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ABSTRACT

High-lumen light sources represent unique challenges and opportunities for the design of practical and efficient interior lighting systems. High-output sources require a means of large-scale distribution and avoidance of high-luminance glare while providing efficient delivery. An indirect lighting system has been developed for use with a 1000 Watt sulfur lamp that efficiently utilizes the high-output source to provide quality interior lighting. This paper briefly describes the design and initial testing of this new system.

INTRODUCTION

Currently the lighting market is seeing the evolution and emergence of sources producing high-lumen output, high-efficacy, and good color rendering quality. These sources, specifically the sulfur lamp and high-wattage metal halides, offer significant advantages in terms of efficacy, color rendering quality, and lamp life.

The emergence of efficient high-lumen output lamps offers the potential for both reduced energy use and reductions in building costs associated with reducing the number of fixtures required to maintain a specific illuminance level. However, working with a source that has significantly higher lumen output presents some difficulties for immediate application in lighting traditional interiors. The primary challenge for the effective market penetration of these systems is the development of high-efficiency light delivery systems. These systems must efficiently distribute the flux of a large lumen package over a wide area to provide appropriate and consistent interior illuminance levels and mitigate the significant potential for both direct component and indirect (for VDT environments) glare associated with such brilliant sources.

SYSTEM DESIGN

Sulfur Lamp Source

One promising technology in the realm of high-output sources is the electrodeless sulfur lamp.[1)] The technology of the sulfur lamp is based on the properties of sulfur being such that, when excited by microwaves in the presence of argon gas, it produces a continuous broad band spectrum of light. The sulfur lamp output closely emulates sunlight with a Correlated Color Temperature (CCT) of 6000°K and a Color Rendering Index (Ra) >79. The sulfur lamp system used in this project consists of a 3 cm diameter quartz lamp enclosed in a wire screen with a metal encasement as shown in **Figure 1**.

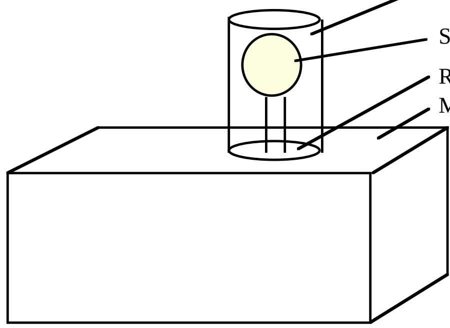

Figure 1: Sulfur Lamp

The semi-transparent screen enclosure serves to concentrate microwave radiation in the bulb region as well as shield outside regions from microwave radiation. Within the encasement is a magnetron and power supply, which produce microwaves. Microwave radiation is guided into the screened cavity where sulfur in the lamp is energetically excited to produce visible light. The sulfur lamp used for the described system has a measured lamp output of 124,000 lumens (including optical losses of the microwave screen enclosure). This represents an approximate source efficacy and luminance of 85 lm/W (including ballast losses) and 3.4E+6 cd/m,[2)] respectively.

Indirect Lighting Approach

One means of effectively distributing flux from high-lumen sources is an indirect lighting approach. Indirect fixtures direct most of their luminous flux upward toward a ceiling. A highly reflective ceiling can then serve as a secondary source of diffusive, low luminance, high visual quality lighting for interior spaces. A primary advantage of indirect lighting is the opportunity to significantly reduce indirect glare potential, and to completely eliminate direct source viewing. In conjunction with a highly reflective ceiling surface, indirect lighting can achieve efficient delivery, particularly in larger spaces (limiting wall effects).

Reflector Design

The design of an efficient, wide-distribution reflector requires special consideration of the sulfur lamp's unique geometry. In the case of high intensity discharge (HID) lamps, the source is generally surrounded by a glass envelope(s), which does not cause significant loss if reflected flux is re-entrant upon it. However, when using a source such as the sulfur lamp, with an extended physical enclosure that is far less transparent and more prone to scattering and absorption losses, extra care must be taken to avoid re-entrant flux.

Two possible design variations for axially or plano symmetric reflectors are determined by whether or not reflected flux from a section of the reflector profile crosses the axis (or plane) of symmetry before impinging on the target. These two profile types will be referred to as converging and diverging (for those that do and do not direct reflected flux across the symmetry axis, respectively).

A converging reflector profile used in conjunction with the sulfur lamp would allow a significant portion of reflected source flux to intersect the semi-transparent microwave screen enclosing the lamp, and thus lead to undesirable scattering and absorption. In an attempt to avoid these losses, a diverging reflector profile would be more advantageous. However, for mounting distances and illuminance levels typical of indirect, interior applications, a diverging reflector profile becomes impractically large when designed for a high-lumen source.

As a hybrid solution to this tradeoff, a 'bi-phase', 'non-contiguous' reflector was designed (**Figure 2**). This design allows reflected flux from the base of the reflector to diverge from the symmetry axis, thus directing it away from the screen enclosure. At a source emittance angle, above which intersection with the screen enclosure is no longer an issue, the profile becomes convergent to limit the physical extent of the fixture to a practical size. Secondarily, in order to prevent the diverging flux reflected from the shallow base section from being blocked by the steep profile of the top section, the two profile phases are physically separated to form two separate, or non-contiguous, reflector stages.

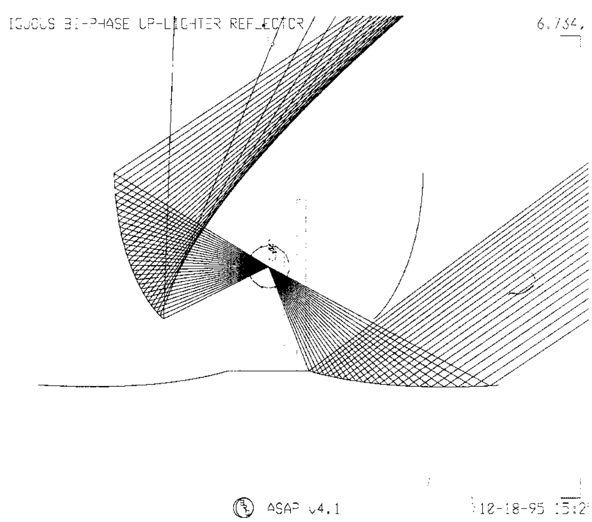

Figure 2. Ray trace of bi-phase, non-contiguous reflector.

Fixture Design
While this design can be utilized in a variety of different sizes and shapes, the prototypes constructed, shown with a cut-away in **Figure 3**, had an outside diameter of approximately 0.6 m and a depth of 0.2 m . Its two polished aluminum reflector dishes and a glass cover were held in place by three threaded rods.

Figure 3. Cut away photograph of bi-phase, non-contiguous reflector.

The lamp and reflector module could be mounted in a variety of ways: kiosk, wall and ceiling-mounted, to provide a high degree of flexibility and suitability across a broad range of lighting applications (**Figure 4**).

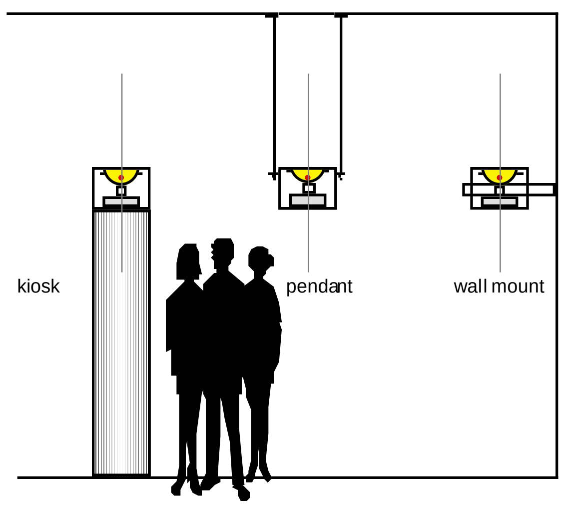

Figure 4. Mounting configurations for high efficiency up lighter.

Additionally, basic optical design of this reflector could be varied to provide different flux distribution patterns depending on the mounting height, illuminance criterion, and symmetry of a given application (**Figure 5**).

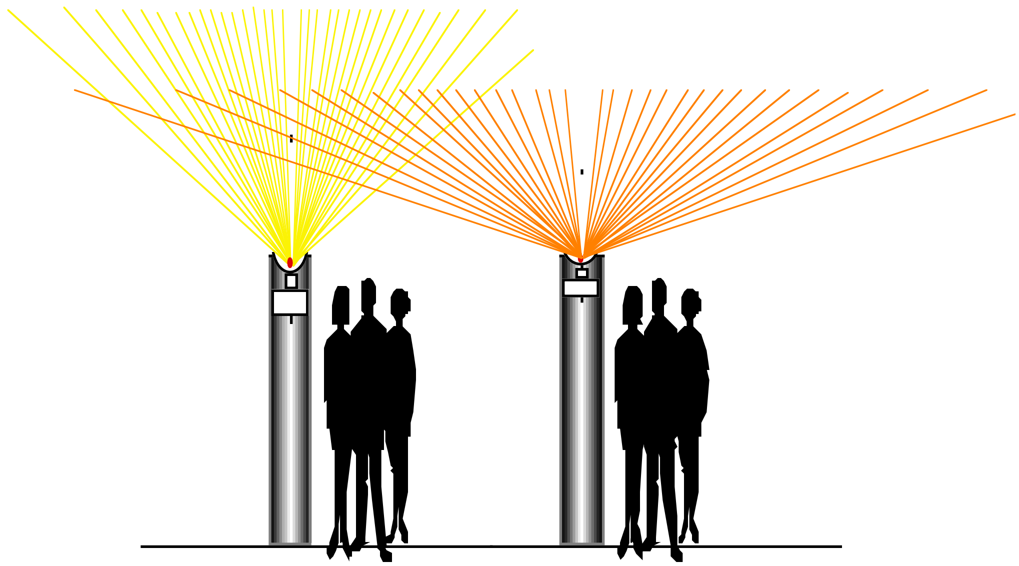

Figure 5. Varying distributions from indirect fixture.

The fabricated prototype for this system utilized the kiosk embodiment. The reflector module was mounted onto a cylindrical, free-standing structure to achieve a 2.0m reflector apperature height; tall enough to eliminate direct view of the source or reflector from floor level occupants. The kiosk is powered from underneath and the body houses the power supply and magnetron. The structure, as a whole, is both sturdy and aesthetically appealing while providing a high degree of mobility and ease of maintenance. For appropriate applications, this system will achieve superior visual quality through means of indirect lighting, while taking advantage of the high efficacy and Color Rendering Index of the 1000 Watt sulfur lamp system. A secondary advantage of this approach is that it allows a significant number of ceiling mounted fixtures to be effectively replaced by a series of high-efficiency, floor-mounted kiosks, reducing building costs and maintenance for lighting fixtures (**Figure 6**).

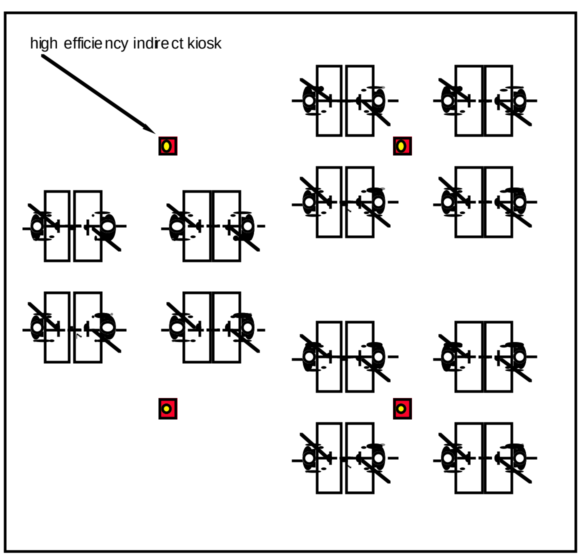

Figure 6. Plan view of indirect lighting approach using free standing kiosks.

SYSTEM EVALUATION

Reflector Performance

A fabricated prototype of the lamp and reflector system was photometricaly tested (**Figures 7, 8**). Results from two independent testing facilities showed a fixture efficiency of approximately 90%.

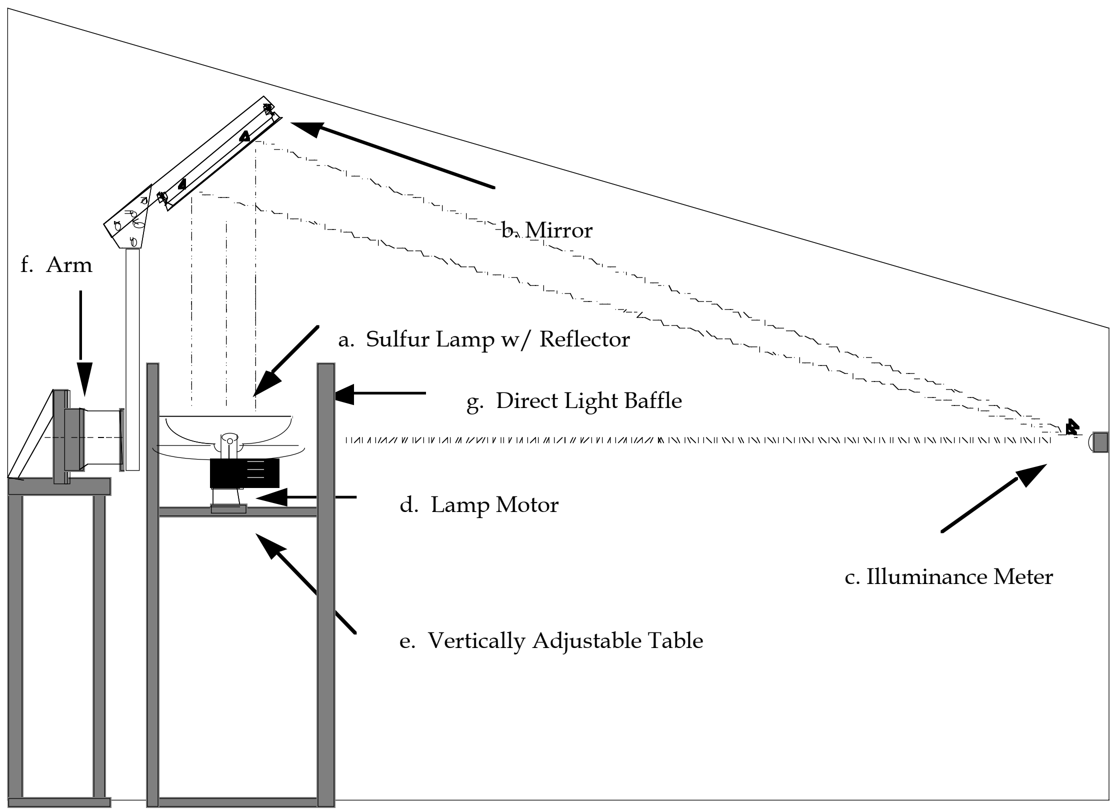

Figure 7. Goniometric assessment of prototype lamp and reflector module.

Fixture Efficiency = 89.2%

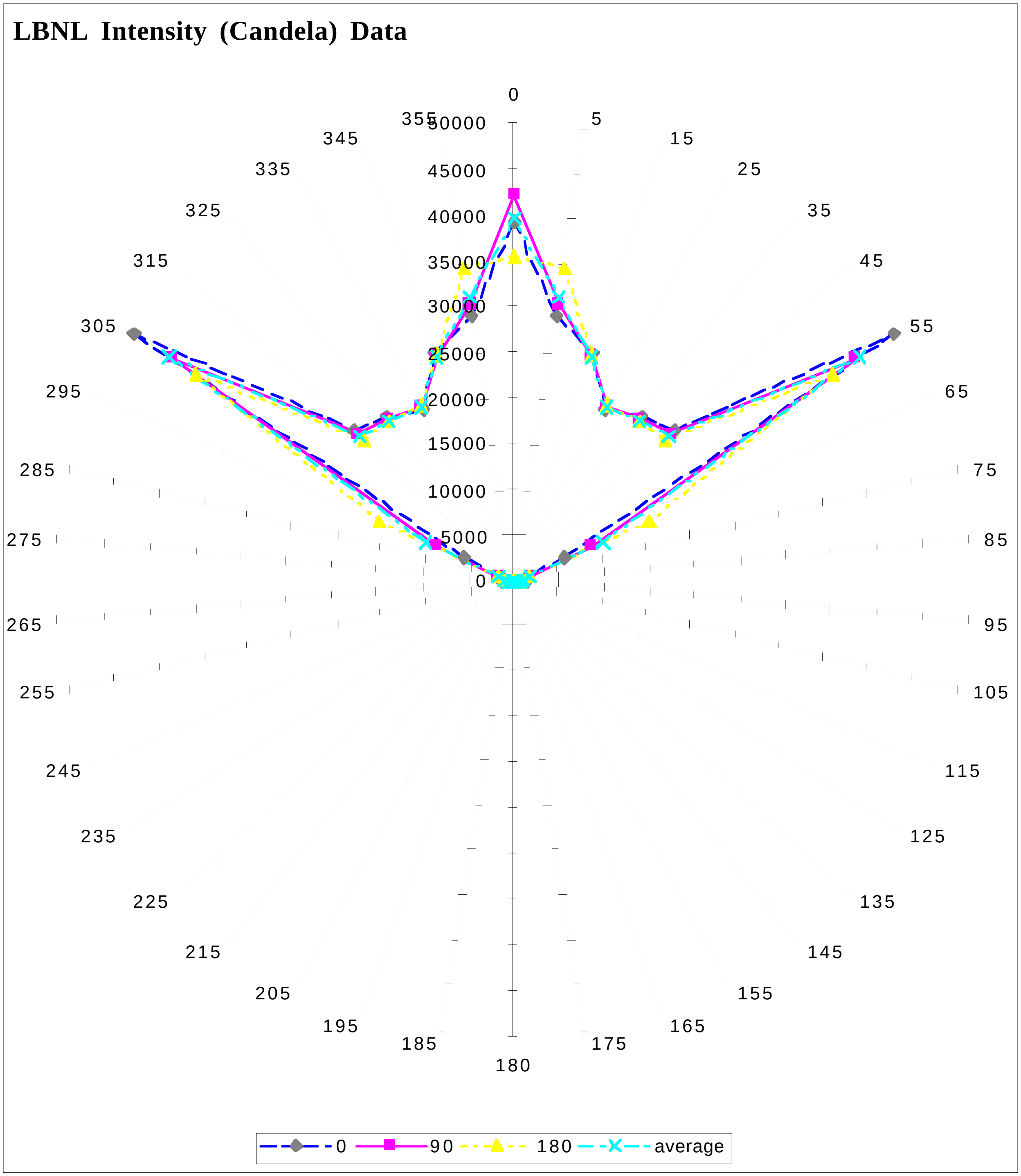

Figure 8. Candela plot of prototype lamp and reflector module.

System Demonstration Performance

Two prototype fixtures were installed as part of the remodeling of a large (12m x 24m x 4.2m) lobby space of a municipal utility (**Figure 9**). This lobby is used as a gathering space in the utilities' main entrance and training rooms, and serves as a demonstration area for energy information and new energy technologies. The 4.2m high ceiling was retrofit with high reflectance (90%), white acoustic ceiling tile. The two 12m long walls have white, 80% reflective paint with small, low reflectance brown cavities near the corners. One of the 24m long walls has a low reflectance brown paint, while the other 24m wall consists almost entirely of windows. The two kiosk fixtures serve as the sole source of lighting for the space, by providing an even illuminance pattern with gradual drop off across the majority of the ceiling.

Figure 9. Installed indirect, kiosk fixture.

A detailed in-situ photometric analysis of the space has not yet been performed. Planned photometric studies of this space include ceiling luminance pattern analysis and work plane illuminance distribution. Initial illuminance readings indicate that the lobby is evenly lit, with a floor illuminance level comfortably above criterion. Media coverage from local television and major US lighting magazines were quite positive and praised the high quality, low glare qualitative performance of the lighting system.[2,3]

SUMMARY

Many new lamps, the sulfur lamp in particular, are emerging that have high lumen output, high efficacy, and good color rendering quality. An indirect fixture was developed that accounts for the unique optical geometry of the sulfur lamp to provide a high-efficiency distribution system.

By combining an efficacious, high-output source with an indirect lighting approach, a lighting system was developed which is capable of efficiently providing low-glare, high-quality lighting in a variety of interior applications. Additionally, a potential for reducing building and maintenance costs is created by effectively replacing numerous ceiling mounted fixtures with a small number of high-efficiency, floor-mounted kiosks.

Two prototype models were fabricated and installed at a demonstration site. Photometric analysis of the unique reflector design demonstrated a 90 percent fixture efficiency. A detailed in-situ analysis has yet to be performed, but initial measurements and qualitative assessments are very positive.

ACKNOWLEDGMENT

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