of the heat sink (R_{th_hs}) plus the thermal resistance of the luminaire (R_{th_lum}). For the reference calculation we have used the following temperatures $T_c = 55\text{ }^\circ\text{C}$ and T_{ambient} is $35\text{ }^\circ\text{C}$ and $T_{\text{ambient luminaire}}$ is $15\text{ }^\circ\text{C}$.

$$R_{th_total} = R_{th_heatsink} + R_{th_luminaire}$$

The R_{th_hs} is calculated by subtracting T_{ambient} from T_c and divided by the $P_{\text{dissipation}}$ of the Light module.

$$R_{th_heatsink} = \frac{T_c - T_{\text{ambient}}}{P_{\text{dissipated light module}}}$$

$$R_{th_heatsink} = \frac{35\text{ }^\circ\text{C} - 15\text{ }^\circ\text{C}}{14\text{ W}} = 1.43\text{ }^\circ\text{C/W}$$

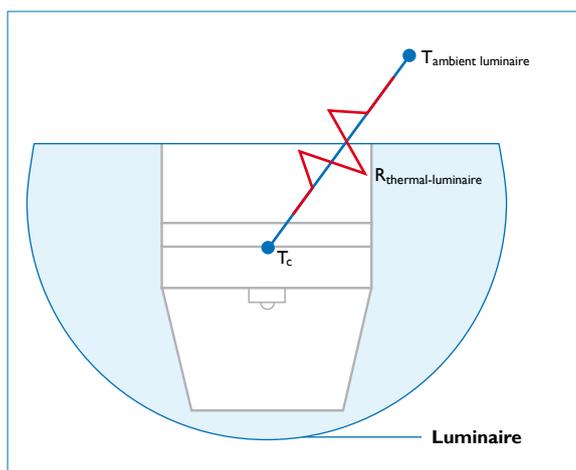
The R_{th_lum} is calculated

$$R_{th_luminaire} = \frac{T_{\text{ambient}} - T_{\text{ambient luminaire}}}{P_{\text{dissipated light module \& driver}}}$$

$$R_{th_luminaire} = \frac{35\text{ }^\circ\text{C} - 15\text{ }^\circ\text{C}}{14\text{ W} + 3\text{ W}} = 1.18\text{ }^\circ\text{C/W}$$

The R_{th_total} is then

$$R_{th_total} = 1.43 + 1.18 = 2.61\text{ }^\circ\text{C/W}$$



Thermal model with integrated heatsink

4.6.11 Thermal management

To simplify thermal management the OEM can design the heatsink in such a way that it becomes one with the luminaire housing. By making the housing of the luminaire an integral part of the heat management which greatly reduces the surface area of the "internal heatsink" and simplifies the calculation.

4.6.12 Calculating your heat sink

So a first indication of the surface area can then be calculated with:

$$\text{Total surface area heat sink} = \frac{1}{R_{th_heat\ sink} \times h}$$

$$\text{Total outer surface area heat sink} = \frac{1}{1.43 \times 7} = 0.099\text{ m}^2$$

The h in the equation is the heat transfer coefficient (W/m^2). Typical the h value is between 5-10.

If you need expert advice we recommend that you contact the complementary partners for heat management.

4.7 Recommendations

4.7.1 Optical

To proof the Fortimo Led Linear concept a reference design has been made. Based on a typical residential street of 8 meters and a poleheight of 6 meters a poledistance of 30 meters can be archived with making the international S5 residential lighting norm.

If you require support in optical design we suggest that you contact one of the complementary partners. You will find information on these partners in the appendix.

4.7.2 Thermal interface

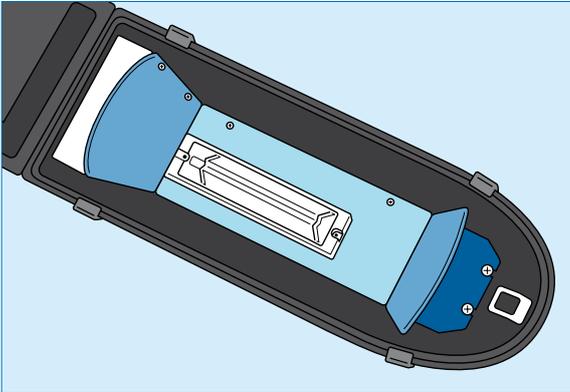
To increase the conduction of heat it is always advisable to use Thermal interface material (TIM). There are several good solutions available in the market place.

We have good experience with the 3 below.

- Bergquist Gappad 1500S30/1500R
- Chomerics G569/579
- Laird T-flex 220

If you require further support for thermal interface material we suggest that you contact one of the complementary partners (see chapter 5 appendix).

5. Appendix



Example of luminaire with Fortimo LED LLM system

5.1 Example Fortimo LED LLM solution

To proof the Fortimo LED Linear we have made a prototype luminaire solution, for reference purposes. The luminaire is made from plastic and has an inner volume of 7 dm³. We will use this luminaire to light up a street in a residential area. The street is 8 meter wide and the poles standing 30 meter apart. The height of the pole is 6 meters. The average temperature is 15 °C. Furthermore this pole is situated in a residential area and we should comply with the S5 norms as stated in the European BS EN 13201-2.

It is possible of course to comply with higher norms by moving the poles closer together or reducing the pole height to 4 meters but that is up to the OEM.

5.2 Complementary partners for optics

Jordan : www.ordanreflectors.co.uk

Alux Luxar : www.alux.de

5.3 Complementary partners for heatsinks

Sapa : www.spagroup.com/thermalmanagement

Nuventix : www.nuventix.com

HS Marston : www.hsmarston.co.uk

AVC : www.avc.com.tw

5.4 Complementary partners for thermal interface material

Laird : www.lairdtech.com

Bergquist : www.bergquistcompany.com

Chomerics : www.chomerics.com

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For more information please visit:
www.philips.com/fortimo
www.asimpleswitch.com
www.philips.com/oem



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