LBL-37856

Improving the Performance of Integral Screw-Base Compact Fluorescent Lamps in a Base-Down Burning Position Using Thermal Bridge Systems

Michael Siminovitch, Eric Pankonin, Chad Praul and Chin Zhang

Lighting Research Group
Lawrence Berkeley National Laboratory
Berkeley, California 94720

ABSTRACT

Many residential applications of the integral ballast, screw base compact fluorescent lamp (CFL) require a base-down orientation, as exemplified by table and floor lamps. Positioning CFLs base-down results in a 10-25% loss in lumen output, due to excess mercury vapor pressure in the lamp. These losses may limit consumers' acceptance of these new CFLs as a viable retrofit strategy. To mitigate output losses, researchers are developing thermal bridge systems that cool the small tubulation of the lamp, thereby optimizing the mercury vapor pressure. Thermal bridge systems consist of small copper heat sinks that fit entirely within the integral ballast compartment. Experimental data indicates most of the thermally based losses are recoverable, allowing for a lamp system that produces approximately the same lumen output regardless of orientation. As base-down positioning has wide residential application, the improved lumen output of these lamps would have a significant impact on residential retrofits.

BACKGROUND

A study done in December of 1991 showed that 30% of all residential sockets in the U.S. could accept CFLs. [1] Many of these sockets, including those in table and floor lamp systems, use the base down orientation. Consumers rate lumen matching as the number one reason for rejecting CFLs [2], meaning they will not accept CFLs that produce less light than the original bulb.

Compact fluorescent lamps are highly sensitive to burning orientation. In a base-up or horizontal orientation, the coldest point on the lamp wall (farthest from the filaments) and the lowest point inside the lamp coincide, and gravity aids the condensation of excess mercury in the lamp tips.[3] When the lamps burn base-down, gravity works against the natural cold spot condensation of the mercury by pulling the liquid mercury down into the hot base of the lamp. Inside the base, at the bottom end of the bulb, is a small glass nipple called the tubulation. Mercury collected in the lamp tubulation is exposed to radiative, conductive, and convective heat transfer from nearby filaments and the electronic ballast. Condensed mercury in this region is quickly vaporized, increasing the mercury vapor pressure within the lamp beyond the optimum level. Figure 1 illustrates the two main orientations of the integral CFL and the internal components. Several current thermal management studies are concentrating on cooling the bulb tubulation in the lamp's base. The most successful technique is the internal thermal bridge that connects the tubulation to a small cooling fin located inside the ballast base cap.

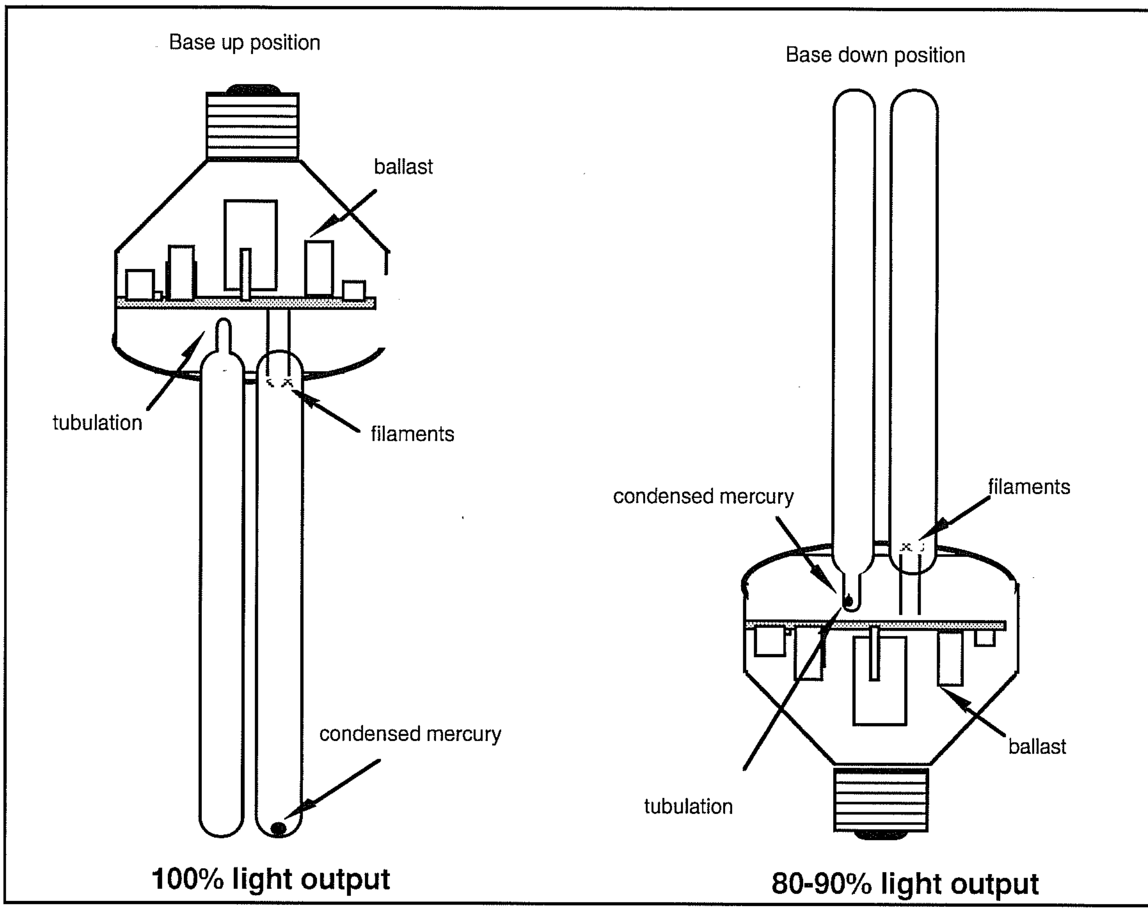

Figure 1. Base up and base down positioning of the integral lamp

DESCRIPTION OF CONCEPT

A variety of thermal bridge assemblies have been developed to conduct heat away from the lamp's tubulation within the ballast compartment. The thermal bridge consists of a conductive element in contact with the tubulation that conducts heat to a heat-exchanging "fin" in a cooler section of the ballast compartment. Bridge elements were constructed to spring or snap onto the tubulation as one piece. This one piece assembly provides both the thermal conduit and heat transport surface.

Current thermal bridge designs consist of a single thin copper strip, 0.02" thick by 3/8" wide, crimped to fit around the extruded tubulation of the lamp, where condensed mercury rests. The copper strip continues to the outer periphery of the base where it is rippled to increase its surface area for heat dissipation. These bridges easily attach to the tubulation in the position shown in Figure 2.

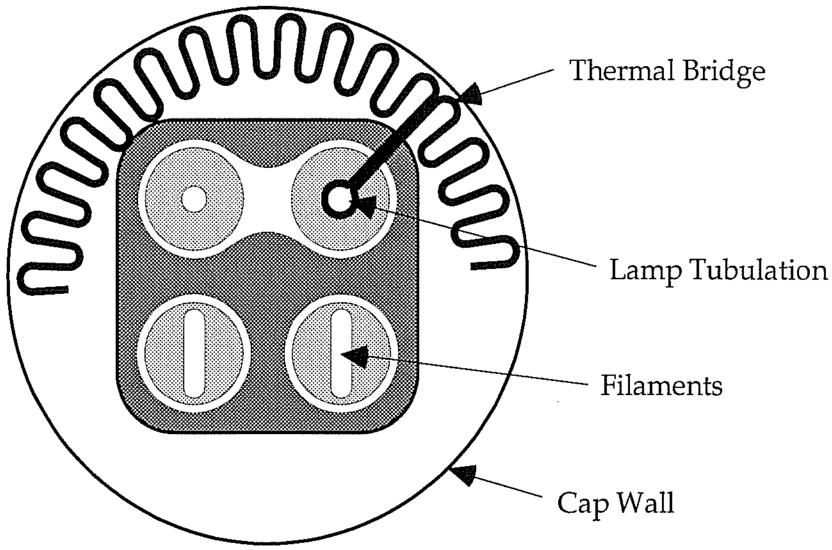

Figure 2. This bottom view of the bulb base cap shows the internal thermal bridge consisting of a copper strip that is crimped around the tubulation and rippled for greater heat transfer area .

EXPERIMENTAL PROCEDURE

Experiments on the thermal bridge are conducted in an integrating chamber that is maintained at room temperature, between 22°C and 26°C. The integrating chamber contains thermocouples and photometers to monitor temperature and lumen output. Each lamp assembly is powered by a voltage stabilizer and held by a rotary positioning device that allows for changes in orientation. Light output and power input are recorded by National Instruments data acquisition software on a Macintosh II computer. At the beginning of each experiment, data were recorded every 2 seconds until the peak light output, when the software switches to a 5 minute recording interval. This absolute light reading is divided by the maximum light output on that run to determine the thermal losses of the fixture.

Before tests begin, each new integral assembly is initially burned in a base down position for a period of 100 hours to minimize lumen depreciation error. The lamps are then moved to the integrating test chamber and operated overnight to re-establish the cold spot. Next, the lamps are switched off so they can cool to a temperature below the optimum mercury vapor pressure. When they are turned on again for the experiment, the lamps will produce the maximum light output as they heat up and pass through the optimum vapor pressure, usually within the first 5 minutes of the experiment. Lamp experiments typically run for 15 to 24 hours; however, once the cold spot has been established, most of the thermally dependent changes in lumen output occur within the first hour.

EXPERIMENTAL RESULTS

Figure 3 shows the variations in relative light output over 16 hours for three different configurations of the integral Edison base quad-tube compact fluorescent lamp, including:

1) a standard integral lamp operating base up
2) a standard integral lamp operating base down
3) thermally bridged integral lamp operating base down.

The standard system operating in a base down position reaches a maximum light output within 5 minutes of being energized. Light output then drops quickly over the next 5 minutes and stabilizes at approximately 78%. The same assembly operating with the rippled internal thermal bridge also reaches its maximum output quickly, then stabilizes at approximately 97% of maximum light output. The standard lamp assembly in a base up position also peaks shortly after it is energized, shows a small reduction in lumen output, and then operates in the 96-98% range (see Figure 3).

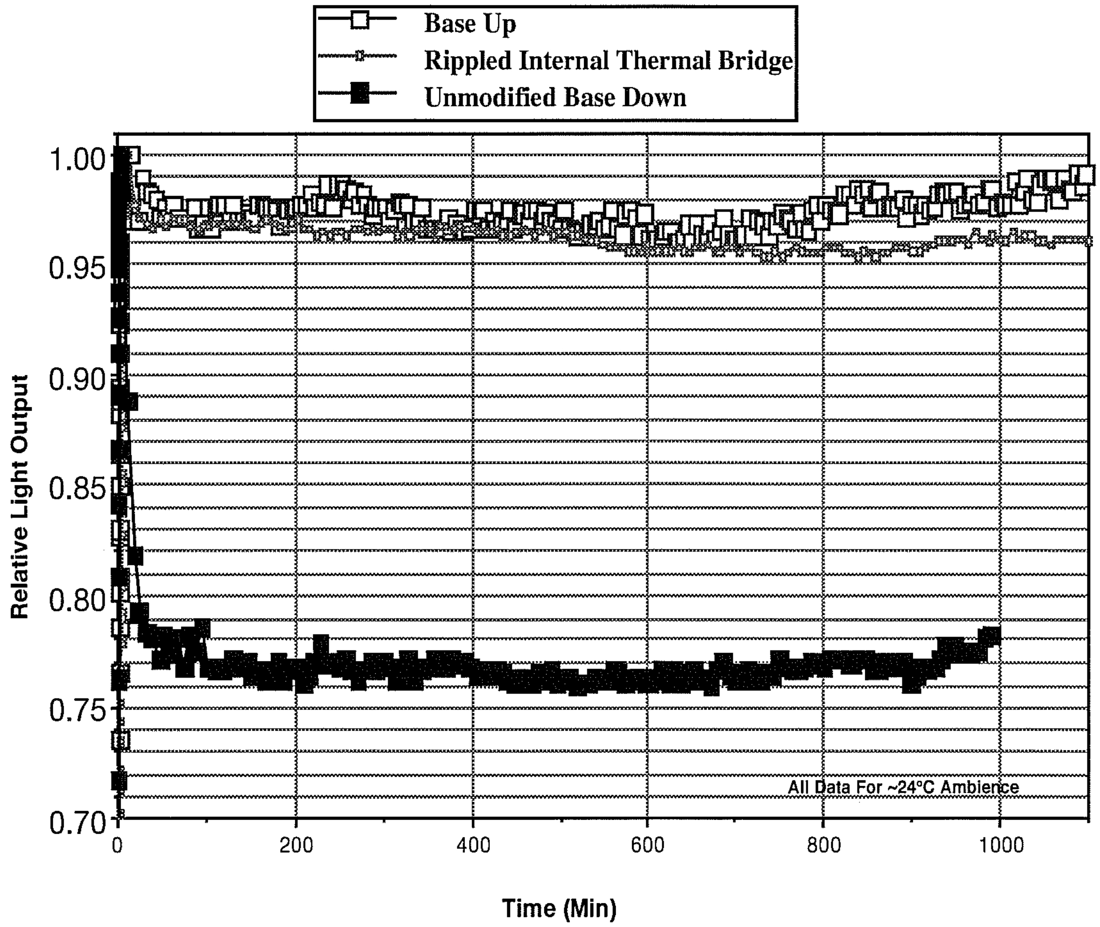

Figure 3. Thermal bridge performance of several integral quad tube CFLs.

DISCUSSION

Base down integral ballast CFLs usually loose 10-25% of their light output compared to base up lamps. The variation in lumen losses is a function of lamp power, ballast compartment constriction, and ambient temperature. Some integral lamp ballast systems significantly under powering the lamp reducing position based losses to approximately 10%; however, lamp output is also reduced. With the thermal bridge assembly, the system operates at or near specifications with near full light output for all orientations.

The effectiveness of the thermal bridge depends on its ability to transfer heat away from the tubulation. Heat transfer depends only on properties of the metal, the area of the "fin," properties of the air around the "fin," and the temperature gradient between the tubulation and the air. Aluminum has been tested as a bridge material as it is inexpensive, but it is also less thermally conductive, reducing the effectiveness of the bridge. Researchers have also experimented with non-rippled fins that are easier to produce, and work almost as well as the rippled fins, which have more area. Vents through the ballast case would increase convection within the lamp base, however they could create problems with UL certification and aesthetics. External thermal bridges were also considered as they have more air flow around them and their temperature gradients are greater, but there could be aesthetic problems for manufacturers.

Additional concerns relate to higher ballast temperatures, electrical shorts, and base up orientations with a thermal bridge. Ballast life strongly depends on ambient temperature; however, preliminary laboratory tests have shown that the thermal bridge causes very little ballast compartment temperature increase. All electronic components of the ballast are electrically isolated from the thermal bridge by an adhesive membrane, and by the fin's location in the outer periphery of the ballast case. In a base up position, excess mercury will condense in the tips, not in the tubulation, and the lamp will operate near its optimum output without the bridge's assistance. Once these concerns were addressed, researchers concluded that the rippled internal thermal bridge was the best design.

CONCLUSION

Orienting integral ballast CFLs base down can decrease light output by as much as 20%. Thermal bridges, which cool the tubulation region in the base of the lamp, can mitigate most of these losses. The bridges consist of thin copper strips connecting the small extruded tubulation to a copper fin that fits inside the base cap. These thermal bridges improve lamp performance, resulting in stabilized relative light output at up to 97% of the lamp's optimum level. With the bridge assembly an integral compact fluorescent lamp will produce near optimum lumen output independent of orientation. The design of the bridge assembly is relatively simple and should be easy to integrate within the manufacturing process. Increasing the lumen output in base down applications will help overcome the reduced perceived brightness barrier associated with CFLs.

REFERENCES

1. Manclark, B. "Of Sockets, Housecalls, and Hardware," Home Energy, Nov./Dec. 1991, p. 26.

2. Manclark, B. "Of Sockets, Housecalls, and Hardware," Home Energy, Nov./Dec. 1991, p. 25.

3. R. Verderber,F. Rubinstein and M. Siminovitch. "Control of Lamp Wall Temperature." Presented at the IEEE-IAS Annual Conference, Minneapolis, MN, Oct. 3-6, 1988.

4. C. Meyer and H. Nienhuis. Discharge Lamps. Philips Technical Library, Kluwer Technische Boeken B.V. Deventer, 1988.

ACKNOWLEDGMENT

This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Building Technologies, Building Equipment Division of the Department of Energy under Contract No. DE-AC03-76SF00098.