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Final LED Specification Report

Deliverable 2.3.1d-e-f – *Elevator downlight*

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Table of Contents

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LED Specification Report

1 Introduction

This report for project *2.3 LED Low Profile Fixtures* provides the specification for the LEDs that will be used for the low-profile LED luminaire in an elevator downlight application. The overall goal of the project is to design, build, and demonstrate in the field a working prototype of a low-profile LED luminaire that is 25 percent more efficient than a comparable incandescent luminaire. The information presented in this report has been gathered during the design phase of a low-profile LED luminaire and was used as a baseline to decide what light source will be used in the final prototype.

The research team for this project includes Nadarajah Narendran, Jean Paul Freyssinier, and Ramesh Raghavan with the Lighting Research Center (LRC).

2 Specifications and General Requirements

2.1 Specifications of the LED used in the low-profile luminaire

The LED chosen for the low-profile luminaire is the Luxeon III Emitter from Lumileds Lighting, which has the photometric characteristics listed in Table 1 (Lumileds, 2004a). Figure 1 shows the typical spectral power distribution, and Figure 2 shows the radiation distribution of the Luxeon III LED.

Table 1. Photometric characteristics of white Luxeon III emitters used in the low-profile luminaire (from Lumileds, 2004a).

Typical light output:	65 lm (at 700 mA and at a junction temperature (J_T) of 25ºC) 80 lm (at 1000 mA and at a J_T of 25ºC)
Average lumen maintenance:	70% after 50,000 hours of operation (at 700 mA and at a J_T of 90ºC) 50% after 20,000 hours of operation (at 1000 mA and at a J_T of 90ºC)
Correlated color temperature: (CCT)	5500 K
Color rendering index: (CRI)	70 ± 5%
Radiation (candlepower) distribution:	Lambertian

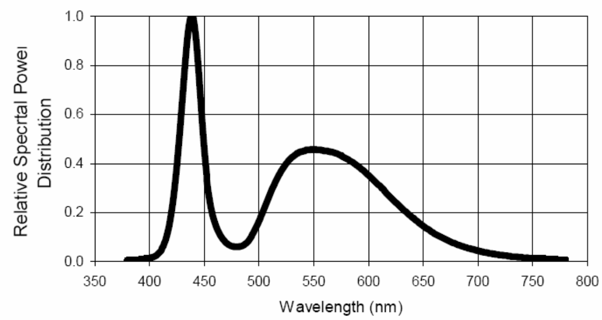

Figure 1. Typical normalized spectral power distribution of white Luxeon III emitters (from Lumileds, 2004a).

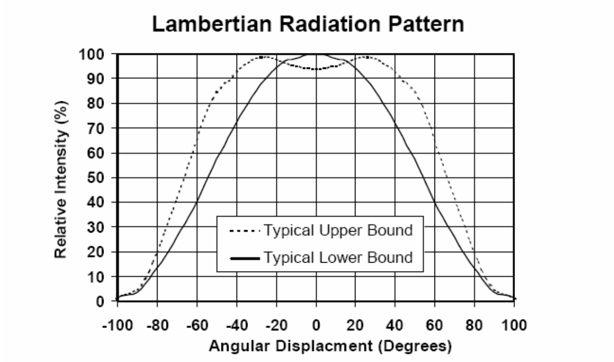

Figure 2. Typical Lambertian radiation distribution of white Luxeon III emitters (from Lumileds, 2004a).

The following sections of this report contain the rationale behind this choice.

2.2 Light Output Requirements

Usually, commercial elevators are illuminated by fluorescent or recessed incandescent lighting. In the current lighting design practice, both standard incandescent and halogen incandescent light sources are used in downlight luminaires. The most common incandescent lamp types used for this application include A19 and reflector (R20 and R30; PAR20 and PAR30; and MR16) lamps ranging in power from 40 to 75 Watts (W). The light output of such lamps ranges from approximately 400 to 1200 lumens (lm).

It would be expected that the low-profile LED luminaire for this application would produce a comparable light output. Typically, one standard elevator cabin (approximately 4 ft. by 6 ft.) is illuminated by four to eight incandescent luminaries, resulting in an average maintained illuminance sometimes higher than 50 fc (Narendran and Raghavan, 2003b). However, lower values of light output per luminaire may be sufficient for many applications. Current recommendations for elevator lighting (Rea, 2000) cite average maintained values of 3 to 5 fc as adequate.

Illuminator-type LEDs (Figure 3) have larger lumen packages (ranging from approximately 20 to 120 lm per device for white light) and operate at significantly higher drive currents (a few hundred mA) than indicator-type (i.e., 5-mm and surface mount) LEDs (Narendran and Raghavan, 2003a). The need for a few hundred lumens per luminaire renders indicator-type LEDs unsuitable for this project.

Figure 3. Examples of illuminator-type LEDs from Lumileds Lighting (left), OSRAM Opto Semiconductors (middle), and Nichia Corporation (right). Photographs courtesy of the respective companies.

On the other hand, with the current LED technology, a single illuminator-type LED with light output as high as an incandescent source is not yet commercially available. Therefore, the LRC has concluded that a cluster of illuminator-type LEDs with the highest lumen output will be the most appropriate light source for the low-profile luminaire.

Using LEDs with 50 to 100 lm or more per package will require approximately six LEDs per luminaire and six luminaires to provide the target average illuminance level of 12 to 14 fc. Low lumen packages (i.e., less than 30 lm per LED) will result in more LEDs per fixture and in more demanding heat sinking requirements, hence, making the luminaire bulkier. Based on the light output criterion, currently there are two commercially available LEDs suitable for the design of the LED luminaire. The first option with the highest lumen package available is a 5W LED from Lumileds (Luxeon V Portable Emitter) that produces 120 lm at a nominal efficacy of 24 lm/W (Lumileds, 2004b). The second option is a 3W LED from Lumileds (Luxeon III Emitter) that produces 80 lm at a nominal efficacy of 25 lm/W (Lumileds, 2004a).

However, the rated life of the 5W LED is 1000 hours, which is much lower than what is desirable for this application, leaving the 3W LED as the best option for this project. As LED technologies improve, other packaging options from more manufacturers will surely become available and be suitable for elevator downlighting.

In summary, the low-profile LED luminaire requires a cluster of LEDs with light output of at least 50 lm per unit. Currently, the best matching commercially available product is the 3W Luxeon III emitter.

2.3 Color Properties Requirements

2.3.1 Color rendering index and correlated color temperature

There are two approaches for creating white light with LEDs. The first approach is to mix multiple colored LEDs, such as red, green, and blue, in suitable proportions. The second approach is to combine a GaN-based blue emitter with cerium-doped yttrium aluminum garnet (YAG:Ce) phosphor, which are then embedded in an epoxy mix (Narendran *et al.*, 2001b).

The multiple colored LEDs approach, commonly known as RGB mixing, can achieve white light with a wide range of correlated color temperatures (CCT), relatively high color rendering index (CRI) values of up to 90, and a theoretically higher luminous efficacy than phosphor-converted (pc) white LEDs. However, in practice it is very difficult to achieve a uniform mix efficiently. In general, RGB systems have the disadvantage of being too sensitive to slight changes in the peak wavelength of the red LED. As a result, the color rendering index (CRI) of an RGB system can range from approximately 20 to 70, but without necessarily changing people's response to color preference of an object illuminated by systems of either CRI value (Narendran and Deng, 2002). Because of this color shift possibility, RGB systems usually require complex feedback controls in order to maintain the light output and color settings over time and to compensate for changes in operating temperature.

On the other hand, the CRI of current pc-white LEDs ranges from 70 to 90 at CCTs ranging from approximately 2800 Kelvin (K) to 6500 K. Such CRI and CCT values fall into the range of traditional light sources currently used for elevator applications (i.e., incandescent and fluorescent). However, research has shown that despite a relatively high (70+) CRI, pc-white LEDs with a CCT of 5500 to 6500 K lack the ability to adequately render warm-toned objects, particularly skin tones (Narendran and Deng, 2002). One potential solution is found in the 1W Luxeon Emitter, which is available in a warm white (3300 K) CCT with a typical CRI of 90 (typical R_9 of 70) (Lumileds, 2004c). Unfortunately, this product only produces 20 lm and is not yet available in a 3W version, thus making it not suitable for this project.

One aspect to be investigated during the field demonstration of the low-profile LED luminaire is the response of users to the color-rendering properties of pc-white LEDs of high CCT (>5500 K) in real applications of general lighting. It is expected that for most commercial applications, LEDs with high CCT values of 5500 to 6500 K will perform similarly to traditional light sources. But as more high-output products become available, higher CRI values of up to 90 at warmer CCTs of approximately 3000 K would be desirable for some elevator lighting applications.

2.3.2 Color consistency

With the current manufacturing processes, most illuminator-type pc-white LEDs in the market show large differences in color from one LED to another. Color consistency of pc-white LEDs may be critical for acceptance as they are used more and more in general lighting applications. One cost-effective solution is to bin batches of LEDs so that their color appearance is consistent when they are clustered together.

A recent study by the Lighting Research Center (2004) recommends color binning within a 2-step MacAdam ellipse when LEDs are placed side by side and are directly visible (such as in the case of the low-profile luminaire), or when they are used to illuminate white surfaces.

LED manufacturers often offer color binning as an option on most of their product lines, and although it may incur premium charges, it should not be a limitation in the design of LED luminaires.

In summary, the low-profile LED luminaire requires a cluster of pc-white LEDs with a CRI of 70 or more at a CCT of 3000 to 5500 K, and color-binned to within a 2-step MacAdam ellipse. Currently, the best matching commercially available product is the 3W Luxeon III emitter.

2.4 System Efficacy

The main factors affecting the overall efficiency of a given luminaire include the efficacy of the light source, the efficiency of the reflector and other optical control elements, and the efficiency of the power gear (e.g., ballast, driver, low voltage transformer).

The efficacy of current incandescent technology, including halogen and infra-red (IR) halogen, ranges from approximately 10 to 30 lm/W. For the purpose of this project, the initial baseline for comparison is a luminaire using a 50W IR coated MR16 lamp, which currently is considered as the best practice for elevator downlighting. This lamp has an estimated typical efficacy of 30 lm/W (Howlett, 2004). The efficiency of open reflector luminaires ranges from approximately 65 to 95 percent, depending on the size, finish, and distribution of the reflector, and the type and size of lamp. Typical four-inch diameter open reflector luminaires for MR16 lamps have an efficiency ranging from approximately 83 to 86 percent. Finally, the efficiency of low-voltage transformers ranges from 70 percent for traditional laminated electromagnetic transformers, to 92 percent for high-efficiency toroidal transformers, depending on the size of the electric load and the load factor. Typically, low voltage luminaires use laminated electromagnetic transformers, with an efficiency of approximately 80 percent.

After accounting for the factors mentioned above, the baseline efficacy of an incandescent luminaire for elevator downlighting could be set at 20.6 lm/W (30 lm/W × 0.86 × 0.80). Therefore, the low-profile LED luminaire is expected to achieve an efficacy of at least 25.8 lm/W (20.6 lm/W × 1.25).

Considering that the efficiency of an electronic LED driver and the reflector could be 90 percent, the efficacy of the LED used in the low-profile luminaire should be at least 31.8 lm/W (31.8 lm/W × 0.90 × 0.90 = 25.8 lm/W).

At present, the 3W Luxeon III emitter selected for this project is rated at a nominal efficacy of 25 lm/W, making it one of the most efficacious LED products available on the market. Current illuminator-type LEDs are rated at efficacies ranging from 25 to 30 lm/W, depending on driving current and operating conditions. These values, close behind the required goal, are expected to increase significantly in the near future. Some products have already demonstrated efficacies of up to 45 lm/W under laboratory conditions.

2.5 Life and Lumen Maintenance

The potential for long life of up to 100,000 hours is one of the most attractive characteristics of solid-state technologies for general illumination, especially in applications where maintenance is difficult or expensive. However, pc-white LEDs have yet to demonstrate this capacity.

For traditional light sources, lamp life is defined as the median operating time that elapses under specified conditions (Rea, 2000). By this definition, LEDs are often rated at 100,000 hours because under nominal operating conditions LEDs rarely burn out. Rather, as with most light sources, the light output of LEDs decreases gradually over time (Narendran *et al.*, 2000, 2001a). Presently, there is no standard definition of life for LEDs in the lighting industry (Narendran *et al*., 2001a). As an initial step, the lumen maintenance of LEDs has been proposed as a criterion to determine “useful life” in a given application. Useful life is defined as the time that elapses until the LED fails to provide a specified light level (Narendran *et al*., 2001a). Some LED manufacturers now provide the number of hours until the lumen maintenance of their products reaches 70 percent (Whitaker, 2004).

The average life of incandescent lamps ranges from 750 to 3000 hours and from 10,000 to 20,000 hours for fluorescent lamps. There are, however, two practical factors affecting the actual lamp life of incandescent and fluorescent lamps in this application. The first factor, applicable only to fluorescent lamps, is the expected increase of life due to constant operation. Under this burning cycle, the average life of fluorescent lamps can increase up to 160 percent than at nominal conditions (3 hours on, 20 min off) (Rea, 2000). The second factor, applicable to both technologies, is the vibrating environment to which the lamps are exposed. Although there are no quantitative data to determine how much an elevator's vibration would undermine the average lamp life of these two technologies, it is an important issue to consider.

For elevator illumination purposes, it is desirable that an LED luminaire outlast traditional light sources. As an initial target, an average life of at least 40,000 hours until the lumen maintenance reaches 70 percent seems a reasonable number. Feedback from elevator manufacturers will be sought on this matter and reported at a later date.

The current specifications of Luxeon III cite average life values of 50,000 hours for a lumen maintenance value of 70 percent, if the operating temperature of the junction is maintained at or below 90ºC (Lumileds, 2004a).

2.6 Radiation (Candlepower) Distribution

Theoretically, it is possible to design a reflector with any given light distribution around commercial LEDs. But in order for a reflector to be efficient, and as a general guideline, it is desirable that most (70 to 80%) of the light output of a luminaire should come directly from the light source, whereas the rest of the light output (20 to 30%) should come from the contribution of the reflector itself.

Most illuminator-type LEDs of interest for this project are available in broad, Lambertian, and side-emitting candlepower distributions. By definition, broad and Lambertian candlepower distributions would provide higher direct contributions from the light source to the light output of a luminaire than would a side-emitting distribution. Since the main goal of this project is to achieve an LED system with high efficiency, side-emitting distributions have not been considered.

The Luxeon III Emitter is available in an almost symmetric and Lambertian distribution, hence making it suitable as the light source of the low-profile luminaire.

2.7 Thermal Management

The high drive currents (200 to 1000 mA) and power consumption (1 to 5 W) of illuminator-type LEDs cause them to generate a significant amount of heat in a very small area. This heat has to be dissipated from the LED efficiently in order to prevent permanent damage and poor performance. Usually, external heat sinks are needed to dissipate heat generation at the junction.

In the case of the low-profile luminaire, there are no specific requirements regarding the heat generation for each LED. Rather, the thermal management will be designed into the heat sink and body of the luminaire so that the operating temperature at the junction is maintained at or below 90ºC (Lumileds, 2004a).

2.8 Controllability

LEDs are low voltage, direct current solid-state devices; therefore, LEDs need power conditioners in order to operate when connected to the mains. Due to the low dynamic impedance nature of LEDs, in which a small change in forward voltage generates a large change in current, it is desirable to operate LEDs under a controlled current regimen (Schie, 2004). Therefore, the fundamental objective of an LED power conditioner, usually called a driver, is to operate the LED under constant current conditions.

On the other hand, the light output of LEDs is proportional to the forward current at which the LED is driven. As a result of driving LEDs at currents lower than nominal, the energy efficiency of the device is usually increased (Narendran and Raghavan, 2003a). This gain in efficacy at lower operating currents is certainly an advantage over fluorescent and incandescent technologies. In the case of fluorescent lamps, dimming is not generally thought to compromise significantly the system's efficiency (Rea, 2000). However, incandescent lamps suffer great decrements of efficiency as they are dimmed (Rea, 2000).

Another advantage of LEDs is that they are impervious to on and off cycles. Along with this capacity to be turned on and off at will without affecting the useful life, LEDs respond almost instantaneously (<100 ns) when changing from off to on state.

In summary, LED technology easily lends itself to different control strategies to further increase energy savings. Continuous and bi-level-dimming, load-shedding, and integration of occupancy sensors are just a few features that could be designed easily into LED drivers. None of the control strategies mentioned poses any special requirement on the LED itself. Rather, electronic drivers can be designed around the desired LED circuit configuration (e.g., parallel, series, or combination), starting characteristics (e.g., ramp up to a maximum), or waveform (e.g., constant current, pulse-width modulation) in order to provide a number of control features, without sacrificing LED life or efficiency.

2.9 Cost and Reliability

Cost continues to be the major barrier to the penetration of LEDs into the general illumination market. At a current retail price of $8.50 per 3W LED, the cost per kilo lumen (klm) of white light with LEDs (approximately $106) is still in the order of 20 to 50 times more expensive than with fluorescent or incandescent technologies. However, the cost of one klm of white LED light is expected to reach a low cost of $15 by the year 2010 (Dixon, 2003).

In the meantime, niche applications can benefit from some of the multiple attributes unique to LEDs that add value to lighting solutions, one of them being high reliability.

For example, elevator service companies with maintenance contracts are initially attracted by the potential long life and non-catastrophic failure mode of LEDs (Norris, 2004). In particular the non-catastrophic failure mode of LEDs enables such service companies to schedule lighting maintenance, as opposed to having to respond to burned out lamps as soon as a failure happens. An additional benefit of a low-profile LED luminaire is the fact that the overall height of an elevator cabin can be shortened by a few inches. The reduced height will ultimately result in significant economic benefits stemming from lower manufacturing costs (less material to build the cabin) and the possibility to use motors, braking systems, and counterweights of reduced dimensions (Pei, 2003).

As a metric of reliability, the 3W Luxeon III emitter chosen for the low-profile luminaire is expected to have an average useful life of 50,000 hours, as defined in item *2.5 Life and lumen maintenance* of this report.

3 Conclusions

Based on an evaluation of the attributes discussed above, the LRC has concluded that 3W illuminator-type pc-white LEDs with a CRI of 70 at a CCT 5500 K, and a nominal efficacy of 25 lm/W, are a good starting point to demonstrate the energy savings potential of LED technology in a general illumination application. The 3W Luxeon III emitter from Lumileds was considered a suitable choice as the light source for the low-profile luminaire. It is expected that in the near future, as technology improves, the efficacy of illuminator-type LEDs will increase significantly to values well over 50 lm/W. Higher efficacy values will make LEDs even more attractive from an energy savings standpoint.

Based on the dimensions of the elevator cabin selected for the field evaluation (51 by 58 by 84 in), six luminaires, each with six LEDs, will be required to achieve a target average illuminance of 12 to 14 fc at the floor.

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