Title

Control of Lamp Wall Temperature

Authors

Verderber, R R

Rubinstein, F M

Siminovitch, M J

Publication Date

1988-06-01

LBL-25430

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

APPLIED SCIENCE
DIVISION

To be presented at the IEEE-IAS Annual
Conference, Minneapolis, MN,
October 3–6, 1988, and to be published
in the Proceedings

Control of Lamp Wall Temperature

R.R. Verderber, F.M. Rubinstein,
and M.J. Siminovitch

June 1988

APPLIED SCIENCE
DIVISION

Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098.

DISCLAIMER

Presented at the IEEE-IAS Annual Conference, Minneapolis, MN, October 3-6, 1988.

LBL-25430
L-131

CONTROL OF LAMP WALL TEMPERATURE

R.R. Verderber, F.M. Rubinstein, and M.J. Siminovitch

Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

June 1988

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Buildings and Community Systems, Building Equipment Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

CONTROL OF LAMP WALL TEMPERATURE

Abstract

A review of techniques to control the lamp wall temperature of fluorescent lamps in luminaires is presented. Past results show large increases in efficacy and light output can be obtained (to 25%) if the lamps can be operated at their optimum lamp wall temperature. It may be judicious to review their cost effectiveness in view of the increased energy cost and advances in the devices technology.

I. INTRODUCTION

This report reviews various techniques to control and optimize the lamp wall temperature of fluorescent lamps in luminaires. It has been well known that the efficacy and light output of standard F40 T-12 fluorescent lamp-ballast systems are maximized at a lamp wall temperature of about 40°C (104°F). While fluorescent lamps are designed to operate optimally under ANSI test conditions [in open air at 25°C (77°F)], in practice the lamps in luminaires operate well above the optimum temperature. Many techniques have been suggested to control the lamp wall temperature[2-11], primarily for high output fluorescent lamps. However, the air handling luminaire is the only concept that has been employed to any significant degree based upon their share of the market.

Based upon statistics compiled by the Bureau of Census[12], air handling luminaires comprised 7% of units sold in 1986. Of the luminaires sold, 20% were strip type luminaires. The remaining 73% (enclosed, wraparound etc.) generally operate the fluorescent lamps 10° to 20°C above the optimum temperature.

The large number of luminaires operating below optimum efficiency represents an opportunity to reduce the energy consumed for fluorescent lighting systems. Thus, it is not surprising that some previous concepts to reduce lamp wall temperature in luminaires have been reexamined[12,13]. If any of the early ideas are now found cost effective, their utilization would be a valuable contribution toward reducing energy use, while preserving lighting quantity and quality. This contrasts with the performance of many new lighting products that save energy by reducing light levels, with little or no improvement in the system's efficiency.

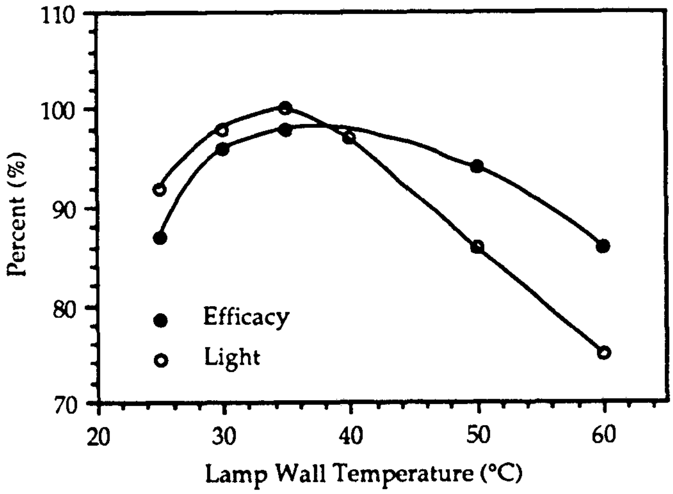
The next section briefly reviews the problem concerned with the thermal characteristics of three types of fluorescent luminaires. The third section will present some past efforts using mercury amalgams to control the mercury pressure in fluorescent lamps. The following section will discuss two devices: the Peltier device, and a thermal syphon that were suggested in the 1960's. We will describe some results using air handling luminaires. These techniques will be discussed in terms of their assets and their liabilities. The final section will summarize the past efforts, and suggest some approaches that may be presently attractive for controlling the lamp wall temperature in fluorescent luminaires.

II. LAMP WALL TEMPERATURE EFFECTS

A. Lamps

Most fluorescent lamps are designed to operate near their efficacy when tested under ANSI conditions; i.e., in open lamp wall temperature of the standard 40W, F40 T-12 rapid start fluorescent lamp is about 38°C (100°F). At this temperature, the mercury pressure is optimum for generating the 253.7 nm ultra-violet radiation, while minimizing the entrapment losses of this radiation. Figure 1 shows the relationship of the light output and efficacy for a two lamp, F40 system over a range of lamp wall temperatures generally experienced in the field.[13]

Figure 1. Variation of Light Output and Efficacy of Two Lamp, 40 Watt F40 T-12 System With Lamp Wall Temperature



B. Luminaires

The lamp wall temperature of lamps in the luminaire is determined by the ambient temperature, as well as by the luminaire design. Table I lists the lamp wall temperature of the F40 lamp and the air temperature within the luminaire (lamp surround temperature) for several types of luminaires in a room with an ambient temperature of 25°C (7°F).[15] The table shows a high lamp wall temperature in the four lamp wrap around luminaire. However, even the parabolic luminaires have a lamp wall temperature above optimum. The lamp wall temperature is different in the various types of luminaires, though the room ambient temperature is the same. This shows that various types of luminaires have different thermal performances. Naturally, the lamp wall temperature will vary for the same luminaire, depending on the mounting configuration (ceiling mounted, pendent mounted etc.) and the thermal environment.

TABLE I
MINIMUM LAMP WALL TEMPERATURES FOR THREE LUMINAIRE TYPES*

Luminaire	Ambient Temp (°C)	Minimum Lamp Wall (°C)
Four Lamp Wraparound	25	61
Four Lamp Enclosed	25	57
Four Lamp Parabolic	25	53

*Standard two lamp CBM ballasts, 40 watt F40 T-12 lamps.

III. LAMP DESIGNS

A. Lamp Geometry

High output lamps operated at higher current levels to increase light output result in lamp wall temperatures exceeding the optimum temperature under standard ANSI test conditions. To conform to the standard lamp design practice, bulb shapes were altered to obtain at least one area of the bulb wall that would be at the optimum temperature. Three methods have been described[3] that: 1) incorporate a bulb wall protrusion at the normal cold spot (usually at the center of the lamp), 2) enlarge end chambers and shield filaments, and 3) constrict the cross section of the bulb wall. The latter method resulted in one part of the bulb wall being further away from the plasma arc, lowering the temperature of that area.

B. Mercury Amalgams

Several studies[4-8] have explored the use of a mercury amalgam to reduce the mercury vapor pressure for high output lamps, so that optimum performance is obtained under standard ANSI test conditions. A mercury-indium amalgam forms a liquid-solid solution over the lamp operating temperature range and maintains a relatively constant mercury vapor pressure (~4 μ). Indium has the desired physical characteristics for the mercury amalgam, that is a very low vapor pressure at the lamp processing temperature, and a high reactivity for mercury, but low for other lamp components. Depending on the atomic percent of indium, the optimum light output could be shifted to an ambient temperature of 40°C (104°F) above that of a standard lamp. Equally important was the reduced dependence of the change in light output with ambient temperature. The high temperature amalgam lamp provided more than 90% of its maximum light output over a range of ambient temperatures from -20°F (-29°C) to +100°F (38°C). The higher the indium content, the higher the lamp temperature at which the maximum light output appeared. Mercury-indium amalgams, with higher indium content, also broadened the light output-ambient temperature curve illustrated in Figure 2.[5]

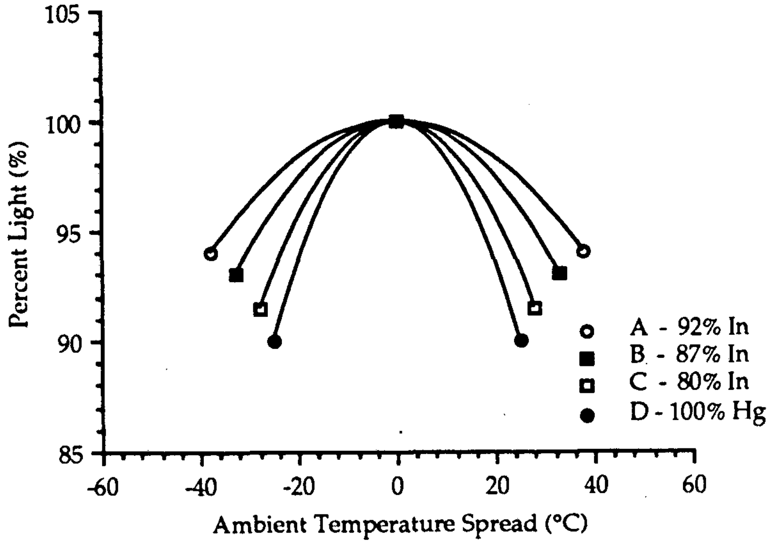


Figure 2. Variation of Light Output and Efficacy of Two Lamp, 40 Watt F40 T-12 System With Lamp Wall Temperature

A later paper[7] examined the effect of various Hg-In amalgam compositions for F40 T-12 lamps. They measured the shift in the optimum lamp temperature, but also reported that the height of the light output peaks were 5% lower for the amalgam lamps, with respect to a standard lamp (100% mercury). However, at an ambient temperature of 80°C (176°F) and 90°C (194°F) the light output of amalgam lamps exceeds the light output of standard lamps by 7 to 17% and 10 to 25%, respectively, depending on the amalgam composition.

The disadvantages of the amalgam lamps were the higher starting voltages at all ambient temperatures, as well as the increase in the lamp lumen depreciation[4,5]. At an ambient temperature of 40°F (4°C), the starting voltage increased from 150 volts to 225 volts for an eight foot 1.5 ampere amalgam lamp. The lamp lumen depreciation at 3000 hours increased by 9% for each 50°F (28°C) increase in the lamp wall temperature above 155°F (68°C). The relative increase in the ratio of the 184.9 nm to the 253.7 nm lines was suggested to account for both the increased lamp lumen depreciation, and the decrease in the peak light output at the higher lamp temperatures.

Recent work[8] on the mercury amalgams comprised of studying mixtures of Hg-Mg and Hg-In alloys, in order to achieve a mercury system which had even less change in the mercury vapor pressure over a large range of bulb wall temperatures.

IV. COOLING DEVICES

A. Cooling Fins

One of the early papers[3] mentioned several devices (Peltier devices and thermal syphons) that could control lamp wall temperature, and examined how fins could be used to dissipate heat from the bulb wall (reducing its temperature). A contoured shoe (1/2 inch wide by 1 inch long) was clamped to the bulb wall and a "sail," in contact with the shoe, greater than seven square inches, was used to dissipate the heat to the ambient air reservoir. Copper and aluminum sails were found to work equally well. Light output gains of 8 to 18% were measured in recessed luminaires with lamp surround temperatures of 112°F (44°C) to 140°F (60°C).

B. Peltier Device

A Peltier device system to control the lamp wall temperature of high output lamps (six foot, T-12 and T-17, 1.5-amperes) for outdoor applications has been described[2]. The concept was described in two patents[9,10] filed earlier and issued in 1967, which consisted of a contoured conductor contacting the bulb wall that was cooled with a Peltier device. The heat extracted by the device was dissipated by a fan, circulating air within the luminaire, or a blower that brought in the cooler external air to the luminaire. With this arrangement, the luminaire provided 90% of its maximum light output over an ambient temperature range of -20°F (-7°C) to +100°F (38°C). The lamp wall temperature was maintained at 100°F. In the same type of four lamp luminaires, at the highest ambient temperature, the spot cooled lamps were at ~90% of the maximum light output, while the uncooled lamps were at 50% of maximum light output.

Recently[13], the thermal performance of standard F40 T-12 lamps controlled with a Peltier device was examined, determining the change in light output and efficacy.

Measurements were made in a temperature controlled integrating chamber, in which the lamp surround temperature was varied from 25°C (77°F) to 52°C (126°F). The lamp wall temperature of the lamp changed from 38°C (100°F) to about 56°C (133°F) over the 27°C (49°F) surround temperature range. The lamp was then spot cooled with a Peltier device system, maintaining a lamp temperature of 40°C (104°F) over the same surround temperature range. The constant 40°C lamp wall temperature was maintained by manually adjusting the input power to the Peltier device. At the highest surround temperature (56°C), the spot cooled lamp's light output and efficacy were higher than the uncontrolled lamp by 22% and 12%, respectively. It took less than 0.24 watts input to the Peltier device, at the highest surround temperature, to achieve this improvement. Similar to observations with other spot cooled techniques, the maximum light output and efficacy were 2% less compared to these parameters, measured for lamps under standard ANSI conditions, i.e., a lamp surround temperature of 25°C (77°F).

B. Thermal Syphon

In 1967, a patent[11] was issued in which a thermal syphon type system was employed to spot cool high output fluorescent lamps. A variable conductance thermal syphon was obtained by a bellows action, which increased the surface area where the heat was being dissipated to the ambient air. As the bulb wall's temperature would increase, the bellows would expand, increasing its heat dissipation, thus maintaining the spot on the bulb wall at a constant temperature. The patent does not describe any measurements of the system. A serious limitation to this device was the mechanical complexity, and the requirement that the syphon must be operated vertically, since the condensed vapor must be returned to the liquid reservoir by gravity feed.

V. DISCUSSION

A. Past Efforts

Previous work in this area clearly demonstrates the technical viability of controlling the lamp wall temperature in luminaires, to obtain optimum light output and efficacy from lighting systems. However, the proposed devices (Peltier device and thermal syphon) were relatively costly and technically not fully developed. Coupled with the lowering cost of electricity, there was no economic incentive to fund the development of these approaches. Even the least costly idea, the conductive fin, was not put into practice.

While all the concepts offer substantial improvements, they are subject to several limitations that preclude obtaining maximum performance. Operating fluorescent lamps at elevated temperatures and higher current densities increases the rate of lamp lumen depreciation. The reduced maximum light output and efficiency (2 to 5%) have been suggested to be due to reduced phosphor performance and the increase of the buffer gas pressure. The nature of the 2 to 5% decrease for the spot cooled techniques may be due to the density variation of the mercury vapor along the lamp's length. Since the pressure in the lamp is constant, the mercury density is only optimum at the cooled spot, while at the hotter regions of the lamp the mercury density is slightly lower than optimum.

The principle technical limitations to the use of amalgams is the higher starting voltages and the time delay in achieving full light output.

B. Present/Future Efforts

Since there is more of an economic motivation to improve the efficiency of lighting systems at present, due to increased energy costs, and technological advances in the cooling devices that have reduced their costs, reexamination of the cooling devices could result in their application in the near future. The information on the poor thermal performance of current luminaire designs offers an argument to also review mechanical luminaire design considerations. A recent report[14] studied the lamp wall temperature and internal air temperature of two types of air handling luminaires (enclosed and louvred parabolic). Data were obtained under static conditions, and with two rates of air flow (20 and 50 CFM). The static measurements showed that the temperature along the lamps varied by less than 2°C (6°F). At an air flow of 20 CFM, the temperature variation was as high as 7°C (13°F), and at 50 CFM the temperature variation was 10°C (18°F). Improved mechanical design of air handling luminaires could achieve a more uniform lamp wall temperature, which would capture the 2 to 5% efficacy decrease for lamp systems cooled in a localized area on the lamp.

VI. CONCLUSION

By maintaining the optimum lamp wall temperature of fluorescent lamps in luminaires operated in elevated surround temperatures (above 25°C), and/or not designed to efficaciously dissipate the heat generated by the lamps, large increases in light output and efficiency can be obtained. It is appropriate now to reevaluate some concepts that have been previously studied, and explore new ideas to obtain the above desired result.

VII. ACKNOWLEDGEMENT

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Buildings and Community Systems, Building Equipment Division of the U.S. Department of Energy under Contract No. DE-ACO3-76SFOO098.

IX. REFERENCES

1. C.W. Jerome, "Effect of Bulb Wall Temperature on Fluorescent Lamp Parameters," Ill. Eng., vol. LI no. 2, 205 (February 1956).

2. H.A. Van Dusen, Jr. and E.F. Schraith, "An Outdoor Fluorescent Luminaire With Optimum Light Output Over a Large Temperature Range," Ill. Eng., vol. LVII no. 5, 353 (May 1962).

3. P.J. Underwood and C.E. Beck, "Mercury Pressure of Fluorescent Lamps and its Application to Luminaires," Ill. Eng., vol. LV, no. 1, 47 (January 1960).

4. C.J. Bernier and J.C. Heffernan, "Design and Application of New High-Temperature Fluorescent Lamps," Ill. Eng., vol. LIV, no. 12, 801 (December 1964).

5. G.S. Evans and P.E. Snyder, "Performance Characteristics of Fluorescent Lamps, Utilizing Amalgam Control of Mercury-Vapor Pressure," Ill. Eng., vol. LVI. no. 1, 51 (January 1966).

6. D. Hodgkiss, "The Amalgam Lamp," Lighting Res. & Tech., vol 2, no. 1, 46 (1972).

7. H. Milke and R.S. Wissoker, "Enclosed Luminaire Performance With 40-Watt Indium-Amalgam Fluorescent Lamps," J. Ill. Eng. Soc., vol I, no. 1, (January 1972).

8. K. Hilpert, "Potential for an Improvement of the Efficiency of Fluorescent Mercury Lamps," Research Report T 78-22, Federal Ministry for Research and Technology, (August 1977).

9. E.F. Schraith and H.A. Van Dusen, Jr., "Controlled Cooled Gaseous Discharge Luminaire," U.S. Patent 3,163,366, (December 29, 1964).

10. P.B. Clark and H.A. Van Dusen, Jr., "Light Output of Fluorescent Lamps Automatically Held Constant by Means of Peltier Type Coolers," U.S. Patent, 3,309,565, (March 14, 1967).

11. E.F. Schraith and H.A. Van Dusen, Jr., "Cooling Device for Fluorescent Lamps," U. S. Patent 3,330,130, (July 11, 1967).

12. U.S. Department of Commerce (Bureau of the Census), "Current Industrial Reports," Electric Lighting Fixtures 1986, MA 36L (86)-1 (August 1987).

13. M.J. Siminovitch et. al., "Maintaining Optimum Fluorescent Lamp Performance Under Elevated Temperature Conditions," L. D. & A., vol. 17, no. 9, 35, (September 1987).

14. M.J. Siminovitch et. al., "The Effect of Fixture Type and HVAC Integration on Fluorescent Lamp/Ballast Performance," P. Proc. of the IEEE Ind. Appl. Soc., Denver, CO, (October 1986).

15. Unpublished LBL Data.

LAWRENCE BERKELEY LABORATORY
TECHNICAL INFORMATION DEPARTMENT
1 CYCLOTRON ROAD
BERKELEY, CALIFORNIA 94720