PIER Lighting Research Program

California Energy Commission
Contract # 500-01-041

LED Task Lamp Design Considerations

Deliverable 2.2.2a
July 8, 2004

Submitted To:
Accounting Office, MS-2
California Energy Commission
1516 Ninth Street, 1st Floor
Sacramento, CA 95814

Submitted By:
Architectural Energy Corporation
2540 Frontier Avenue, Suite 201
Boulder, Colorado 80301

Table of Contents

Contact Information:

Project Manager:
Steve Johnson
Lawrence Berkeley National Laboratory
1 Cyclotron Road
Berkeley, California 94720
510-486-4274
SGJohnson@lbl.gov

AEC Program Director:
Judie Porter
Architectural Energy Corporation
2540 Frontier Avenue
Boulder, CO 80301
303-444-4149
jporter@archenergy.com

Summary of Research Performed to Date on the Development of the Optics for the LED Task Lamp

Lighting Research Group
Lawrence Berkeley National Laboratory

Introduction

This report summarizes the research performed to date on the LBNL project, “LED Task Light Utilizing New Materials to Reduce Thermal Stress on High Brightness LEDs.” The goal of this project is to accelerate the use of energy efficient light emitting diode (LED) technology for general lighting applications by developing a task lamp utilizing high brightness LEDs in a consumer acceptable light fixture. At the time of writing this report, lamp reflector prototypes have been developed, the spatial output and illuminance pattern of two reflectors have been measured, and the spatial output and illuminance pattern of 10-LED/reflector configuration has been simulated.

Background

The design of the LED task lamp was based upon the photometric performance of the Luxo 01A Vision asymmetric task luminaire (Figure 1).

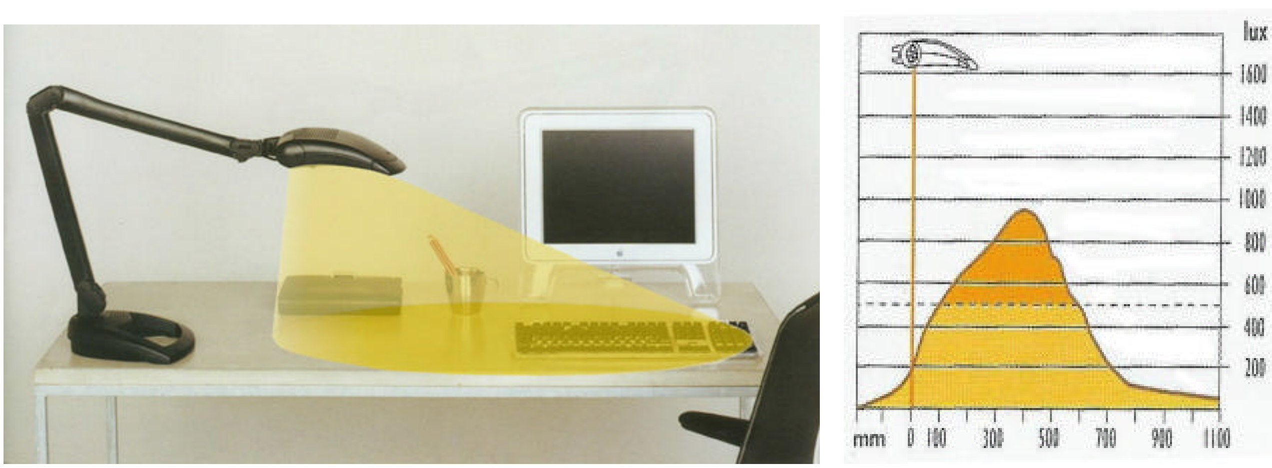


Figure 1. LED task lamp with two rows of five lamps each. Each row can rotate around its axis.

The intent of the design was to maintain the existing illuminance pattern of this luminaire on the workplane, while replacing the compact fluorescent lamp (CFL) with LEDs as the light source.

Task Lamp Design

The LED task luminaire designed by LBNL contains 10 LED lamp units, in two rows of 5 lamps each as shown in Figure 2. This figure is a three dimensional simulation of the lamp reflector viewed looking up into the reflector cups, where the small black dot indicates where the LED would be located. Each row of lamps is able to rotate ± 10 degrees around the central axis of the reflector, and the two rows rotate simultaneously. Figure 3 demonstrates the two extremes of the rotation, looking at the end of the rows.

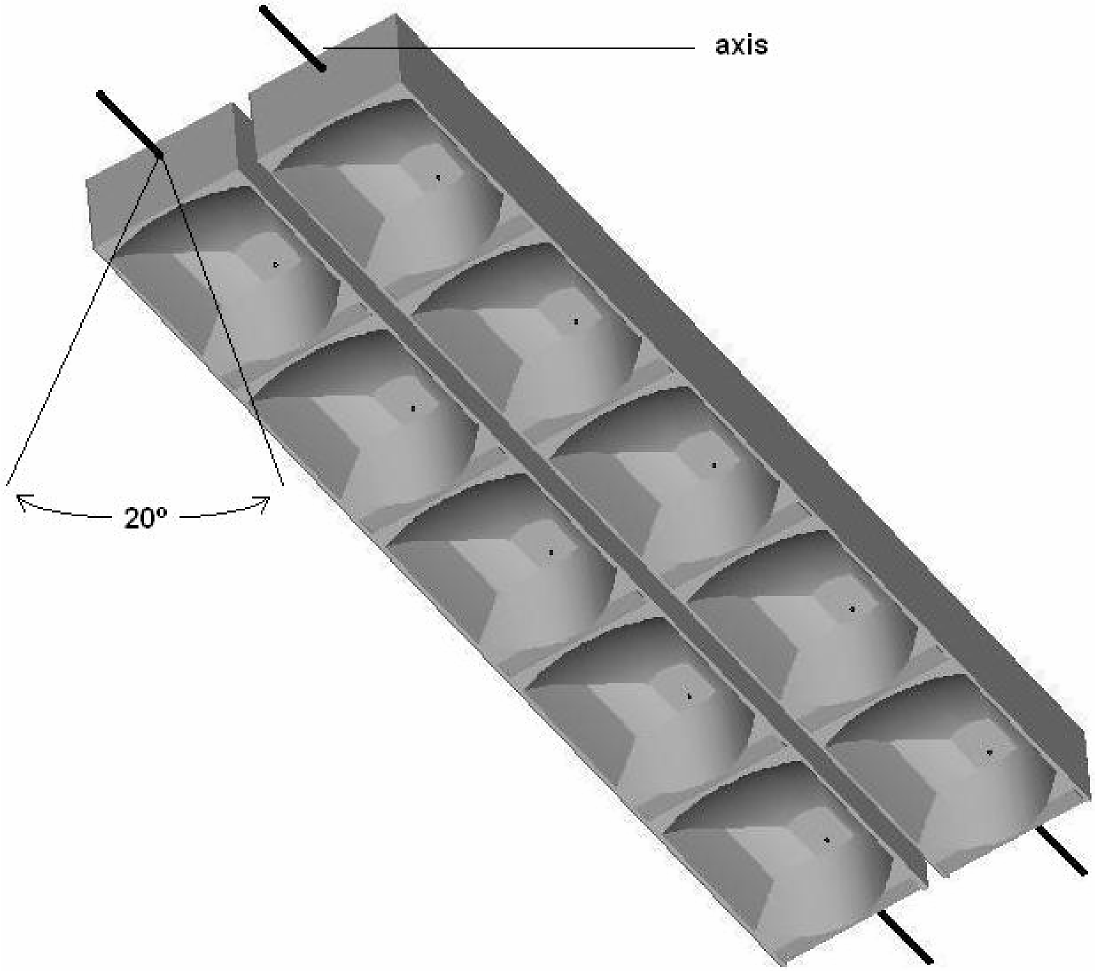


Figure 2. LED task lamp with two rows of five lamps each. Each row can rotate around its axis.

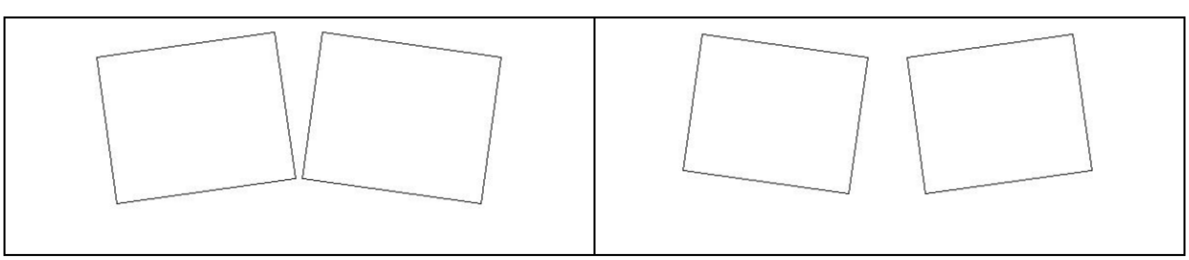


Figure 3. Inward and outward rotation of LEDs around the central axis

The design of the reflector cups was developed using a ray tracing simulation program, TracePro, with the intent of simulating the illuminance pattern of the Luxo 01A Vision asymmetric task luminaire as given in Figure 1. The illuminance pattern was not segmented into different areas for the separate LEDs, but rather each reflector replicated the entire distribution pattern. Hence, the reflectors have a cumulative effect in raising the overall illuminance within the pattern and the failure of one source will not be disruptive to that distribution pattern.

The design of the reflector cups assumed a point source with a Lambertian distribution. Measurements in the far field of the LEDs being used verified this assumption. The calculations also assumed that each source would have an efficacy or 25 lumens per watt and that the reflector was 90% efficient. The resultant simulations indicate that ten 1-Watt LEDs in separate reflectors would provide the same illumance as the 18W CFL in the Luxo 01A Vision task lamp. Each reflector has the dimension of 46 X 32 X 22 mm (LxWxH).

Once the simulation program generated a solid model of the reflector cup, having the desired optical properties, the information was transferred to fabrication equipment. The prototype reflector pieces for the task lamp were fabricated by a stereo-lithography (SLA) process and modified to be able to take the new Cree XLamp prototype mounted on a heat sink (Figure 4).

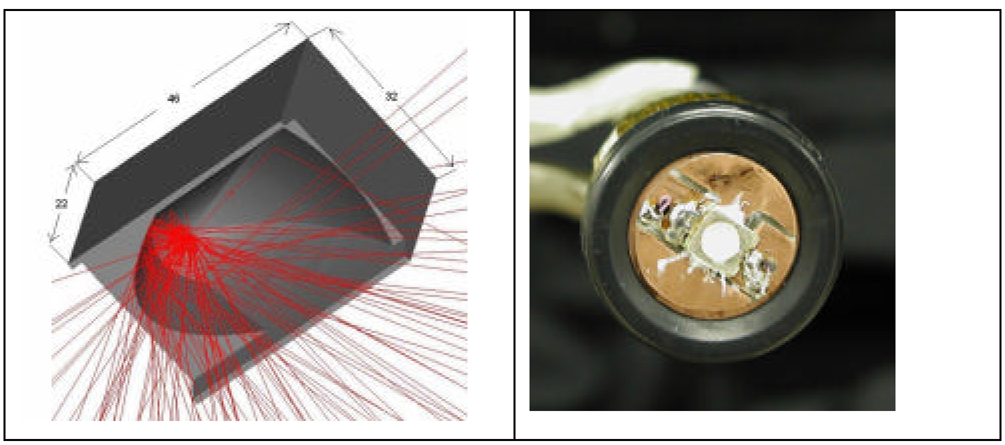


Figure 4. CAD model of LED tasklamp reflector (left) and the heat sink mounted Cree XLamp prototype (right)

Two different types of coatings were applied to the reflector surfaces in order to test the output with both specular and diffuse reflectance. In case of the specular coating (Figure 5), the surface of the reflector was smoothed by the application of two very thin UV cured epoxy layers prior to aluminizing the surface. No treatment was applied to the other reflector before application of the diffuse white paint coating (Figure 6).

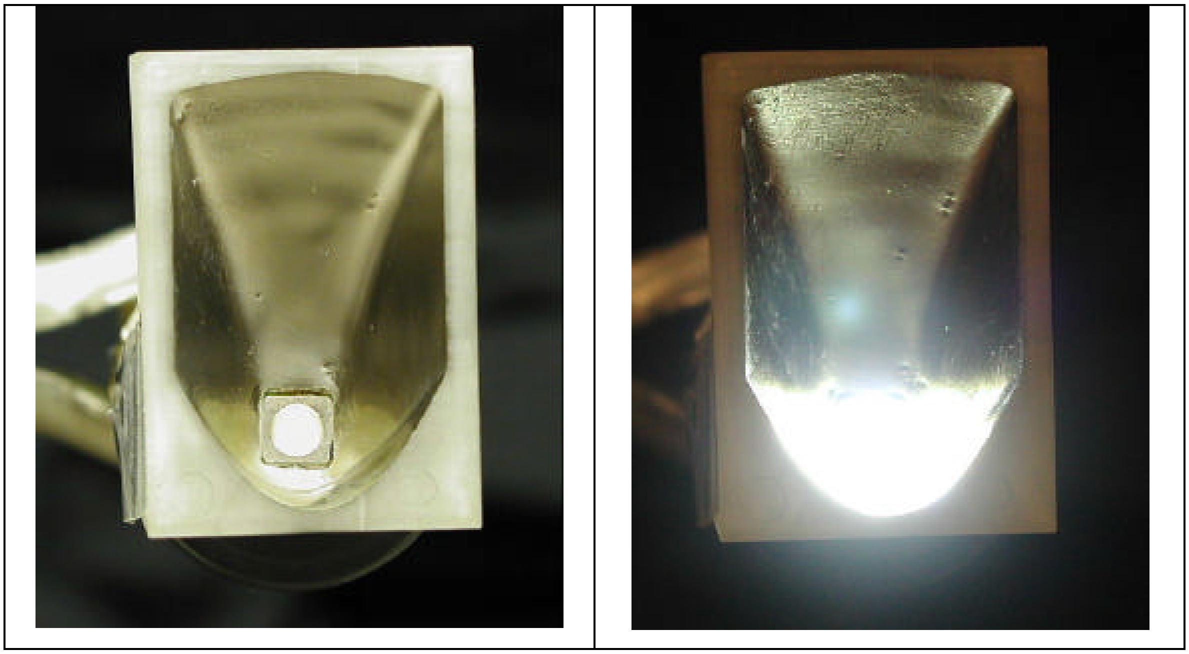


Figure 5. SLA prototype reflector with specular metal coating.

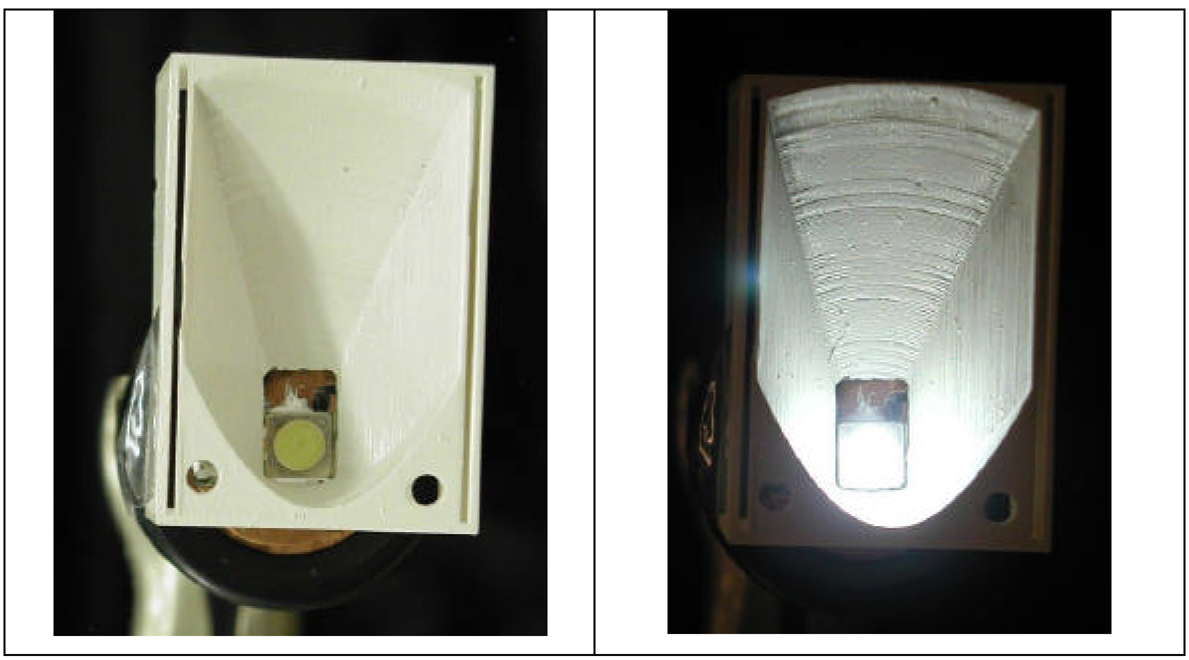


Figure 6. SLA prototype reflector with diffuse white paint coating.

Results of Testing and Simulations

Testing performed on the SLA reflectors measured the spatial intensity distribution pattern relative to the simulated reflector. A comparison of the measured values for the specular reflector to the simulated values is given for the centerline distribution in Figure 7.

The simulated distribution has a broader distribution with a maximum value further from the optical axis of the source, the "0" set point, than the measured distribution. The difference in the observed and simulated distributions may be attributed to several factors:

1) The simulation assumed a point source. Given the size of the source and its close proximity of the source to the reflector walls, this assumption is not entirely valid, introducing some error into the simulation.
2) The surfaces of the reflector were not as smooth as those used in the simulations. This is visible in the photographs of both reflector surfaces (Figures 5 and 6), being more pronounced in the white diffuse reflector where a smoothing epoxy was not used.
3) The accuracy of the dimensional replication of the solid model is limited by the SLA prototyping process and hence limits the development of exact replicas of the simulated reflectors.

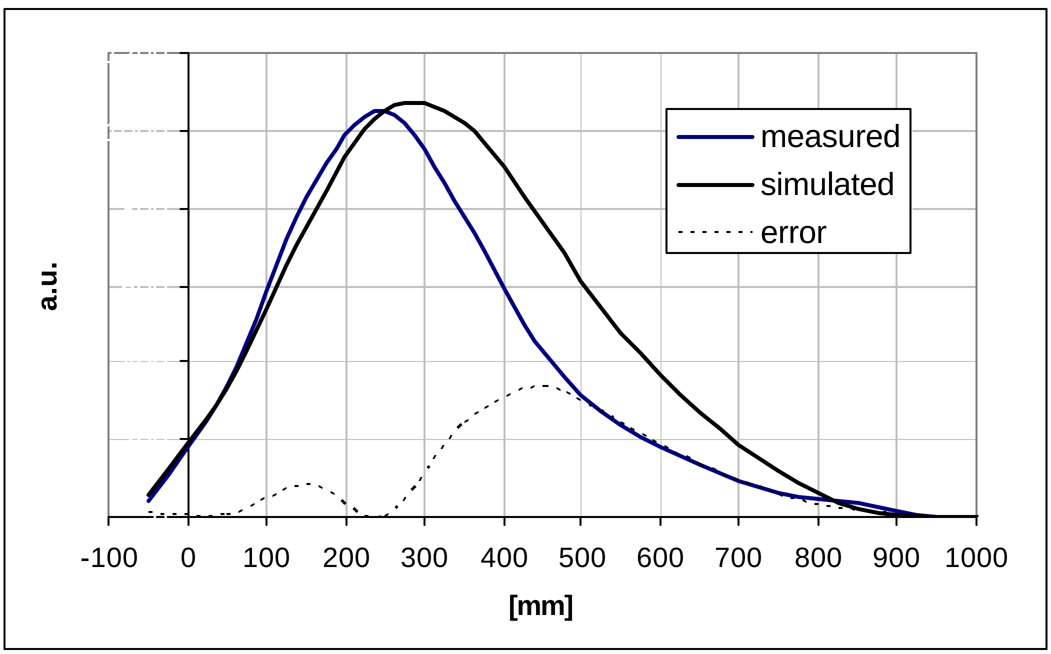


Figure 7. Specular Reflector: simulated and measured spatial output

Figure 7 represents the results of a single reflector, as the five reflectors are aligned in a row the resultant distribution will be broader like the simulation because of the spatial separation of the sources.

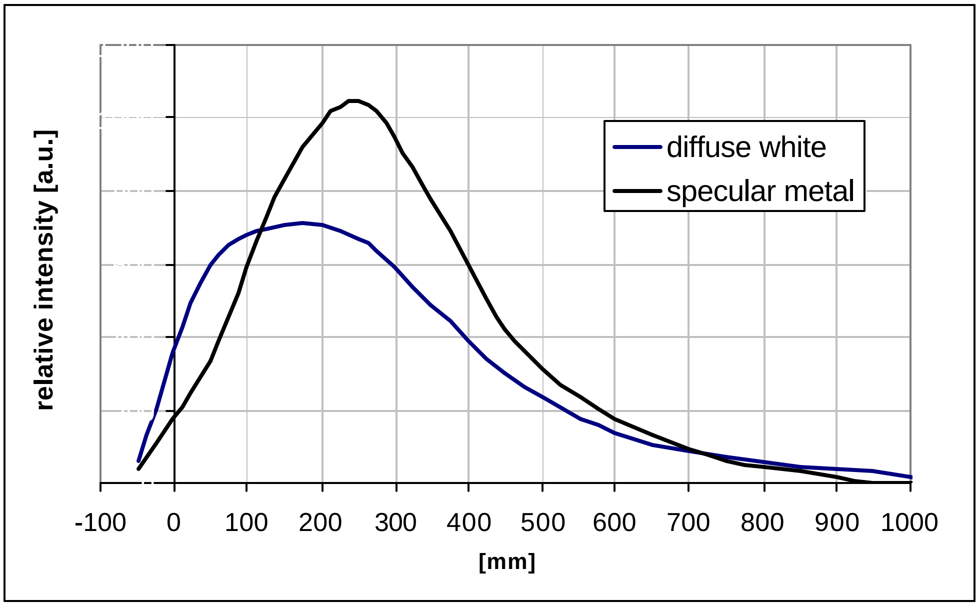


Figure 8. Comparison of the distribution of the diffuse white Coating to the specular reflective coating

Figure 8 compares the distribution of the specular reflector to the reflector using a diffuse white paint. The paint used was not designed for this application and has a lower reflectance than may be anticipated for commercial products designed for luminaires. The maximum of the diffuse coating is shifted further toward the optical axis demonstrating that the reflector is directing less of the light than specular surface. The width of the distribution curve of the diffuse white coating at full width half maxima is much broader than the specular reflector and equals that generated for the simulated reflector. It may be possible to combine these two effects by having a reflector cup with the specular portion near the source and the diffuse reflector at the outer edges to realize a distribution closer to the simulated design.

Simulations of the spatial distributions were also calculated for the 10 LED luminaire at a source height of 400mm with the two rows of reflectors in different orientations. These simulations demonstrate the change in distribution and intensity that would be realized by this rotational dimension of flexibility. Figures 9, 10, and 11 provide the distribution pattern as the rows are rotated from 8 degrees inward, to 0 degrees rotation, to 8 degrees outward, respectively. If the rows are turned inward, the hot spot illuminance level increases, while the illuminated area decreases, as shown in Figure 9. Figure 10 represents the distribution pattern for the reflectors normal to the illuminated surface, generating a pattern similar to the Luxo luminaire to which the system was designed. The outward rotation of the rows of reflectors facilitates the illumination of a larger area and consequently decreases the overall illuminance level (Figure 11). Relative to the light intensity, a dimmable driver will also provide an additional element of flexibility in control of the light intensity and in comfort for the end user.

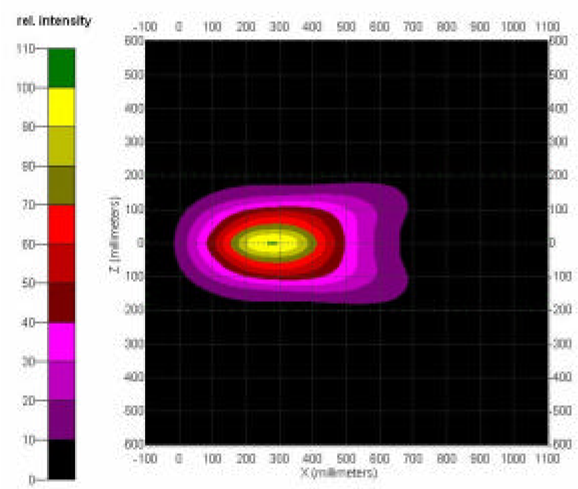


Figure 9. Simulated output showing how turning the reflector rows inward increases illuminance levels.

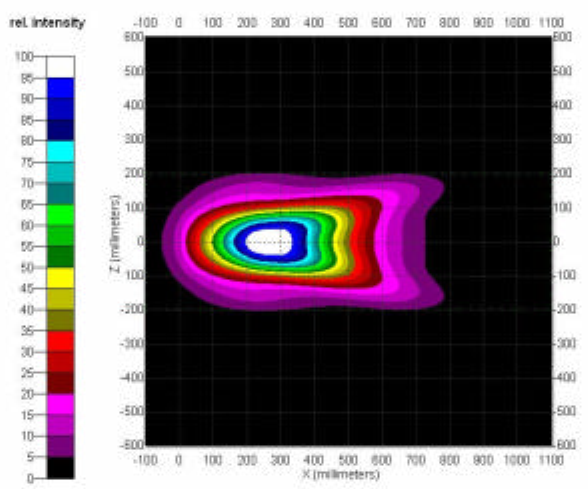


Figure 10. Simulated output showing illuminance levels when the sources are normal to the illuminated surface.

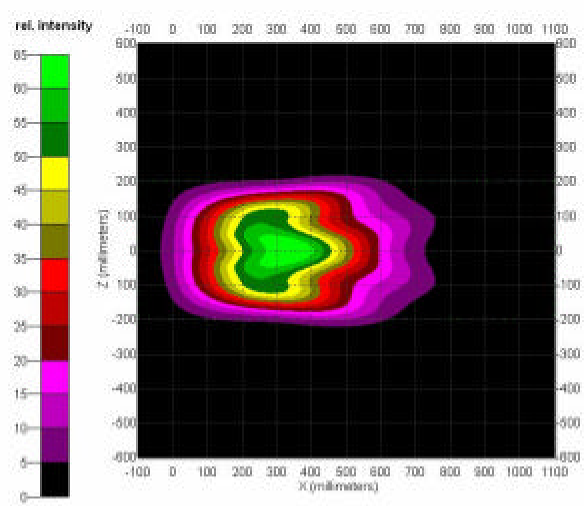


Figure 11. Simulated output showing how rotation of the reflector rows outward allows a larger area to be illuminated.

In conclusion, the results shown above for the prototype reflectors are the culmination of multiple runs of designs modified to reach a distribution that simulates the design criteria for the lamp. Minor modifications may be made to the existing reflector cup design, but further effort will be focused on developing the circuit board layout, integration of the heat sink into an esthetically pleasing design, integrating the LED driver into the design, and assembly or a prototype lamp.

Using the attributes of the LED source, we will produce the same distribution and output as the one (1) eighteen watt (18W) CFL with ten (10) one watt (1W) LEDs. Since both use electronic ballasts with comparable efficiency having a power loss of about 15% of the power of the sources, the resulting energy use would be:

LED Luminaire: (10 X 1W: LEDs) + (10W X .15: ballast) = 11.5 W

CFL Luminaire: (1 X 18W: CFL) + (18W X .15: ballast) = 20.7 W

This assumes that the light distribution and intensity given in the Luxo product literature accurately represents product performance. The second assumption is that we can make all of the LED reflectors as efficient as the one silvered prototype made to date. This would be no problem for a manufacturer, but LBNL's prototype tooling is not as reproducible as a production process. We believe that we will attain the project objectives since the designs are based upon a 25lpw source and we should have sources with significantly higher efficacies.

Design of the LED cooling structure for the prototype task lamp

It will be necessary to attach coiling fins onto the side of the two LED light bars that form the light distribution system for the task lamp to dissipate the heat generated by the LEDs, assuring their optimum performance. Each light bar is composed of 5 individual reflectors housing a single 1W LED. The top of the light bars will be an aluminum core circuit board that supports the electrical connection to the LEDs and provides the conductive thermal path to the aluminum fins, which are convectively cooled by airflow up through the fins.

To follow are 7 designs which are being considered for the head of the task lamp

Arrangement 1: This design is the simplest application of fins attached directly to the side of the light bars.

Arrangement 2: The design has a reduced surface area of the fins by shaping the fins in a triangle that blends with the top of the lamp.

Arrangement 3: The design additional contour is added to the fins to give a softer appearance.

Arrangement 4: The design adds more dynamics to the shape, blending the fins to both the ends and the top of the light bar.

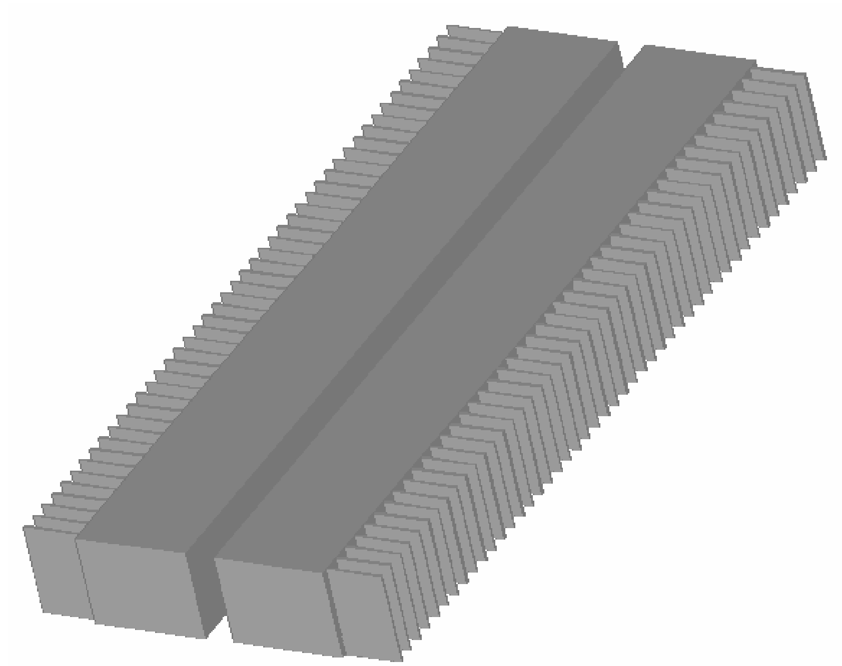
Arrangement 5: This design takes the elements of arrangement 2 and adds safety strip to the ends of the triangle to reduce any sharp edges.

Arrangement 6: This design takes the elements of arrangement 4 and adds the safety strip. We thought the safety strip could be made of colored plastic or metal to further the visual dynamics.

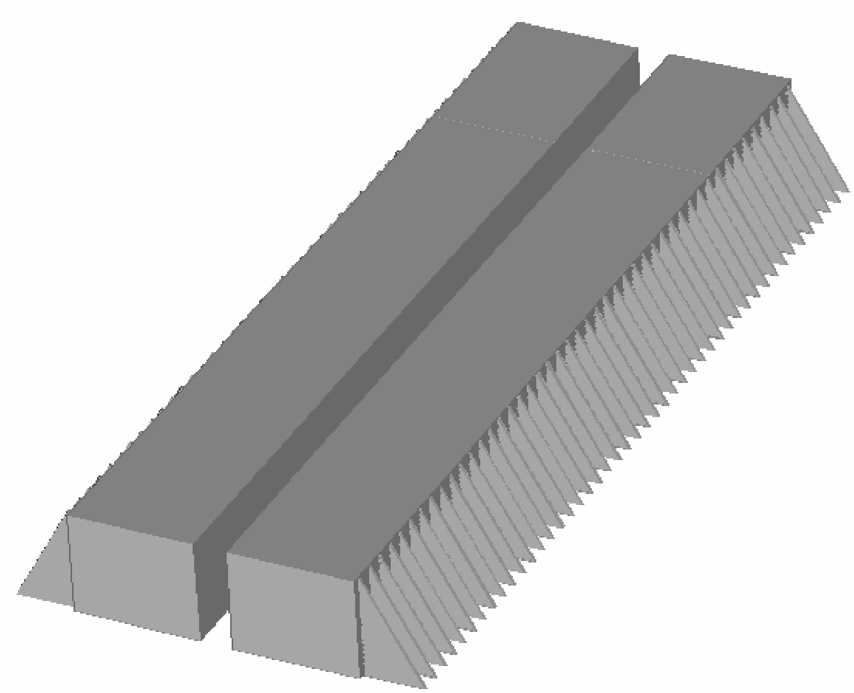
Arrangement 7: Is a more robust version of Arrangement 6

Report 06/29

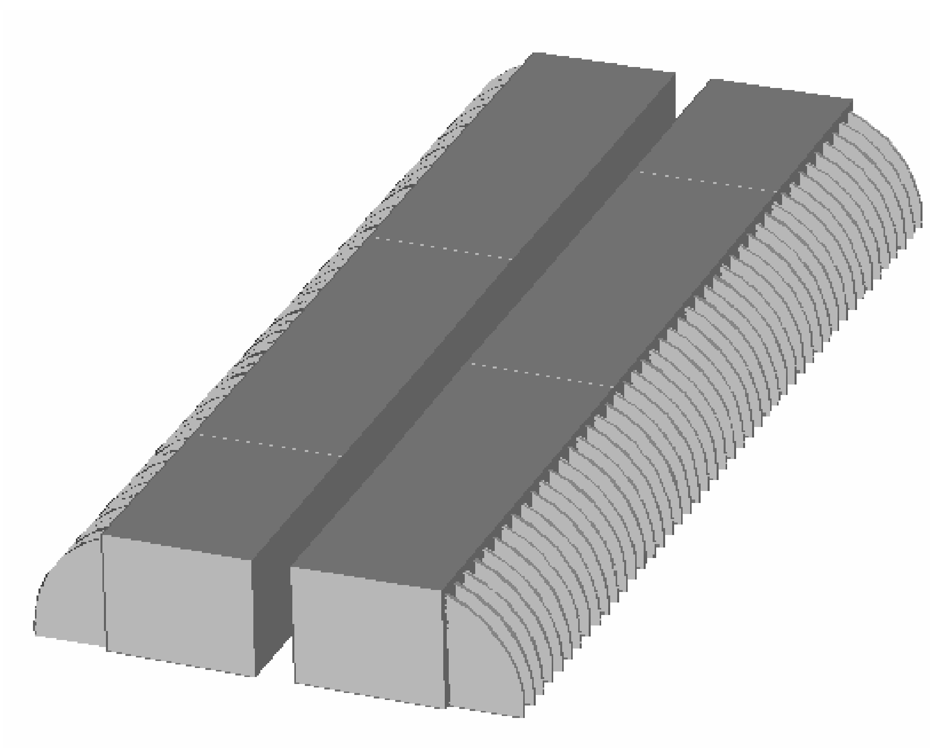
Task lamp cooling flange designs



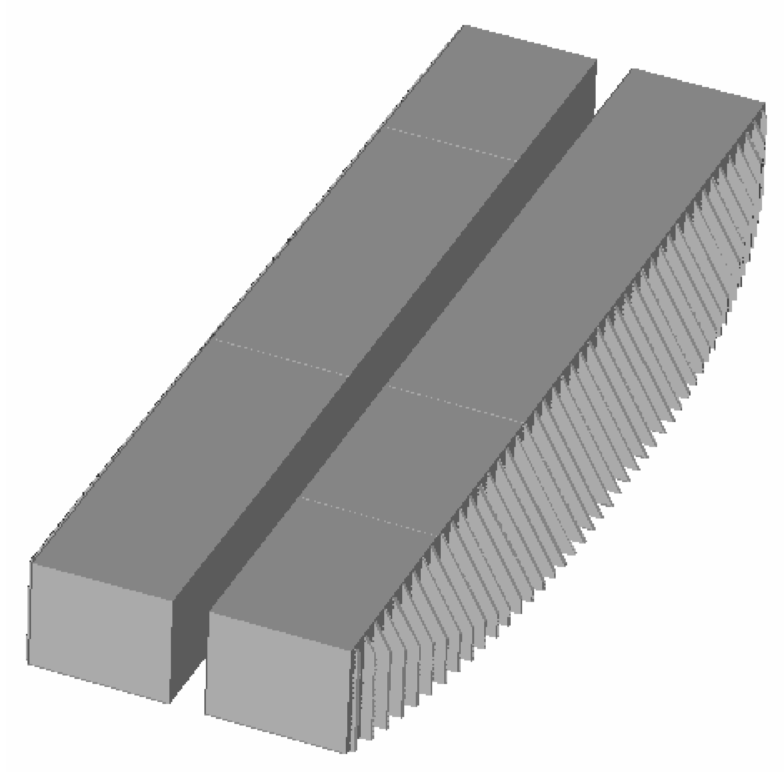
Arrangement #1



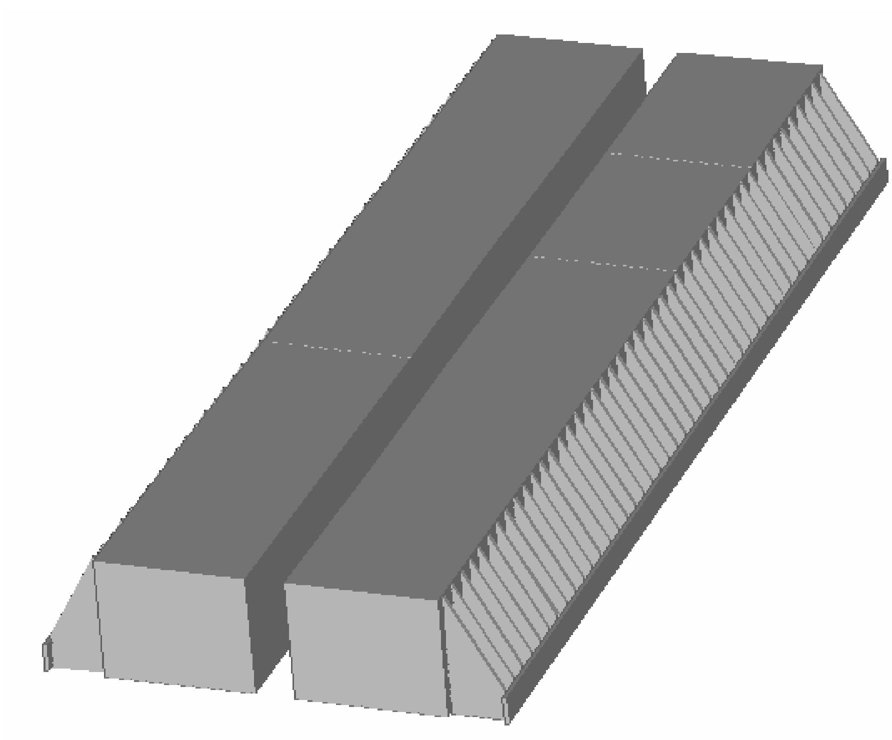
Arrangement #2



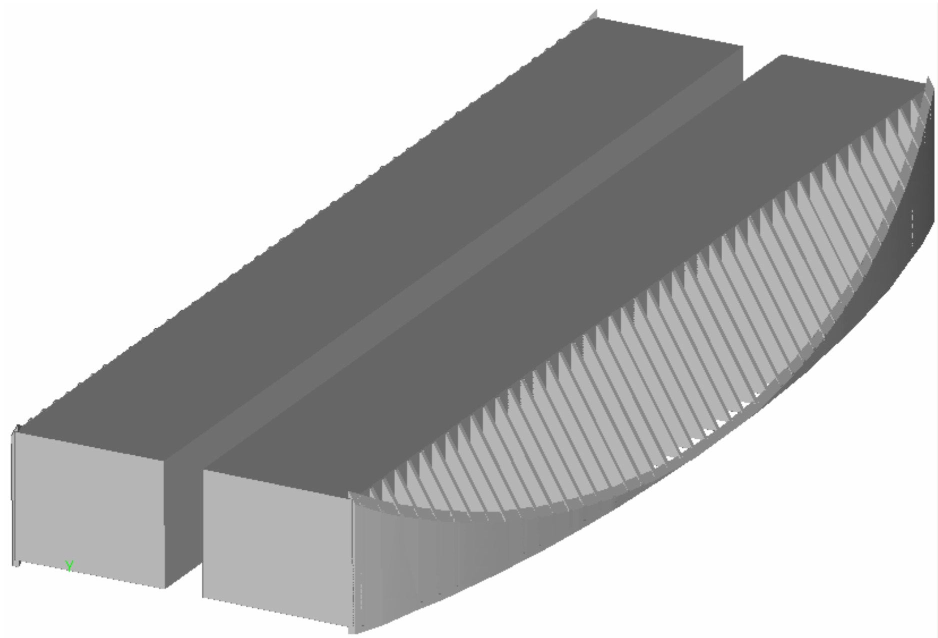
Arrangement #3



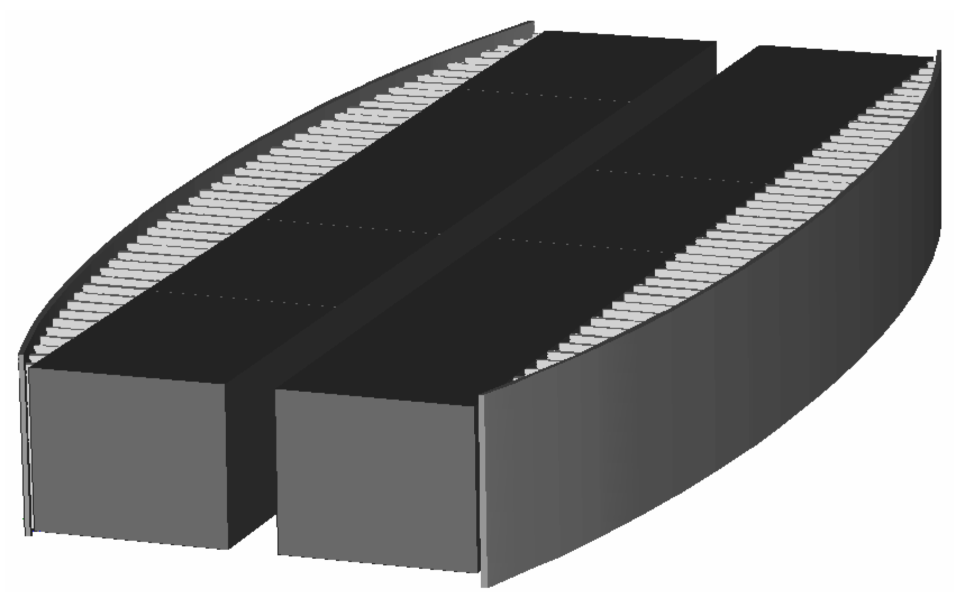
Arrangement #4



Arrangement #5



Arrangement #6



Arrangement #7