Scalable LED Outdoor Area Light

Reference Design

Introduction

To define outdoor area lighting, consider parking lots, streets, and walkways among other applications in the outdoor environment. The outdoor area lighting system must be able to meet various requirements such as specific light distribution patterns and light/intensity levels.

To meet and exceed LED outdoor area lighting performance requirements, a system approach that considers interrelated elements and design criteria is required.

Optical, photometric, and thermal characteristics will help determine the ideal heat sink for the system. The combined components of the system will define the size of the housing needed.

LED outdoor area lighting systems are expected to provide superior efficacy (in lm/W) and product lifetime over existing lighting technologies such as metal halide (MH) and high pressure sodium (HPS). Thus, the selection of LED drivers and ballast design plays a crucial role in the overall design. Component cost and ease of manufacturing must also be considered along with optical, thermal and mechanical needs. Other, more subtle, requirements such as luminaire appearance and performance comparison with the existing light source will also be discussed in this document.

A correctly designed LED system can be more efficient and have a longer service life than almost any other lighting technology in the world. However, LED technology is still considered new and unfamiliar territory for many designers.

This reference design illustrates the entire design of an LED luminaire intended for an outdoor area light. This document describes specification development, design processes, evaluation of prototypes, conclusions, and recommendations.

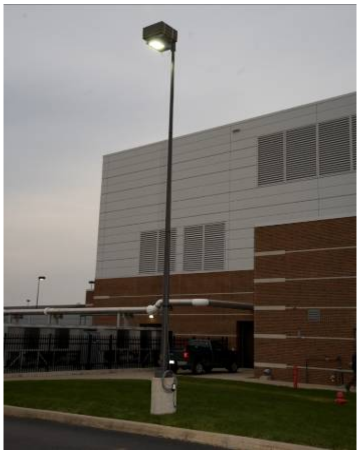


Figure 1.

Area light reference design in the field for feedback from students and staff at Kettering University.

Specification Definition

For application of an LED system where there is existing lighting, it is useful to reference the existing lighting technology to help define a baseline specification. HID (High Intensity Discharge) light sources have established performance characteristics which can be found in publications from regulatory and standards groups such as the IESNA, UL, Energy Star, NEMA, etc. Companies that sell HID lighting also offer specifications, datasheets, photometry files, and standard photometric reports for HID-based area light luminaires.

There are many outdoor area lights on the market today using metal halide lamps as the light source. Metal halide is currently one of the best solutions available in terms of a white light source. High pressure sodium could also be considered, but differences in the color spectrum make a direct performance comparison difficult without considering the human factors element for the night-time human eye response (yellowish light vs. white light). Pulling flux and illuminance requirements from a HPS system would result inevitably in an oversized and over-performing LED system. Therefore, the design phase will use metal halide fixtures as a baseline specification. ***Figure 2*** is a compilation of design requirements for this reference design.

Optical	
Distribution Type	Type V
Luminous Flux[1]	> 10,500 lumens
FTE Score[1]	≥ 49 lm/W
Minimum Illuminance[2]	0.1 foot-candles
Uniformity[1]	6:1 avg to min & 30:1 max to min.
Optical Classification	Unshielded

Thermal	
Operating Temperature Range	-40° C to +60° C
Lifetime Rated Ambient Temperature	25° C
Req. Ts to Support LED Lifetime	≤ 105° C
LED Current	350 mA
Watts Per Module	50 W
Other	Ease of Manufacture

Electrical	
Efficiency	≥ 90%
Power Factor[1]	> 0.9
LED Operating Frequency[1]	≥ 120 Hz
Lifetime	≥ 60,000 hours
LED Current	350 mA
Voltage Input	120-277 VAC

Mechanical	
Operating Temperature Range	-40° C to +60° C
Rated Ballast Enclosure	≥ IP-65
Rated LED Module[3]	≥ IP-65
Other	Easy Access/Maintenance
Modularity	1-4 LED Modules

Figure 2. Example system specification targeted for an LED replacement of a 400 W HID application

[1] **Energy Star draft requirements for integral LED bulbs v. 3**
[2] **Recommended illumination value IESNA RP-20-98**
[3] **CBEA LED Site Lighting Performance Spec v. 1.2**

LED Modular Solution

In the realm of HID outdoor area lighting, as a rule of thumb, the wattage of the HID lamp typically represents the flux performance of the overall HID system. For example, if you specify a 400 W HID lamp you can expect a given lumen performance, and with a properly designed system around the lamp, you can expect specific application performance. This HID wattage information is the correct place to start when defining lumen output requirements for an LED source for the same outdoor area lighting application.

Outdoor area lights are available with multiple lamp technologies and multiple power levels .For example: 70 W, 100 W, 150 W, 250 W, 400 W are very common HID lamp wattages. Low pressure sodium and CFL (Compact Fluorescent Lamp) are also examples of source technology for this application space that have different wattage ranges and well-defined lumen output.

The LED system must be able to cover the range of application lighting requirements of traditional sources without requiring a custom system design for each performance level. Thus a modular LED solution makes sense in this regard.

There is a general expectation that any LED area light solution should be able to pay for itself in a reasonable timeframe to justify a change to the new technology. A four years payback timeframe was set as a maximum for this area lighting system, and solutions were selected that would meet this goal. Assuming yearly maintenance costs are modest, payback is estimated at less than three years for the LED 400 W HID replacement system.

Optical Requirements

Industry standards determine the shape of the light from an area light fixture. ***Figure 3*** provides a basic illustration of several of the defined standard shapes.

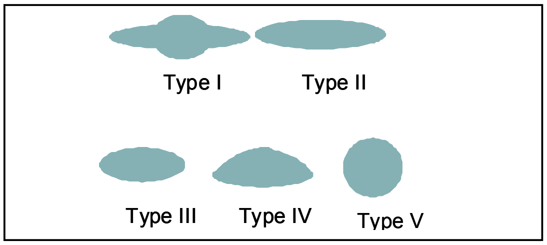


Figure 3. IESNA Photometric types are a metric to define the shape of the light.

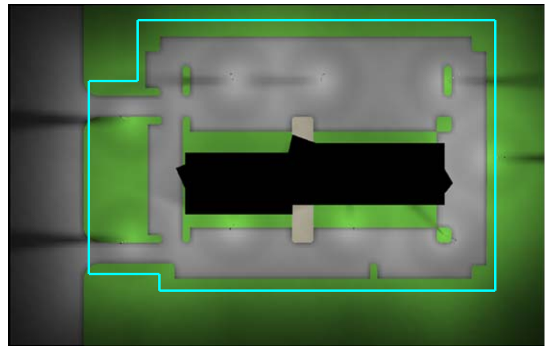
Type III and V are very common IES photometric types for area lighting.

Efficacy targets in system-level lumens per watt (lm/W) are usually defined based on energy savings goals. FTE is an Energy Star defined target which counts only the lumens in the specified target area. Energy savings also relates to system payback.

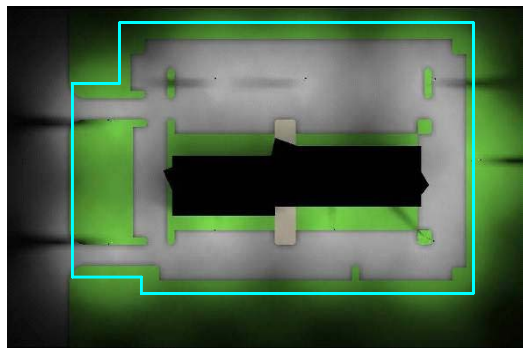
LED is a directional source emitting light in only one hemisphere therefore it is easier to design optics that allow the light from the source to escape the luminaire. The lighting industry uses the term coefficient of utilization to describe the amount of light that escapes the luminaire vs. the light created by the source.

Application factor is a term describing the useful lumens in an application. If a luminaire has high lumens or lumens per watt this does not necessarily imply better lighting of a space. The application factor forces an 'apples to apples' comparison for luminaire design by considering the photometric requirements of the application. Photometric requirement include total illumination within a target area, uniformity, glare and up-light limits and other intensity requirements.

The example in figure 4, defined by the blue line shows the area in the parking lot that needs to be illuminated. The area illumination specification requires more light and more light uniformity in the paved area than in the grassy perimeter. The LED design does a much better job of focusing the lumens where they are needed and not creating light trespass.



400W Type 5 Metal Halide
30-40% Wasted Light
Application Factor: 0.6-0.7
6:1 Max:Min



LED Design
10-20% Wasted Light
Application Factor: 0.8-0.9
3:1 Max:Min

Figure 4. Application Factor comparison of parking lot illuminated with metal halide and LED luminaires.

LEDs for Outdoor Lighting

There are several LEDs in the OSRAM Opto Semiconductors portfolio suitable for outdoor area lighting applications.

For this design, the OSLON SSL was chosen due to its high efficacy (lm/W), and small footprint allowing for dense optical arrays, low thermal resistance, and long lifetime. This LED component when designed correctly into outdoor lighting applications will have a typical lifetime greater than 100,000 hours, resulting in a LED system with high reliability.

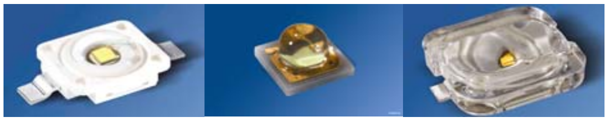


Figure 5. SSL High Power LEDs for outdoor lighting. Golden DRAGON Plus (left), OSLON SSL (middle), Golden DRAGON Oval Plus (right)

Opto-Mechanical Design of LED Modules

Conventional HID luminaires often use a reflector optic to direct and shape light from the HID lamp. Some sort of transparent cover lens is required to protect and further shape the light. As LEDs are a directional light source, for this reference design there is no collecting reflector, only a beam-shaping optic. The 80 degree lens of the OSLON allows an efficient beam shaping lens with a small optic size. Further, this design minimizes the number of optic/air transitions and thus minimizes losses in the overall optical system.

By incorporating the lens in the cover plate of the LED module, the LED components and PCB are in a protected environment and the optical efficiency is maximized. It is possible with this concept to realize not only a rotationally symmetric type V distribution but also asymmetric distributions such as Type II, III, and IV. Type V and III optics were realized in hardware for this reference design.

Cover lenses at the luminaire level to protect against moisture and dust intrusion should be carefully considered in this optics calculation. You must consider the impact on the shape of the light and the efficiency of the system if a cover lens is used.

In the case of this reference design, an integrated approach was used to maximize the lumen output of the system. The outer cover of the module has a dual purpose to both protect the circuit board and LEDs from exposure to the environment al elements, while eliminating extra optics layers that would introduce losses to lumen output. There are additional design challenges when this approach is selected. The optics must meet photometric requirements of the luminaire on their own but must also be rugged enough for the outside environment.

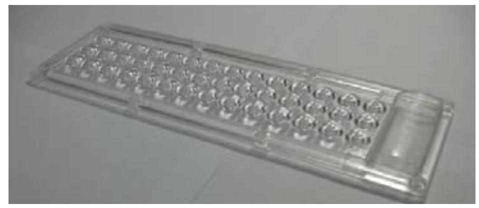


Figure 6. Module cover plate with integrated lens array

The proper interface to the base plate of the heat sink must be designed so the system can be rated for outdoor use and also remote maintenance such as cleaning with a water hose.

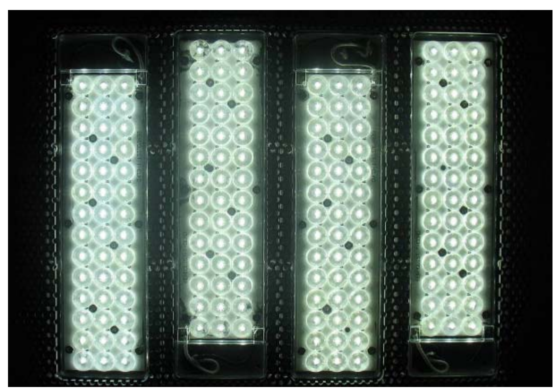


Figure 7. Module cover plate with lens array shown lit in luminaire

Thermal Design for the Area light

A heat sink comprised of baseplate, heat pipe and stacked fins was chosen for this design for several reasons. The selected solution maintains a low LED junction temperature below 85 C for 42 LEDs at 350 mA. This enables a lifetime well above the required 60 krs and a good system efficacy. The very high thermal performance of this design allowed for high thermal dissipation of heat from 42 LEDs driven at 350 mA. The low weight and compact mechanical construction allows for a compact design of the LED module and a lower overall luminaire weight of less than 20 lbs. When considering installation by maintenance crews (often in bucket trucks) the lower weight is a significant advantage.

Figure 8. LED thermal solution with heat pipe and stacked fins (SLM2).

Metal core PCB was selected over other circuit board technologies such as standard FR4 due to its superior thermal conductivity from the LED to the interface material. A high thermal conductivity and electrically isolating thermal interface material was placed between the back of the board and the base plate of the heat sink. Screw hole placement, not only on the perimeter of the board but distributed over the board area, provided even pressure for even thermal management.

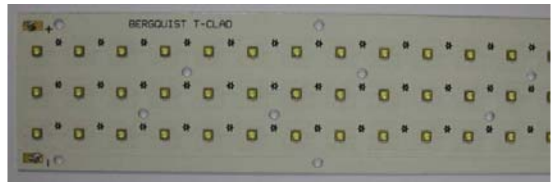


Fig 9. Top view of metal core PCB, part number 804200, populated with OSLON SSL LEDs with thermal interface to heat sink

In order to create a module sealed from the environment a gasket is placed between the optical cover plate and the base plate on the heat sink. With a sealed IP65 LED module that conducts heat away from the LEDs, outdoor rated ballast, and interconnects, the luminaire housing may have openings for airflow. Finned heat sink solutions operate best with airflow to the ambient environment.

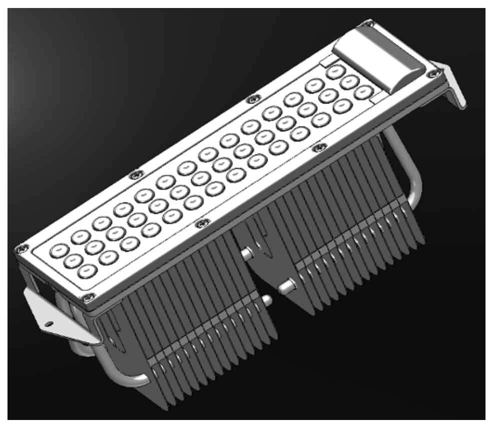


Figure 9. Isometric view of LED module

Electrical Solution

In order to enable the drive and control of a scalable LED system, the ballast solution must also be scalable. The ballast used to realize a 400 W HID replacement is a 200W, 1-4 channel ballast which can drive each channel with constant current and variable from 100-500 mA. The flexibility of the current enables system designs that are

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optimized for efficacy, energy savings and optimized for light output.

Ballast electrical efficiency at 350 mA is above 90% with high efficiency maintained at the current min and max levels. The efficiency of the ballast is greater than 85% for the minimum to maximum current range.

Fig 10. Model series 1072, 200W, 4-channel scalable ballast. LED constant current, dimmable from 100-500mA.

The ballast architecture is scalable and suited to drive 1 to 4 strings of LEDs with up to 50 W per channel within an area light system. A family of ballast configurations using this scalable architecture means a designer does not have to take 4 output channels if the application only requires 1.

An example of a 1 channel design could be area lights installed near a walk path in a park. Traditional fixtures may use a 70 W HID source. In this case a single module driven by a single 50 W channel would be sufficient for that installation.

The ballast also includes surge protection in accordance with ANSI C136.2 requirements.

A variable voltage reference allows LEDs to be dimmed by dynamic current control. System efficacy and energy savings will improve as the current is reduced. Thus, dynamic control of the LEDs is a feature that is important to the overall design. This reference design was controlled using an OSRAM Opto Semiconductors *Ambient Light Sensor SFH 5711*. When this sensor was exposed to ambient light, the ballast dimmed the LEDs. A configuration such as this could further improve the energy savings and payback calculation for a LED based streetlight.

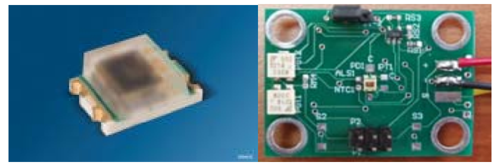

Figure 11. OSRAM Opto Semiconductors Ambient Light Sensor, SFH5711. Hardware reference design for control of SSL applications

For the reference design, we used ballasts that were not sealed for the outdoor environment. We incorporated environmental sealing as well as thermal management in the luminaire design. The ballast has a case temperature that must be maintained for over 60 khr lifetime. For this luminaire reference design, a simple extruded heat sink was welded to the IP-65 rated ballast compartment. Like the LED modules, the ballast heat sink has airflow to the fins. ***Figure 14*** shows placement and orientation of fins on the ballast compartment. The ballast was mechanically fastened to the luminaire structure and a thermal interface was placed between the case and housing. With this solution the case temperature was maintained below the required case temperature for system lifetime.

System Level Measurements

Thermal analysis on the system level concluded that an air gap between modules would be the best approach to achieve homogeneous temperature of the modules. ***Figure 12*** shows why, without adequate module airflow, center modules would be warmer than edge modules.

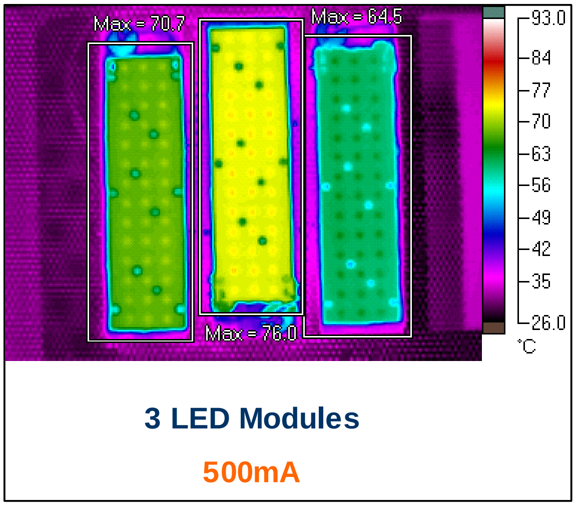

Figure 12. Thermal image of three LED modules inside the luminaire housing in application orientation. Solutions with uneven airflow cause uneven LED temperatures in the luminaire.

For system reliability and performance optimization it is critical to assess the weakest thermal link in the system and design to reduce this temperature variation. An optimized module layout (**fig. 13**) was determined with airflow between modules. This arrangement can meet 400 W application lighting requirements with only three modules and achieve even and reasonable LED junction temperatures with reliability to exceed defined targets of 60 khrs.

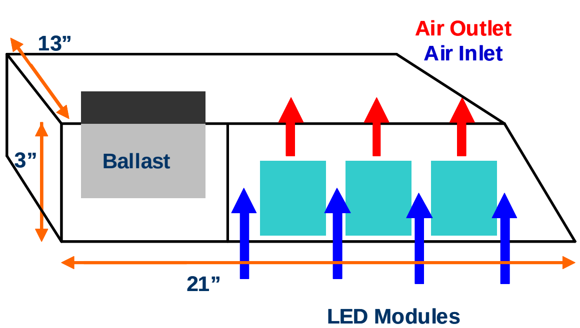

Figure 13. Preferred arrangement of LED modules in luminaire for adequate airflow

Mechanical integration of all components within the constraints of the luminaire industrial design (size, weight, appearance) is no trivial task. With LED systems in particular, special care needs to be taken for the proper design of thermal management components such as heat sinks and mounting brackets. Air intake placement can dramatically influence thermal transfer. Materials selection can make a difference in the thermal design. A target is to have all LEDs at a similar temperature.

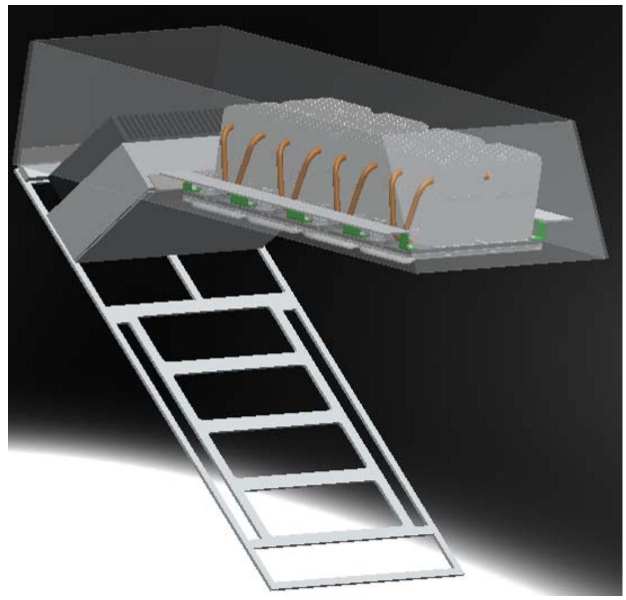

Figure 14. Luminaire Integration of LED modules

To optically characterize the complete LED system — as is commonly done in the industry for all luminaires independent of technology — a goniometer measurement was performed. A lighting industry standard 3-dimensional intensity characteristic was produced by this test confirming the optical shape type V, cut-off classification for limitation of high angle, and up light. The max intensity was found in the correct angle according to design and the overall lumen output was within the expected range at approximately 14.7k lm. With a system power of 200 W this yields an efficacy of approximately 74lm/W. Final tooled optics

Fig 15. Final *Area Light Reference Design* hardware

will even out the distribution for additional uniformity, but the prototype hardware performed and confirmed feasibility of this system according to the original specification. LED system power consumption was also measured after system warm-up. For details on this measurement data and IES file output please contact OSRAM Opto Semiconductors.

The lumen maintenance of the LED system over time has a more gradual degradation than a metal halide system. In ***Figure 16***, we show the approximate lumen maintenance of the OSLON-based LED system vs. that of three types of common metal halide technologies in-fixture. Each peak in the lumen characteristic of metal halide represents a re-lamping of the lamp. Metal halide lamps are often re-lamped in groups at about 60-75% of rated life instead of as they burn out. End of life for an HID lamp is when it burns out or L0 for lumen maintenance of 0%. In comparison, LED component estimated median lifetime for lighting applications is when the LED light output decreases by 30% from original output (L70.) Note the faster lumen depreciation of HID in comparison to LED. Although the initial lumens of the system is not as high as metal halide, application efficiency is not factored into this graph and in the case of the application in ***Figure 4*** would reduce initial flux of both technologies to a similar level. Over time the LED solution degrades more slowly requiring less maintenance and providing more consistent illumination over time. Beyond 60k hrs, the LED would continue to emit light as long as the whole system was stable. Simple solutions like current compensation or additional LEDs over time could extend L70 well beyond 60k hrs. As more sophisticated electronic solutions become available for LED applications the options for high reliability, longer lifetime LED systems will increase.

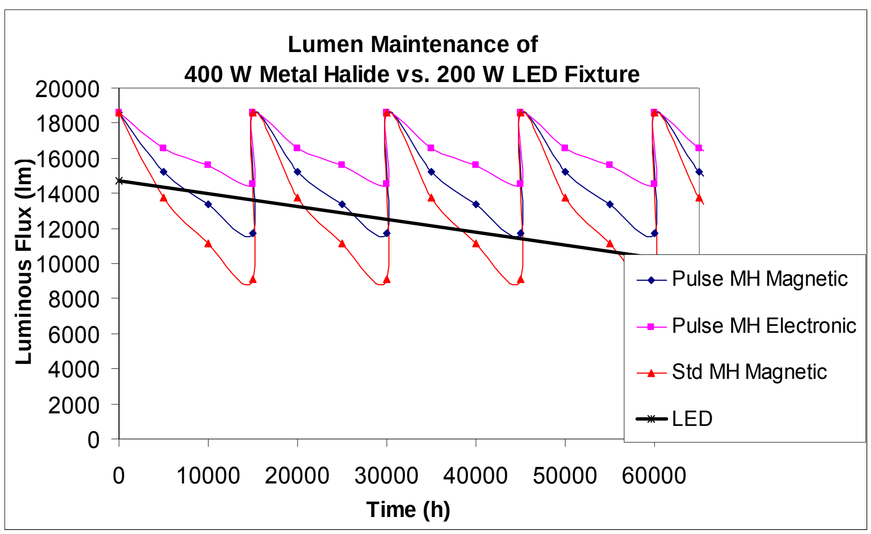

Fig 16. Calculated system lumen maintenance of LED vs. metal halide (re-lamp at 75% initial flux) with three available types of lamp and ballast technology

Conclusion

The design of the LED-based area light was successful, as it outperformed the HID luminaires. The estimated lifetime to 70% lumen maintenance of the LED system is over 60,000 hours at 25° C ambient, and the luminaire has an initial light output of approximately 14,700 lumens, which in application can exceed the performance of equivalent metal halide luminaires.

The scalable architecture allows this system to effectively replace applications formerly using HID lamps from 70-400+ W. Power consumption is cut by half with a 400 W replacement operating at only 200 W. This reference design is one example of how LED systems can meet industry standards and compete as a commercial product once designed for mass production. The measured electrical efficiencies and light distributions show that the LED solution is on target. A test installation showed that the LED system performs well *in situ* next to 400 W metal halide equivalents and received positive feedback by lighting management at Kettering University as well as students and faculty observers who park their cars under these area lights.

This is only one example of how to design this application. Reference designs are also constantly evolving as new LED performance levels are reached and there are improvements in LED system technologies.

For the latest system solutions and details on this design, including measurement data, IES files, design files and alternative optics please feel free to contact your local OSRAM Opto Semiconductors salesperson and the LED Light for you companies below for contributed solutions.

Fig 17. Test installation at Kettering University. Kevin Markell presents prototype system to university building management, faculty, and students

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	Solution	LED Light for you Partner	Partner Website
Thermal	Metalcore Printed Circuit Board (PN 804200), Thermal Interface Material (Hi-Flow 225F-AC)	THE BERGQUIST COMPANY	www.bergquistcompany.com
Thermal	Streetlight module thermo-mechanical solution (SLM1, SLM2),	COOLER MASTER	www.coolermaster.com
Electrical	LED Power Supply (1072 model series)	POWER VECTOR ENGINEERED LED POWER	www.powervector.com

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- Kevin Markell, student of electrical engineering at Kettering University and former co-op with OSRAM's application engineering team.

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