Increasing Luminaire Efficiency With "Spot Coolers" LBL-33069

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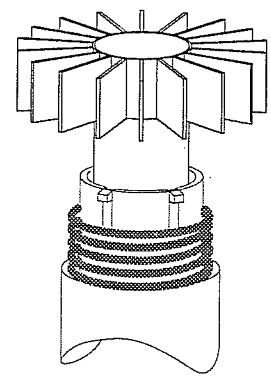
Abstract

A potentially energy saving heat sink device for use in common fluorescent luminaires is presented. This heat sink, or "Spot Cooler", increases luminaire efficiency by eliminating losses of light output and system efficacy that normally occur when lamps are heated beyond optimal temperatures in the thermally constrictive lamp compartment typical of most recessed luminaires. Unlike cooling devices suggested in the past, the Spot Cooler presented is inexpensive and completely passive, yet maintains an optimum performance level by recovering light losses that can vary from 10 to 25%. While the prototypes presented were designed for and tested with F40T12 type lamps utilized in standard recessed troffers, the design could be modified for any cylindrical fluorescent lamp type utilized in many standard fixture geometries.



Background

The total light output from a fluorescent lamp is sensitive to the minimum temperature of the lamp wall [1-10]. This value of minimum temperature on the lamp wall termed "MLWT" (Minimum Lamp Wall Temperature) has a narrow optimal range for which steady state light output is maximum. The relationship between MLWT and light output is derived from the behavior of the vaporized mercury inside the lamp [1,2,3].

Since the lamps in a majority of fluorescent luminaires operate at temperatures well above the optimal range of MLWT, various cooling techniques have been developed to lower the MLWT to a value that corresponds to maximum light output. These cooling techniques include the use of passive ventilation [8], active ventilation in air-handling type luminaires [11,12], active cooling devices [13-15], and passive thermal bridges [8,15,16]. Lamp design strategies to maximize light output over a range of common lamp compartment temperatures have also been explored, the most promising of which involves the use of an amalgam [17].

An effective passive thermal bridge can be designed to cool only one small spot on a standard lamp wall. Only one small spot need be cooled since even a small area of MLWT sets the steady state mercury vapor pressure inside the lamp and hence the steady state light output of the lamp. The actual area and location that the MLWT occupies is unimportant provided the area is large enough for the excess mercury available at the desired mercury vapor pressure to condense in a thin layer [4].

While passive thermal bridges can be easily designed for high performance, a successful thermal bridge will most likely need to be designed with sensitivity to relamping, manufacturability, luminaire integration, and aesthetics.

Spot Cooler Design Concepts

A Spot Cooler consists of a thermally conductive rod and fin cooling assembly, a springable element, and a thermally insulative collet as shown in Figure 1. Many variations of design features are possible, a few of which are illustrated in Figure 2.

Spot Coolers are easily integrated into standard recessed troffers after a small circular hole is punched in the fixture housing directly above the center of each lamp. A Spot Cooler is then inserted through each of the resultant openings and each is secured in place by an insulative collet. Prior to and during lamping, each Spot Cooler is free to rotate about its axis which, in conjunction with the ellipsoid saddle contact, allows for self-alignment with the contour of the lamp wall.

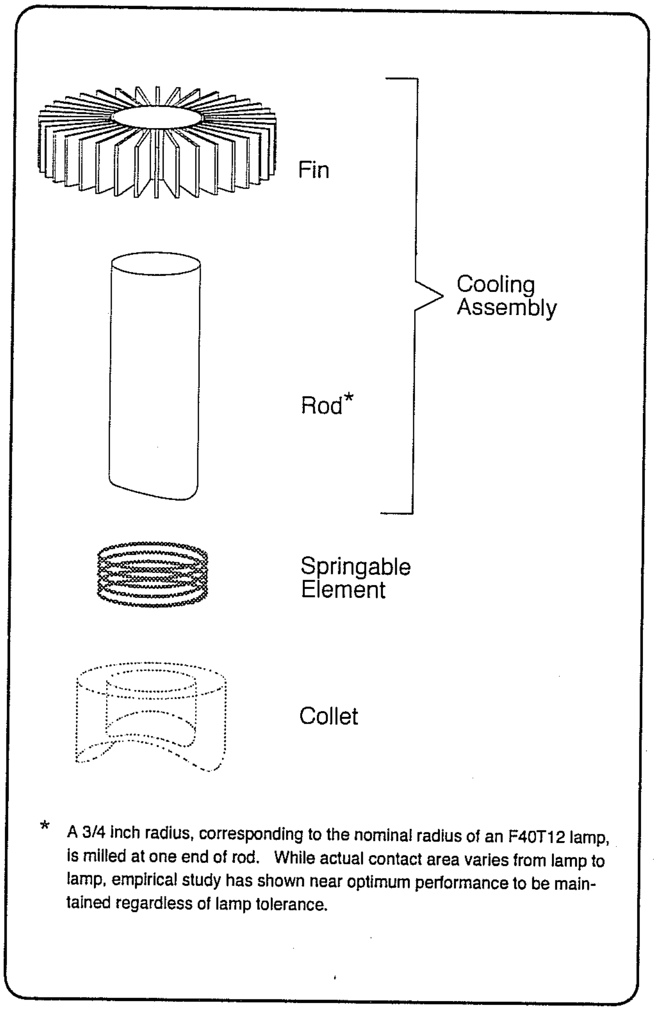


Figure 1 - Spot Cooler components

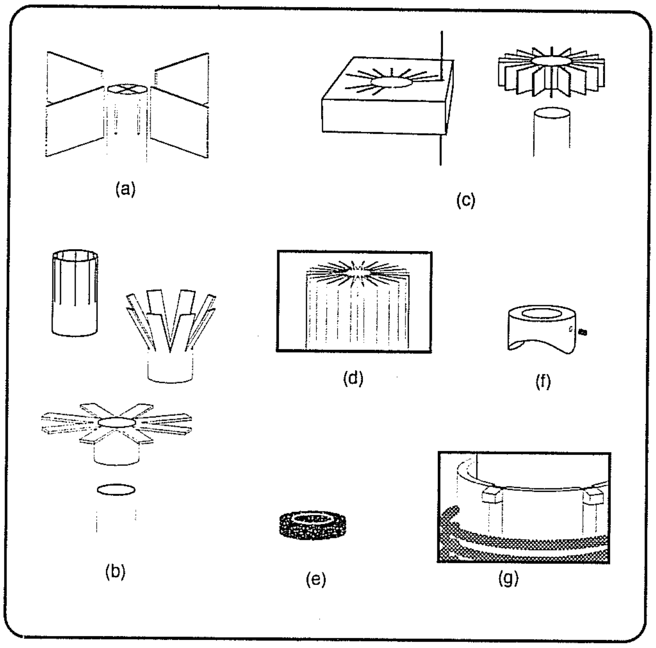


Figure 2 - Some design variations of Spot Cooler components

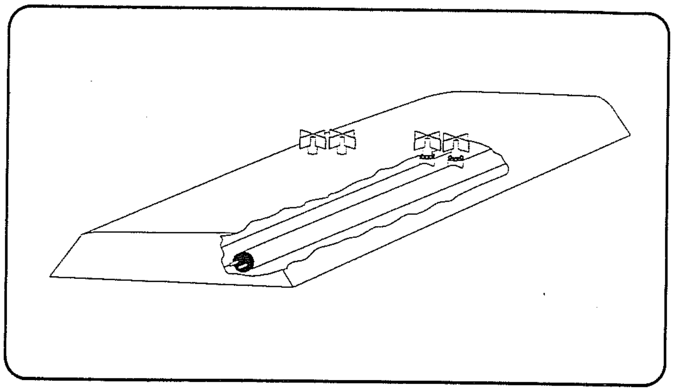


Figure 3 - Spot Coolers installed in luminaire

Once installed, the Spot Coolers lower the MLWT of each lamp by establishing an isolated thermally conductive path from a spot on each lamp wall to the cool plenum space above the fixture as shown above in Figure 3.

The induced spots of MLWT are maintained near optimum provided the geometry of the Spot Cooler cooling assembly is properly sized for the lamp-to-housing spacing and intended range of lamp compartment temperature.

The springable element insures adequate, yet gentle, contact pressure at the lamp wall. When a lamp is installed, the element compresses between the plastic insulating collet and the fixture housing which, in turn, pushes the contact end of the rod portion of the cooling assembly against the lamp wall. Only a slight pressure is needed to insure good thermal contact, so a highly elastic spring or a foam washer could be utilized.

The collet insulates the otherwise exposed surface of the rod in the lamp compartment that is not in contact with the lamp wall. Thus, less unwanted heat enters the spot cooler, and more heat is transferred directly from the lamp wall to the plenum space.

Prototype Fabrication

For prototype fabrication, the rod portion of the cooling assembly was milled from nominally sized stock aluminum rod between 5/8 and 7/8" diameter. The fin assembly was formed from stock sheet aluminum (Fig. 2a) or aluminum tubing (Fig. 2b), and was attached to the rod by force fit. More intricate prototypes were cut from an aluminum block with a hot wire EDM machine (Fig. 2c). Fins were also formed by milling grooves into the rod (Fig. 2d). The pieces of the cooling assembly could, of course, be manufactured by casting or extruding the aluminum.

Springable elements were formed from 1/4-inch-thick closed-cell neoprene gasket material by cutting out washer shapes (Fig. 2e).

The collet was milled from 1-1/4 inch diameter acrylic rod and was secured to the rod of the cooling assembly by force fit, glue, or a nylon set screw (Fig. 2f). An injection molding of the collet could incorporate a twist and lock mechanism for securement to the rod as well as snap tabs for securement to the fixture housing (Fig. 2g).

Experimental Method

Spot Cooler devices were tested in both commercial recessed luminaires and simulated luminaire chambers. Performance of each Spot Cooler design was determined on a relative basis by comparing the amount of losses of light output with and without the Spot Cooler in place while operating in different thermal environments.

Figure 4 depicts a schematic of the simulated luminaire test configuration. A heating tape with thermostat provided control of lamp compartment temperature. The heater controller was manually adjusted to create typical lamp compartment temperatures ranging from 35 to 60°C. The outside ambient above the chamber represented a typical plenum temperature which varied between 25 and 30°C for all experiments. Lamps that had been operated for a minimum of 100 hours were utilized during testing.

Prior to each test run, lamps were operated with Spot Coolers in place for a minimum of 10 hours until light output stabilized. Lamps were then de-energized and allowed to cool for a minimum of 3 hours after which time they were re-energized while light ouput and system input power measurements were recorded continuously. After light output peaked, usually within 15 minutes, the heater inside the test chamber was energized and data was gathered every 5 minutes until steady state light output did not vary by more than 1% for 2 hours.

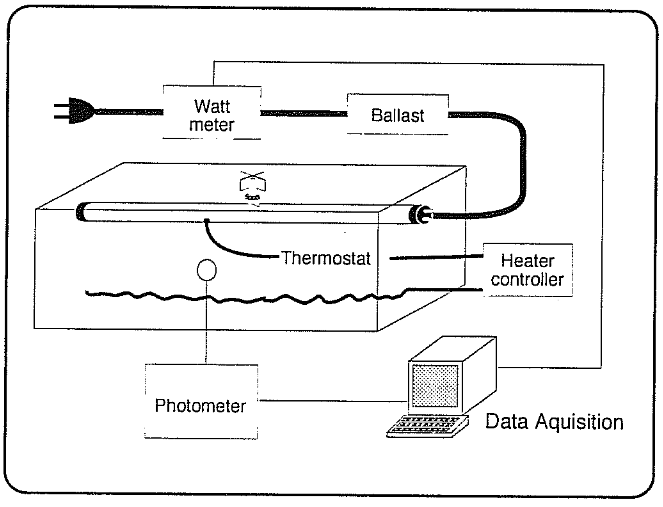


Figure 4 - Simulated luminaire test configuration

Figure 5 illustrates the test configuration for a commercial luminaire. One-inch-diameter holes were cut in the test fixture housing above each lamp to accommodate the Spot Coolers. After installation, the commercial luminaire was operated for a minimum of 10 hours. The fixture was then allowed to cool to room temperature for a minimum of 3 hours after which time the fixture was re-energized while light output and power were recorded continuously until the light output reached a peak value. After light output had peaked, typically within the first 10 minutes of operation, measurements were recorded every 10 minutes until light output and power did not vary by more than 1% for at least 5 hours. Average plenum temperature was maintained between 25 and 30°C.

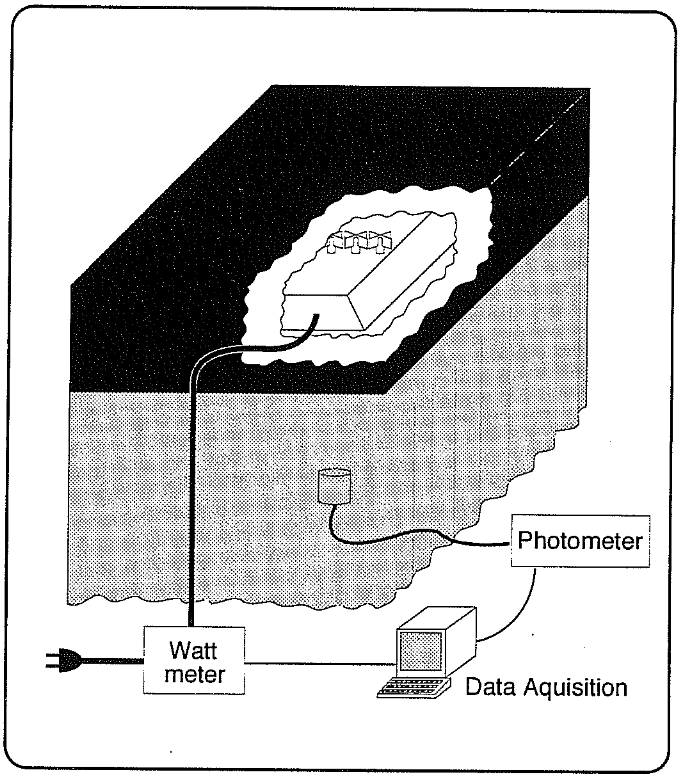


Figure 5 - Commercial luminaire test configuration showing simulated plenum

Experiments involving the performance of any fluorescent lamp cooling device or cooling method are sensitive to many variables which can cause performance to vary significantly during different experimental runs. Some sources of depreciated Spot Cooler performance include poor machining of the lamp contact portion of the cooling assembly, poor alignment of the collet with respect to the rod, and poor rod-to-fin contact. Once sources of depreciated performance were identified and corrected, data for each style prototype was consistent to within 1%.

Results

Figure 6 illustrates typical steady state performance levels of Spot Coolers operated in a simulated luminaire. With Spot Coolers, light output was maintained above 97% of maximum over lamp compartment temperatures ranging from 35 to 60°C. Light output without Spot Coolers in place dropped to as low as 70% of maximum when the temperature of the simulated lamp compartment reached 60°C.

Figure 7 depicts a graphical representation of a typical performance run in an actual fixture. The test fixture was a standard 4-inch-deep lensed "two-by-four" recessed troffer provided with energy saving magnetic ballasts and four F40T12 lamps. Light output, which normally dropped to 82% of maximum after steady state conditions, was maintained above 99% of maximum, representing an increase in steady state light output of more than 20%. Efficacy, which normally dropped to 91% of maximum, was maintained near 100%.

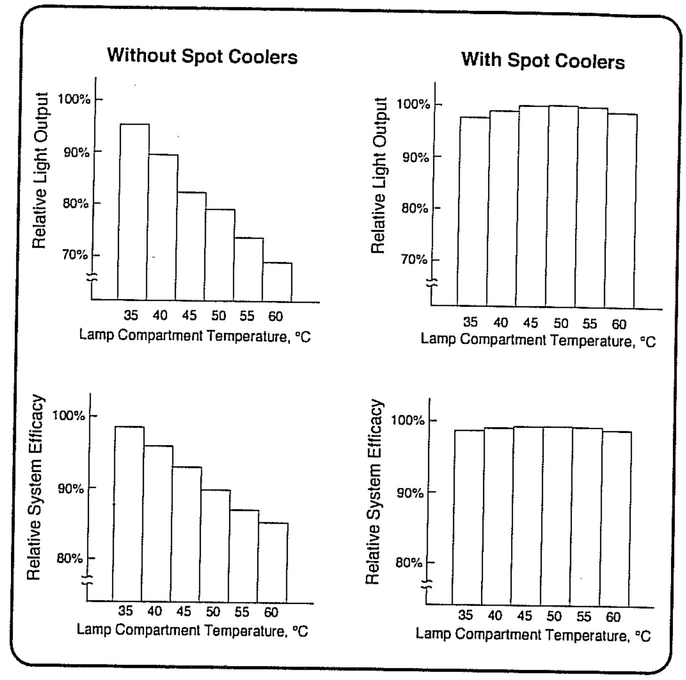


Figure 6 - Typical steady state performance of Spot Cooler in simulated luminaire

Applications

Efforts to explore energy saving applications of Spot Coolers should prove worthwhile. If Spot Coolers were implemented, for example, fewer luminaires could be specified in new installation plans since each luminaire would provide more light output.

As a theoretically energy saving alternative, a lighting layout that would normally require four-lamp troffers (which can lose 20% of potential light output) could be handled with three-lamp troffers utilizing Spot Coolers. System power would be reduced while total illuminance could be maintained near that of the unmodified four lamp troffers by means of spot cooling.

Spot Coolers could theoretically be a component of a special luminaire in which the ballast factor has been reduced. With lost light output recovered by Spot Coolers, a specially designed ballast with a lower ballast factor could be utilized thereby reducing power input to the system while maintaining an illuminance level comparable to an equivalent luminaire with higher ballast factor.

In addition to their energy saving utility, built-in Spot Coolers could allow manufacturers to produce smaller and sleeker fixtures without sacrificing luminaire efficiency.

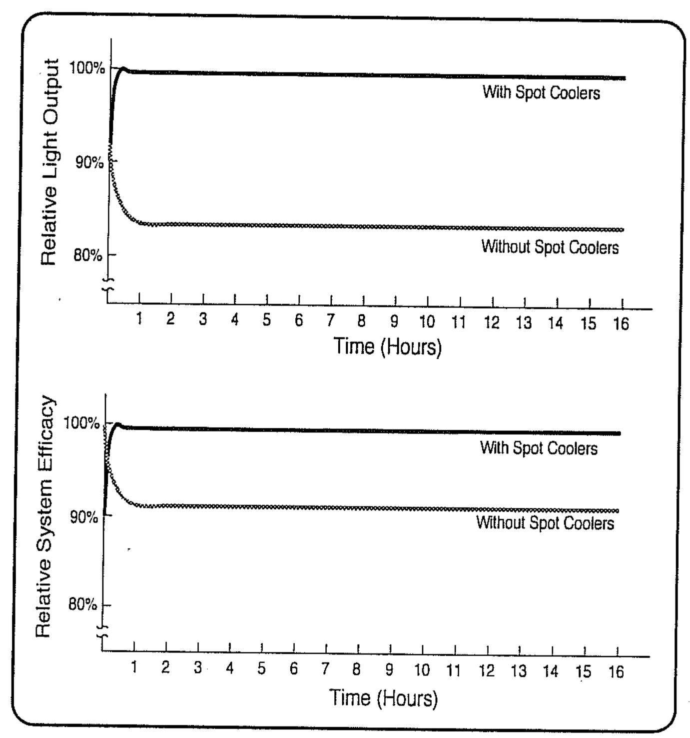


Figure 7 - Graphical representation of typical Spot Cooler performance versus time in a standard four-lamp troffer

Research Needs

Topics that merit further investigation include, but are not necessarily limited to:

- Effect of Spot Coolers on lamp life
- Effect of Spot Coolers on net HVAC energy demand and peak cooling load
- Production costs and cost-effectiveness
- Quantification of prospective energy savings in a variety of luminaires
- Applications to other lamp and fixture types

Conclusion

Prototypes of the design concepts presented have consistently performed near optimum. The prototypes were easily produced, easily installed, and did not introduce significant relamping or noticeable optical interference. Based on prototype preparation and testing, production version Spot Cooler devices could be effective, reliable, durable, and easy to install.

The Spot Cooler presented can increase luminaire efficiency by virtually eliminating light and efficacy losses that normally occur when F40T12 type lamps heat beyond optimal operating temperatures. Light losses which typically range between 10 and 20% for standard enclosed recessed troffers can be recovered with increased system efficacy.

Since Spot Coolers can increase luminaire efficiency by increasing light output and boosting system efficacy, the use of Spot Coolers could prove to be a viable option for control of MLWT in production luminaires.

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