LBL-21004

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

APPLIED SCIENCE DIVISION

Presented at the Annual Illuminating
Engineering Society Conference,
Boston, MA, August 16–23, 1986

MAINTAINING OPTIMUM FLUORESCENT LAMP PERFORMANCE UNDER ELEVATED TEMPERATURE CONDITIONS

M.J. Siminovitch, F.M. Rubinstein,
T.A. Clark, and R.R. Verderber

April 1986

**APPLIED SCIENCE
DIVISION**

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

Presented at the Illuminating
Engineering Society Conference
Boston, MA, August 20, 1986

Maintaining Optimum Fluorescent Lamp Performance Under Elevated Temperature Conditions

by

M.J. Siminovitch, F.M. Rubinstein, T.A. Clark, and R.R. Verderber

Lighting Systems Research Group
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

Abstract

This paper describes a new technique for optimizing fluorescent lamp performance under elevated temperature conditions. This approach uses a thermo-electric Peltier device to produce a localized cold spot temperature of approximately 40°C, allowing the lamps to maintain maximum light output and efficacy independent of prevailing ambient temperatures inside a luminaire.

Experimental data shows that a 20% increase in light output and a 10% increase in efficacy over typical lamp performance in a warm fixture environment can be obtained using this device. Only 0.25 watts must be supplied to the Peltier device to produce these results.

Introduction

The functional dependence of light output on the minimum lamp wall temperature (MLWT) of an F40 lamp and CBM ballast is well documented [1,2,3]. Figure 1 shows the changes in light output and efficacy over a wide range of MLWTs, illustrating this functional dependence [4]. For a standard-ballast F40 lamp system, the lamps should operate at a MLWT of 37°C±1°C for optimum light output, or at 40°C±1°C to obtain optimum efficacy.

These conditions occur because the MLWT determines the mercury vapor pressure within the lamp, and therefore, the mercury concentration available to the discharge. Below the optimum MLWT, less gaseous Hg is available to the discharge,resulting in less Hg excitation and UV radiation striking the light-emitting phosphor. Above the optimum MLWT, the mercury vapor pressure is higher and a UV entrapment process prevails, resulting in an increase of non-radiated transitions for the excited Hg to return to the ground state. The change in Hg vapor pressure also alters the electric load presented to the ballast, both increasing and decreasing the power transferred to the lamps which also contributes to the changes in light output.

Photometric measurements of fluorescent lamps under ANSI reference conditions (25°C ambient) indicate that they operate at or near optimum at MLWTs of 37° to 40°C. However, when lamps are operated in an enclosed fixture, the MLWT increases due to the constricted thermal environment that inhibits thermal dissipation. Field measurements and laboratory studies have shown that the MLWT can range from 55° to 60°C in a typical four-lamp enclosed troffer [4,5]. At these MLWTs, light output reductions can approach 25% with a corresponding reduction in efficacy of 12%.

This paper describes a technique that can maintain an optimum cold spot temperature independent of ambient temperature and type of fixture. We describe the experimental procedure as well as the results obtained for an F40 fluorescent system. The results are discussed in terms of controlling light output and system efficacy, including the power used by the Peltier device needed to maintain the optimum MLWT.

Description of Technique

The temperature-control technique involves maintaining a small 0.25-in^2 area on the lamp at an optimum MLWT of 37°C±1°C (for maximum light output), by Peltier-effect cooling. The Peltier effect can produce either a heating or cooling of the semiconductor p-n junction, depending upon the direction of current flow.

The cooling system consists of a concave copper surface to make thermal contact with the glass wall, a Peltier device, and a heat sink to help dissipate heat. Figure 2 shows a cross-section view of the system, attached to a F40 T12 lamp, and identifies the principal components. A controllable DC source supplies the power to the Peltier device. During operation, the junction of the Peltier device is at a low temperature, cooling the lamp wall and maintaining the desired MLWT. Varying the electric input to the Peltier device changes the junction temperature to obtain a range of cold spot temperatures.

Experimental Method and Apparatus

A temperature-controlled photometric integrating chamber was used to determine lamp performance as a function of operating temperature [3]. This apparatus permits the ambient air temperature surrounding the lamps to be continuously controlled and monitored between 10°C and 60°C, which encompasses the complete range of temperatures encountered in interior lighting applications. The apparatus is also instrumented to measure lamp lumen output, lamp/ballast system power, and minimum lamp wall temperature. Figure 3 shows a cross section of the temperature-controlled integrating chamber, indicating the relative scale and position of major components.

The MLWT control system was attached at the natural coldspot (at the midsection to the underside) of a standard F40 T12 lamp operated with a CBM ballast as illustrated in figure 2 . In this position the MLWT/cold spot of the lamp is determined and maintained by the power supplied to the Peltier device.

When the lamp/ballast system is operated, the ambient temperature inside the flux integrator is ramped from 25°C to 60°C at 10°C/hour, while maintaining a MLWT of 37°C±1°C. The constant MLWT was maintained by adjusting the input power to the Peltier device. Light output, power input, and temperature conditions were monitored continuously. The power supplied to the Peltier device to maintain the 37°C MLWT was also measured over the entire range of ambient temperatures.

For comparison , the experiment was repeated while operating the lamp without controlling the MLWT over the same range of ambient temperatures. Under these conditions the MLWT of the lamp is determined by the prevailing ambient temperature and heat dissipated by the lamp. Light output, system power input, and temperatures were also continuously monitored.

Experimental Results

Figure 4 shows lamp light output as a function of ambient temperature, with and without controlling the MLWT. Light output is expressed as a percentage of the maximum light output. The lamp without the cold spot control device shows the typical reduction in light output as the ambient temperature increases. The reduction in light output approaches 25% (MLWT = 56°C) compared to its maximum value at the 25°C ambient (MLWT=37°C). Controlling the cold spot/MLWT of the lamp with the Peltier device maintains nearly full light output over the entire range of ambient temperatures (25° to 52°C).

Figure 5 shows the change in system efficacy relative to its maximum as a function of ambient temperature for the lamp operating with and without cold spot control. The efficacy is the ratio of light output and system power. System power does not include the power supplied to the Peltier device. The lamp operating without a controlled MLWT shows a reduction in efficacy as the ambient temperature rises above 30°C , approaching 13% at an ambient temperature of 50°C (MLWT = 56°C). The lamp operated with cold spot control maintained an efficacy of 98-99% of the maximum over the entire range of ambient temperatures.

Figure 6 shows the power supplied to the Peltier device to maintain an optimum cold spot temperature as a function of the ambient temperature. At an ambient of 50°C, 0.25 watts of power was required to maintain an optimum cold spot temperature on the lamp of 37°C±1°C. Under steady state conditions the required power supplied to the device is approximately proportional to the ambient temperature over the range from 40°C to 50°C. The rate of increase in power, increases slightly at the higher ambient temperatures due to the decrease in dissipation of the heat sink in the higher temperatures.

The MLWT- control technique was also applied to a two-lamp/ballast sytem and tested under the same conditions described for the single-lamp/ballast system. Experimental data showed similar results in terms of maintaining light output and efficacy over the range of temperatures tested, using the MLWT-control technique.

Discussion

The described technique is one method to control the MLWTs in elevated ambient temperatures. Another method involves the design of fixtures incorporating air handling capabilities using lamp compartment extract, which results in lowerMLWTs. This is achieved by forced convective cooling of the lamp wall. These fixture types are more expensive compared to standard enclosed wrap around fixtures and can only be employed in certain buildings that have the proper return-air systems. Most office lighting layouts employ standard enclosed troffers or surface mounts for ease of construction and economy. The MLWT-control technique described here could be applied to these commonly encountered fixtures as a retrofit measure to increase light output. More importantly, this technique could be used in new construction to reduce both the number of fixtures and the lighting power density required to achieve a specified illuminance. In both applications, the system efficacies will be optimized.

To illustrate the potential benefits of maintaining an optimum MLWT at elevated temperatures, we model a lighting layout designed to maintain an average 50fc for 10,000 ft^2, using a standard F40 two lamp/ballast system (Table 1). We compare two-lamp ballast

TABLE 1

SYSTEM COMPARISON

	Lamps without Controlled MLWT (Basecase)	Lamps with Controlled MLWT (optimum)	
A. Lumen output of lamps under elevated fixture conditions	4800	6000	
B. System power under elevated fixture conditions	82.41	94.6	
C. System Efficacy under elevated fixture conditions	58.24	63.41	
D. Maintained Workplane lumens*= Ax 0.5	2400	3000	
E. Required Lumens	500,000	500,000	Based on 50FC for 10,000 ft
F. Number of lamps required=(E/D)x 2	416.6	333.3	
G. Number of ballasts required=F/2	208.3	166.6	Based on 2 lamps per ballast
H. Number of fixtures required=F/4	104.1	83.3	Based on 4 lamps per fixture
I. Lamp/ballast System power=Gx B	17,166	15,760	
J. Peltier power	--	83.3	Based on 0.25 watts per lamp
K. Total power =I+J	17,166	15,843	
L. Lighting power Density=K/10,000	1.71	1.58	

* Maintained lumens on the work plane is obtained by multiplying the lumen output of the lamps under fixture conditions by a factor of 0.5. This factor accounts for the optical efficiency of the fixture ,room geometry and surface reflectances. It is an estimated scaling factor applied equally to both cases.

performance with and without controlling MLWT and a four-lamp lens enclosed troffer. Based on measured lamp performance for this fixture type [3], the MLWT would operate at about 56°C, resulting in a 20% reduction in light output and a 10% reduction in efficacy relative to its operation at 40°C. The number of lamps, ballasts, and fixtures required to maintain 50fc is determined for both lamp conditions. The power required for both layouts is determined, including the power used by the Peltier device to maintain an optimum MLWT. The lamp lumen output values given in Table 1 implicitly include a thermal factor that accounts for the lower light output in the base case. The values used in the calculations were for lamps at the 56°C MLWT.

As shown in the table ,lighting power density for the lamps at the optimum MLWT is 1.58W/ft^2 compared to 1.71W/ft^2 for the base case, including the power supplied to the Peltier device. With MLWT control, the lumen output of the lamp is maintained at elevated fixture temperatures. With a higher lamp lumen output, the required number of lamps, ballasts, and fixtures can be reduced by approximately 20% to maintain a prescribed illuminance level. A 20% reduction in lighting system hardware would represent an initial capital-cost savings to a building owner.

This control technique to allow the lamp to maintain a constant lumen output independent of fixture temperatures could increase the accuracy to enhance the lighting design process. The designer could be assured of a specific lumen output regardless of fixture design and ambient thermal environment .

In order for this technique to be applied in the cooling system, design concerns of integrating the device with the lamp, power supply, and control need to be addressed.

Device Position. In the initial tests, the Peltier device was attached to the outer surface of the lamp at midsection. This location presents difficulties in terms of electric connection to the lamp/ballast system and potential obstruction of light output. Locating the control device at the end of the lamp would facilatate an electric connection to the lamp/ballast and would have only a minimal effect on light output.

Controlling the MLWT at the end cap has been tested and preliminary results show similar performance to that achieved with a midsection location.

The MLWT control technique could also be developed for internal operation by locating the Peltier components within the lamp envelope at the end cap. This approach would be better suited for new lamp applications since it could be integrated into the manufacture of the lamp.

Power Supply. An external DC power supply was used in experimental testing and development of this technique. Since the supply voltage need is only .06 to .152 volts, the power required to supply the Peltier device could be obtained by connecting it directly across the lamp pins (filament power). For both retrofit and new lamp applications, connection to the pins of the lamp would allow for using filament power in conjunction with a rectification device to drive the Peltier device.

Heat Sinking. A Peltier device requires heat sinking for efficient operation, and empirical data show that the size of the heat sink effects the power required to maintain the optimum MLWT. The heat sinking can be achieved by an attached fin, as described earlier, or by thermal connection to the fixture for heat dissipation. Using an internal lamp-control technique would require a specialized heat sink design. This could be achieved by reconfiguring the conventional endcap as a heat sink.

Control. During experimental testing, the optimum MLWT was maintained by monitoring temperature sensors on the lamp and compensating when nessessary with manual adjustment of power input to the Peltier device. The practical control options for maintaining optimum cold spot temperature during lamp operation could include on/off systems with thermally sensitive switching. Other more sophisticated devices, such as proportional feedback controllers, are being examined.

SUMMARY

A system based on the use of a Peltier device has been described and shown to control the MLWT to maintain light output and system efficacy of the lamp/ ballast system at elevated fixture temperatures.

Only 0.25 watts was required for the device to maintain the ideal MLWT of 37°C±1°C for optimum performance in a thermal environment that would normally result in a MLWT of approximately 55°-57°C. This device could be applied in retrofits where lamps normally operate at a high MLWT, or in new construction where other methods to control MLWT cannot be applied.

In new construction the application of this technique can potentially allow for a 20% reduction in lighting system hardware and a 10% reduction in power density in comparison to typical office lighting designs.

Acknowledgements

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

References

1. Jerome, C.E., "Effect of Bulb Wall Temperatures on Fluorescent Lamp Parameters, " Journal of the Illuminating Engineering Society, 1956.
2. Hammer, E.E., "Improved 35-Watt Low-Energy Lamp Ballast Systems," Journal of the Illuminating Engineering Society, No. 3, April 1980.
3. Siminovitch, M.J., et. al., "Determining Lamp Ballast System Performance with a Temperature-Controlled Integrating Chamber," Journal of the Illuminating Engineering Society, Vol. 14, No. 1, October 1984.

4. Verderber, R.R., "Fluorescent Fixtures and Ballasts," Lawrence Berkeley Laboratory Report, LBL-17929, May 1984.

5. Siminovitch, M.J., et. al., "A Luminaire/Plenum/HVAC Simulator," to be published in the Institute of Electronic and Electrical Engineers Transactions on Industry Applications, (1985).

Figure Captions

Figure 1. Light output and efficacy vs MLWT for a F40 lamp and CBM ballast.

Figure 2. Cross section of MLWT control device attached to lamp.

Figure 3. Cross section of temperature controlled integrating chamber.

Figure 4. Light output vs ambient temperature, with and without contolling MLWT.

Figure 5. Efficacy vs ambient temperature, with and without controlling MLWT.

Figure 6. Peltier power vs ambient temperature.

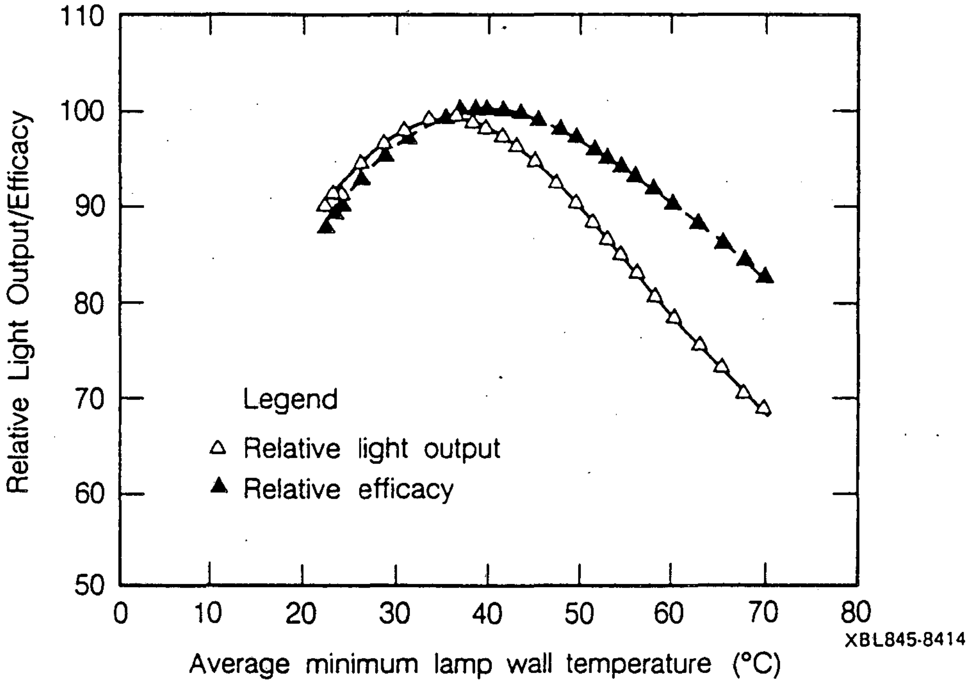


Figure 1. Light output and efficacy vs MLWT for a F40 lamp and CBM ballast.

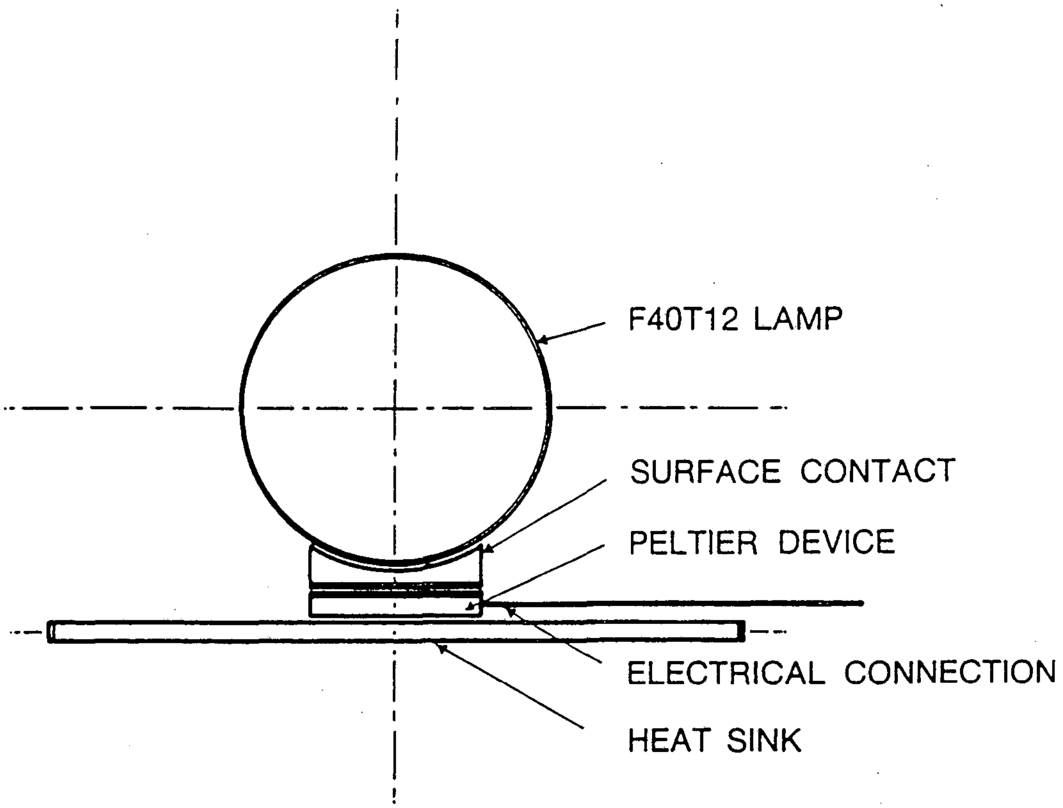
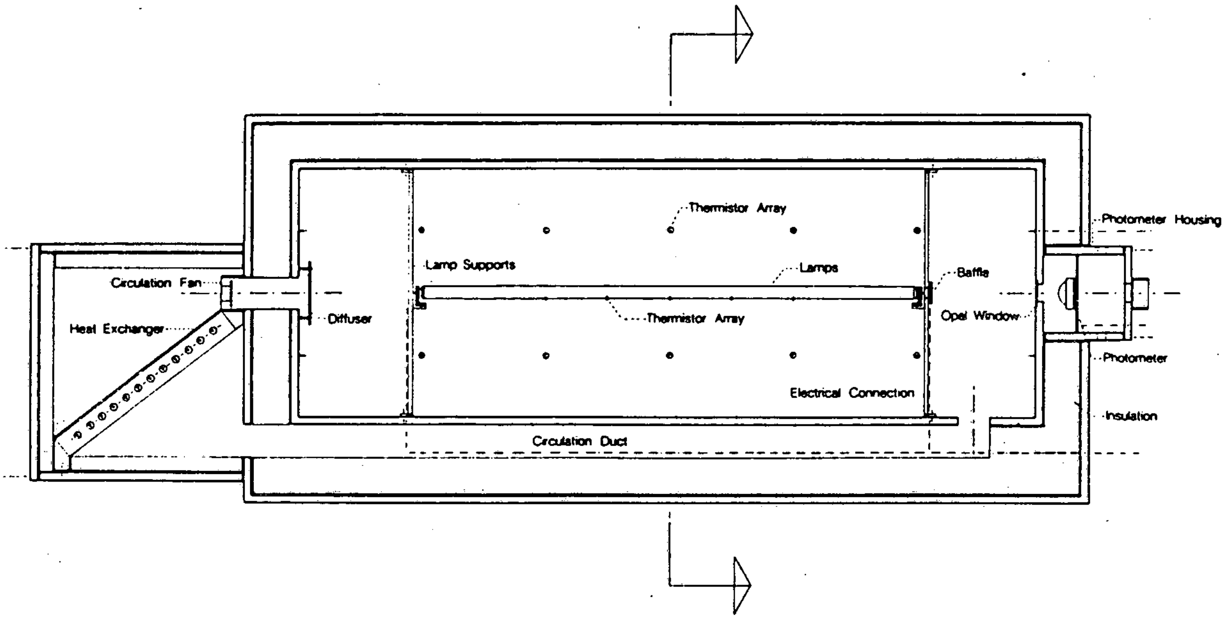


Figure 2. Cross section of MLWT control device attached to lamp.



XBL 846-2140

Figure 3. Cross section of temperature controlled integrating chamber.

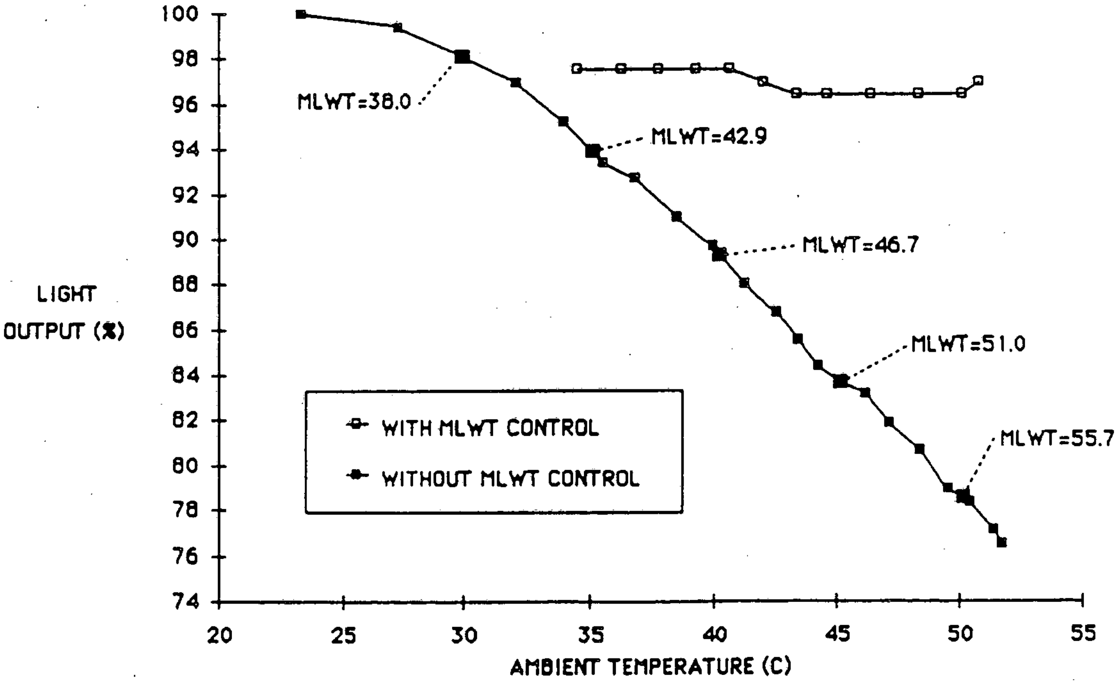


Figure 4. Light output vs ambient temperature, with and without contolling MLWT.

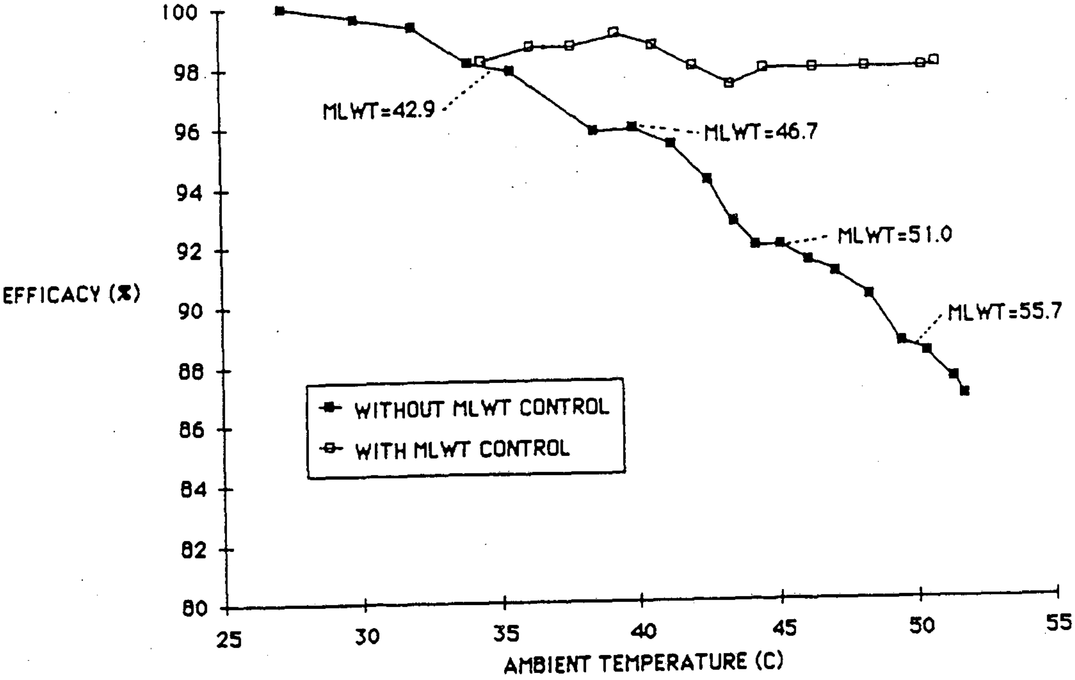


Figure 5. Efficacy vs ambient temperature, with and without controlling MLWT.

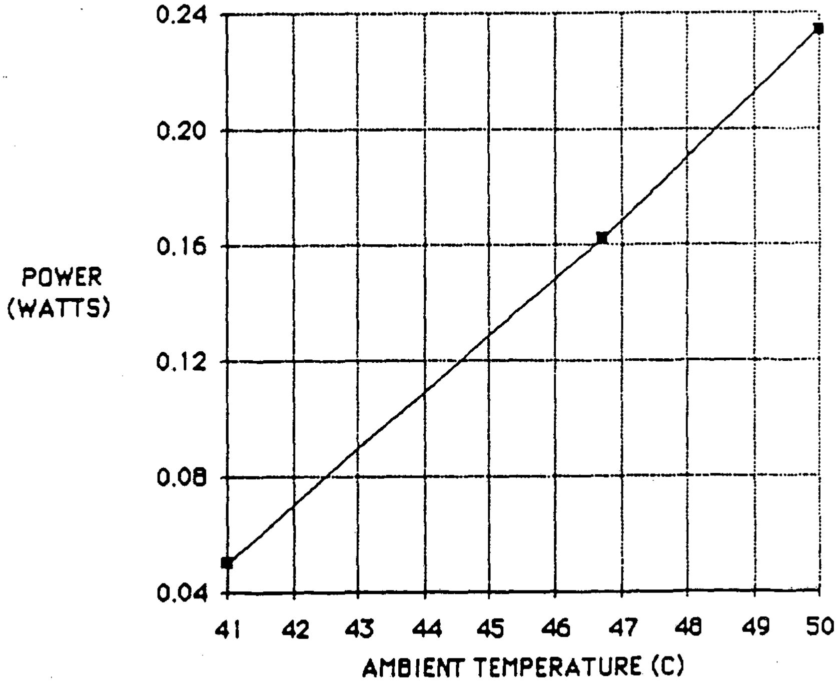


Figure 6. Peltier power vs ambient temperature.

LAWRENCE BERKELEY LABORATORY
TECHNICAL INFORMATION DEPARTMENT
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720