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FIXTURE EFFICIENCY PROGRAM

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ABSTRACT

This paper describes the research program involved with the development of energy efficient fluorescent fixtures. The program effort is directed at improving the efficiency of both compact and T12 fluorescent fixtures by the development of advanced thermal management systems. Most enclosed compact and T12 fluorescent fixtures produce elevated lamp wall temperatures that result in reduced light output and efficiency of the lamp ballast system. Fixture efficiencies for these types of enclosed fixtures typically range between 50 and 70%. Approximately half of the efficiency losses are due to thermal affects and half due to optical factors. This indicates that substantial conservation potential exists by enhancing the thermal performance of fluorescent fixtures.

The ongoing program is directed at developing enhanced fixture geometries that mitigate these thermal losses, and at working with the fixture industry to transfer these thermal management systems to the marketplace. The overall methodology and sample experimental results are presented in this paper. Specific prototype developments are included demonstrating the application of the laboratory facility.

INTRODUCTION

Fluorescent fixture efficiency is a function of both the optical and thermal characteristics of the fixture. Both these factors are determined by the particular geometry of the enclosure that makes up the fixture surround and the thermal characteristics of the lamp ballast system. There are two approaches to increasing fixture efficiency. One is by improving the optical characteristics such as using highly specular reflectors so that more light can exit the fixture. Secondly fixture efficiency can be increased by modifying the fixture environment for cooler operation of the temperature sensitive fluorescent source.

Most efforts to increase efficiency in fluorescent fixtures have concentrated on optical parameters and not on thermal factors. Thermal considerations are an important element as compact and standard T12 fluorescent lamp ballast systems can lose both light output and system efficacy when operated within thermally constricted fixture environments. These changes are a function of minimum lamp wall temperature (MLWT) the coldest point on the lamp surface which controls the output characteristics of the lamp [1]. Most fluorescent lamp systems maintain optimum light output and efficacy with MLWT between 35-40C°.

If the thermal dissipation of the lamp is reduced by a constricted fixture surround, the MLWT rises above optimum and can exceed 50C° inside typical enclosed fixture environments. Thermal losses inside T12 fixture systems have been studied in some detail and it is estimated that enclosed types of fixtures, such as lens troffers and wrap arounds, can result in light output losses in the range of 10-20% depending upon the number of lamps [2].

Secondly most fixture systems designed for the operation of compact fluorescent lamps also present a highly constricted thermal environment to the lamp which inhibits heat dissipation to the surroundings. Experimental studies indicate that minimum lamp wall temperatures can exceed 55C° inside constricted compact fluorescent fixtures, with fixture efficiency losses approaching 20% [3].

In order to address this thermal efficiency problem, a program has been established at Lawrence Berkeley Laboratory. The objective of this program is to identify the efficiency losses that occur within a typical range of compact and T8,10,12 fluorescent fixture systems, and to research and develop thermal management systems to improve fixture efficiency [4].

Further objectives of these studies include developing thermally efficient fixture prototypes that embody a range of advanced thermal management systems, and presenting these prototypes to industry to accelerate the transfer of these technologies to the marketplace.

OVERVIEW AND DESCRIPTION OF EXPERIMENTAL PROGRAM

The overall program is directed at the experimental development of thermally-efficient fixture prototypes. This involves assessing the thermal, photometric, and electrical performances of a broad range of compact and T12 fluorescent fixture systems. Based on this assessment, thermal management techniques are then developed and applied to generic fixture systems to improve efficiency based on lamp temperature control.

The experimental program is divided into the following areas:

- Measuring the thermal and operating characteristics of lamp ballast systems

The thermal performance characteristics of compact and T12 fluorescent lamp ballast systems are examined. This involves the measurement of light output and power input for generic lamp ballast systems as a function of ambient and lamp wall temperatures. Specific apparatus includes temperature-controlled photometric integrating chambers that are used to measure the light output and power input of a lamp operating in free air over a wide range of ambient temperatures [5].

Ongoing studies are also directed at identifying the performance variations associated with lamp burning position in free air as a function of how the lamp is integrated within a fixture. Figure 1 shows a cross section of one of the photometric integrating chambers used for characterizing the light output and efficacy characteristics of compact fluorescent systems. This apparatus is also adjustable in terms of spatial orientation (tilt angle) and is used to study the effects of lamp position and lumen output.

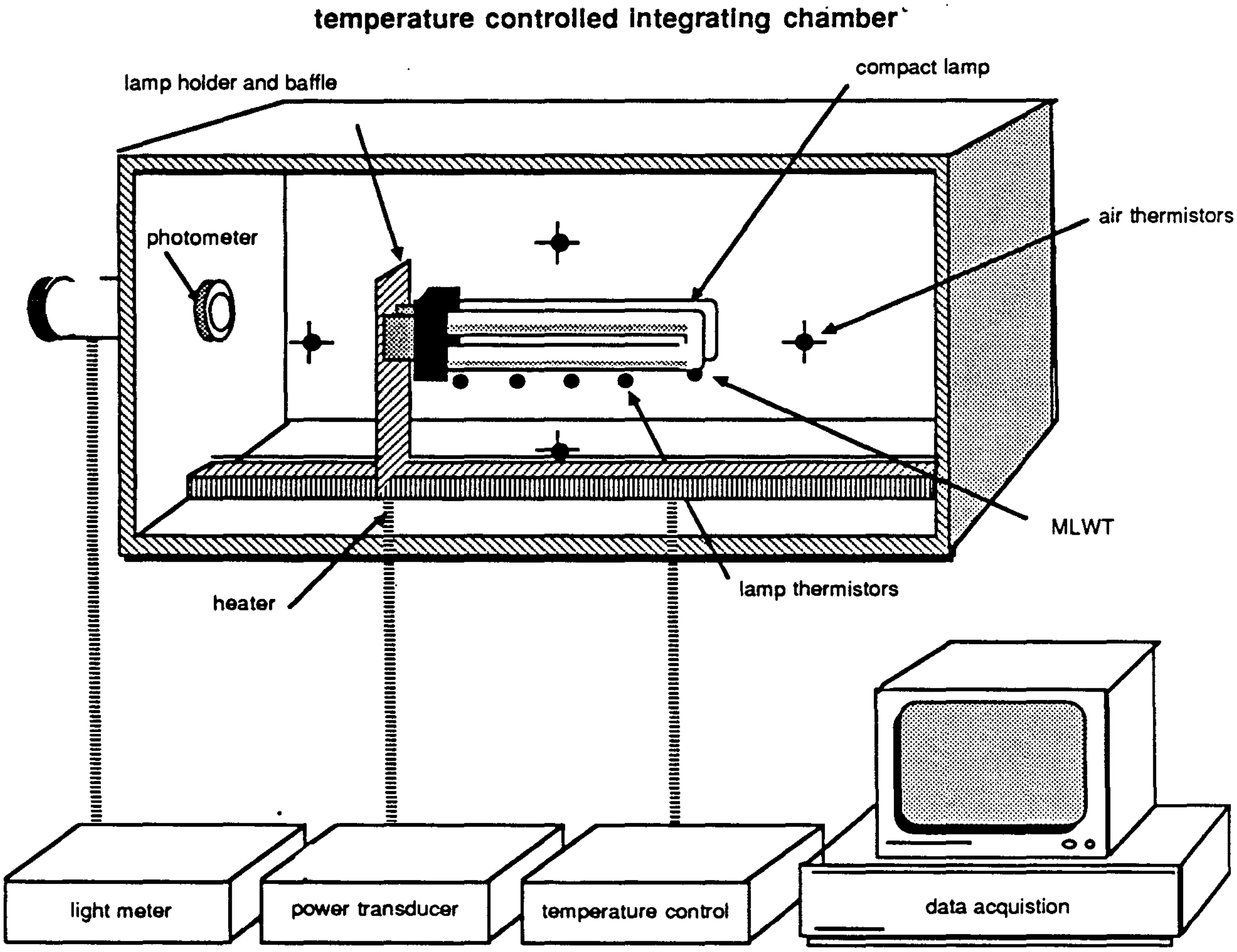


Figure 1. Schematic of temperature controlled integrating chamber

Figure 2 plots the changes in light output and efficacy for a 26 watt compact lamp as function of MLWT, measured inside the temperature controlled integrating chamber. Light output and efficacy are maximal at a MLWT of approximately 40°C.

With increasing lamp temperature, there is a progressive loss in both light output and system efficacy. At a 60°C MLWT, these losses in light output and system efficacy approach 20%.

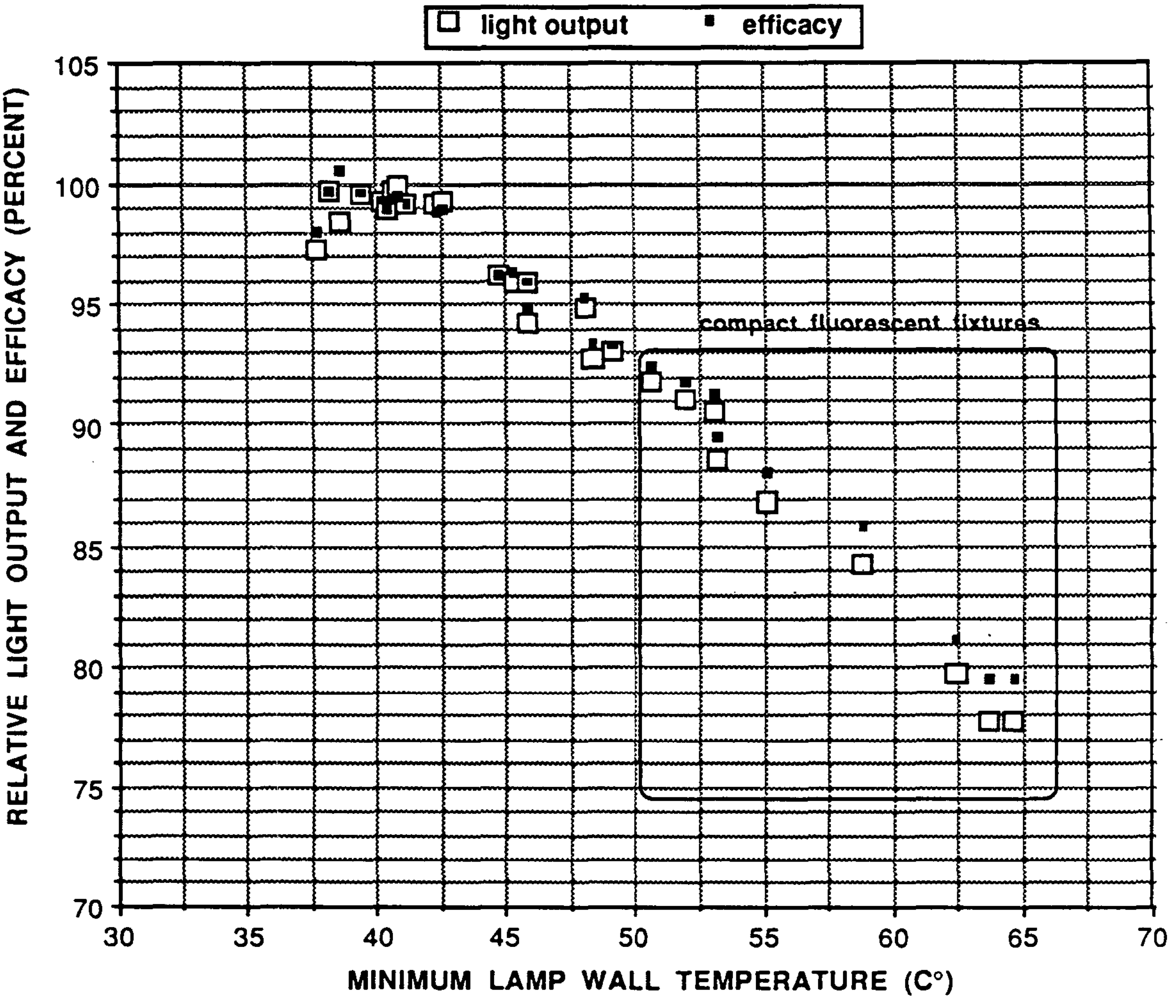


Figure 2. Light output and efficacy vs, MLWT

- Assessing the thermal performance of fixture systems

This work is directed at characterizing the thermal performance of the complete fixture system as installed within the ceiling and plenum environment. This includes measuring the relative changes in light output and power input for fixtures operating over time. Temperatures of the lamp, lamp compartment, fixture surfaces, and the surround are also monitored. Experimental test racks have been developed that allow for the positioning of the fixture system within a simulated ceiling and plenum environment in order to simulate the range of thermal conditions typically encountered within a space [6].

The various apparatus include:

- experimental ceiling planes for testing surface-mounted and pendent-mounted fixtures.
- experimental ceilings and plenums for studying recessed compact fluorescent fixtures
- simulated plenums for studying mechanically and passively ventilated fixtures

All of the fixture test apparatus are instrumented with thermistors, photometers and power analyzers, and are connected to a data acquisition unit in order to monitor changes over time. Figure 3 shows a schematic of the experimental apparatus used for studying the performance of recessed compact fluorescent down lights.

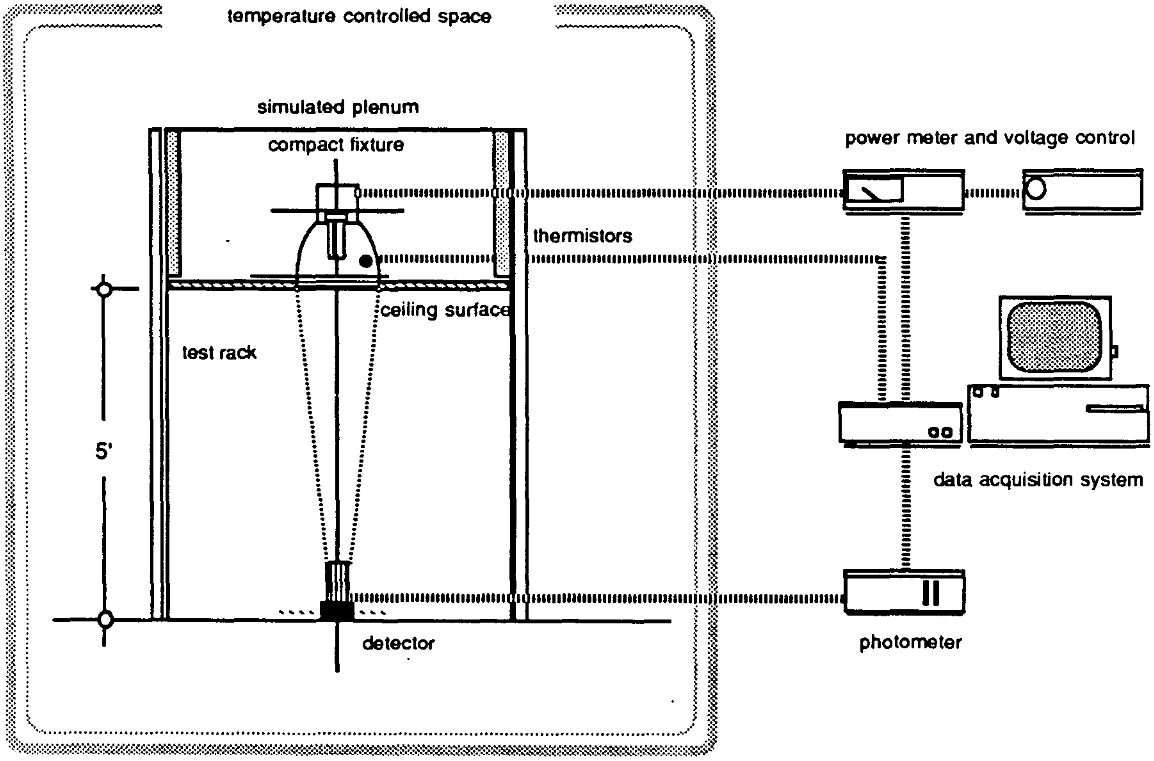
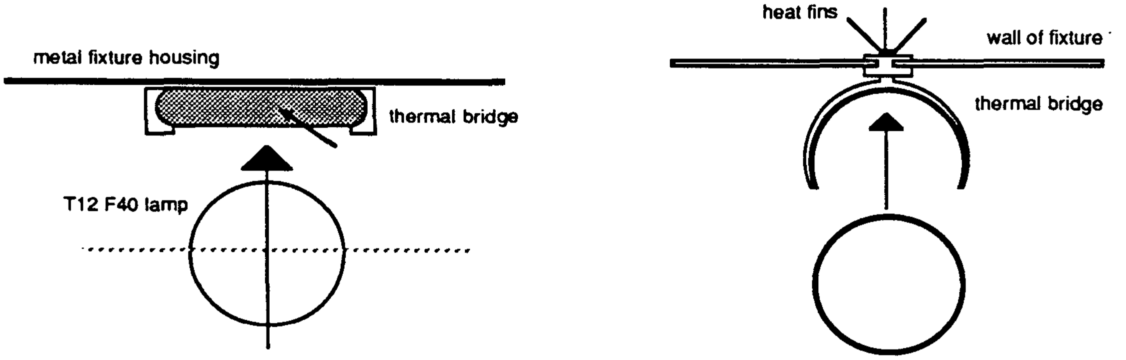


Figure 3. Experimental apparatus for studying recessed down lights

• Development of thermal management systems

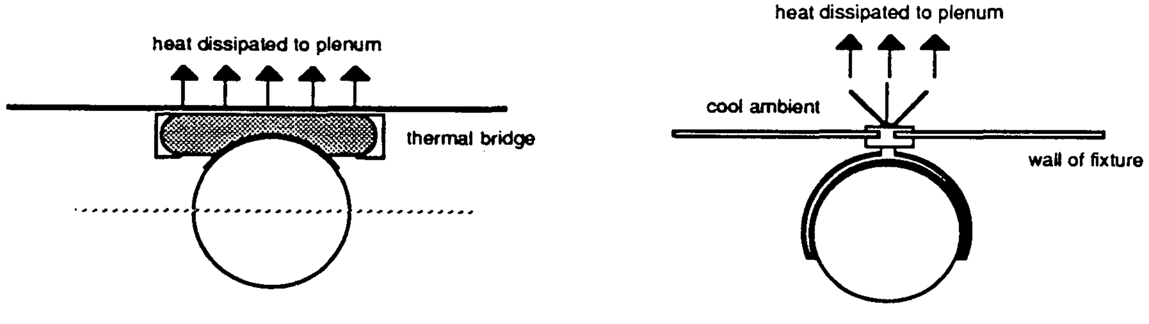
Specific lamp cooling techniques are being researched and developed for different types of fixture systems. These cooling strategies all involve the removal of heat from a small localized area on the lamp surface. These spot cooling techniques allow the MLWT to be reduced closer to its optimum point, resulting in an increase in light output, and therefore an increase in fixture efficiency. Spot cooling techniques under development include two basic approaches. The first involves the addition of small inlet and outlet apertures that promote convection through the lamp compartment of the enclosed fixture. This convection reduces the compartment temperature resulting in reduction in MLWT with a corresponding increase in lumen output.

A second spot cooling approach involves the attachment of small devices to a portion of the lamp surface to form a thermal bridge between the lamp and envelop of the fixture. Heat transported from the lamp to the fixture through the bridge is dissipated by conduction and convection to the cooler ambient surround. These thermal bridge assemblies include both semi-rigid and flexible systems that are installed within the lamp compartment in contact with the lamp and the envelop of the fixture.



fluorescent lamp is positioned onto bridge

lamp snaps into heat transfer assembly



Liquid thermal bridge system for spot cooling fluorescent lamps inside fixtures

Spring action thermal bridge system for spot cooling fluorescent lamps inside fixtures

Figure 4. Thermal bridges for T12 fixtures

Figure 4 shows the geometry of a springable thermal bridge for T12 lamps that is attached to the upper surface of the fixture. As the lamp is positioned within the fixture, the bridge attaches itself to the lamp and conducts heat away to the plenum.

A second bridge geometry for T12 lamps employes a flexible pad encapsulating a convective fluid which is attached to the top of the fixture [7]. As the lamp is positioned into the fixture, the flexible thermal bridge conforms to the geometry of the lamp forming an intimate thermal connection or bridge to the fixture surround. The bridge then convects heat away to the sheet metal of the fixture were it is dissipated to the plenum above. Figure 4 shows a cross section of the flexible thermal bridge system.

- Development and testing of thermally efficient prototypes

The various cooling strategies are applied and tested inside specific types of fixtures. The fixture is monitored measuring changes in light output, power input, and temperature over time as a function of different thermal control systems. This data is compared with the fixture operating without a thermal control system in order to assess the potential range of efficiency enhancement. Efficient cooling strategies are identified and prototype fixtures are refined and developed. These fixture systems are tested, and the specific efficiency enhancements are measured and documented. Additional experiments are conducted in order to identify specific optical losses that may occur with the addition of spot cooling devices located on the lamp surface. Supplemental research efforts concentrate on manufacturing issues and potential cost benefits associated with the efficiency improvement.

- Technical transfer and industry involvement

The technical transfer of the thermal efficiency work is divided into two areas. The first involves the development and dissemination of technical information in the form of technical notes and papers circulated to the industry directly and through professional conferences and seminars.

The second avenue of technical transfer involves the development of direct contacts and cooperation with the fixture industry in the development of efficient fixture prototypes. This includes the development of specific fixture prototypes that embody a refined thermal management or spot cooling system to enhance the fixture efficiency.

An example of this cooperation has led to a licence agreement between Lawrence Berkeley Laboratory and a major manufacturer of compact fluorescent fixtures. This Licence involves the transfer of thermal management technology for increasing the efficiency of their fixture systems.

EXPERIMENTAL RESULTS AND PROTOTYPE PERFORMANCE

This section reports on a series of ongoing experiments illustrating the performance variations that occur with fluorescent fixtures. Sample prototype fixtures are described that employ thermal management systems to improve efficiency by spot cooling techniques.

1) Recessed double 13 watt compact fluorescent fixture using convective venting

A recessed fixture system with two 13 watt compact fluorescent lamps was tested operating with and without convective venting. Figure 5 shows a cross section through the enclosed fixture showing the diagonal mounting position of the two lamps. This fixture was mounted inside the experimental plenum chamber and changes in light output and temperature were monitored for a period of approximately 3 hours. The lamps were previously operated for 24 hours to insure establishment of a stable cold spot.

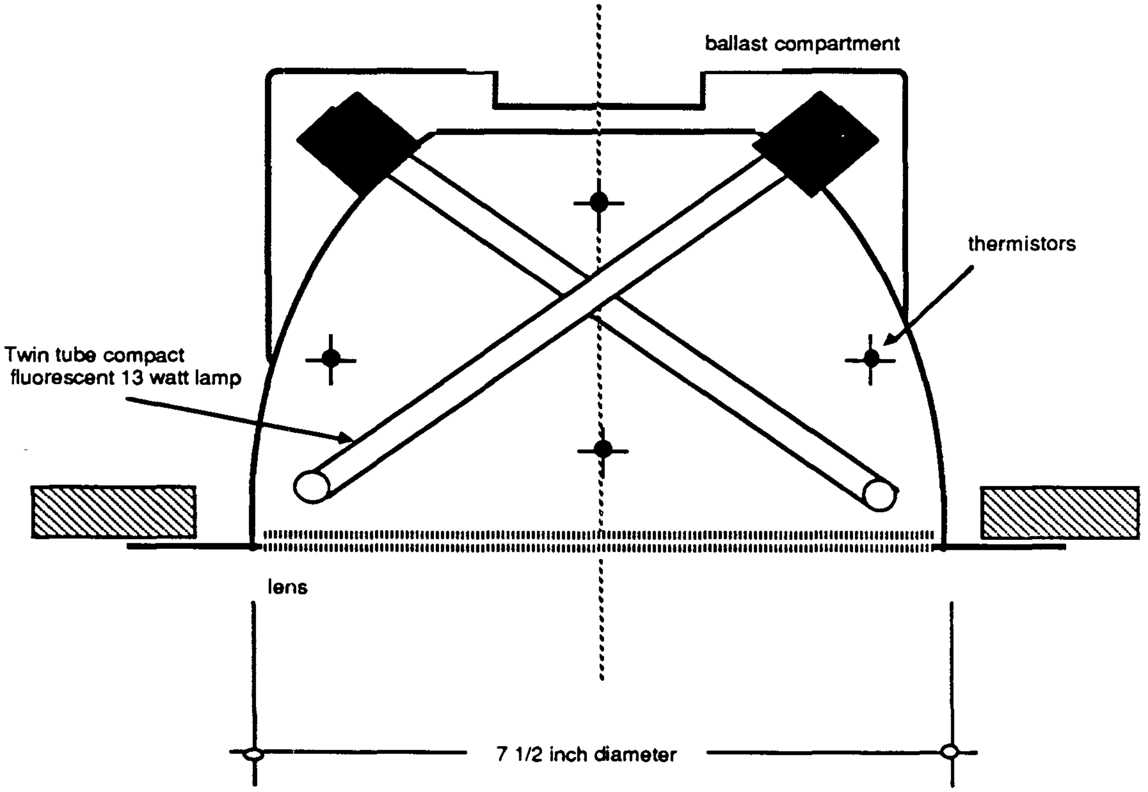


Figure 5. Cross section of recessed 13 watt fixture

Figure 6 shows the changes in both light output and system efficacy for the enclosed fixture. Both light output and system efficacy reach a maximum shortly after the fixture is energized. Light output and efficacy then decline to approximately 82-84% of maximum after a period of three hours due the constricted thermal environment surrounding the lamps. Ambient temperature inside the fixture reaches approximately 45C°.

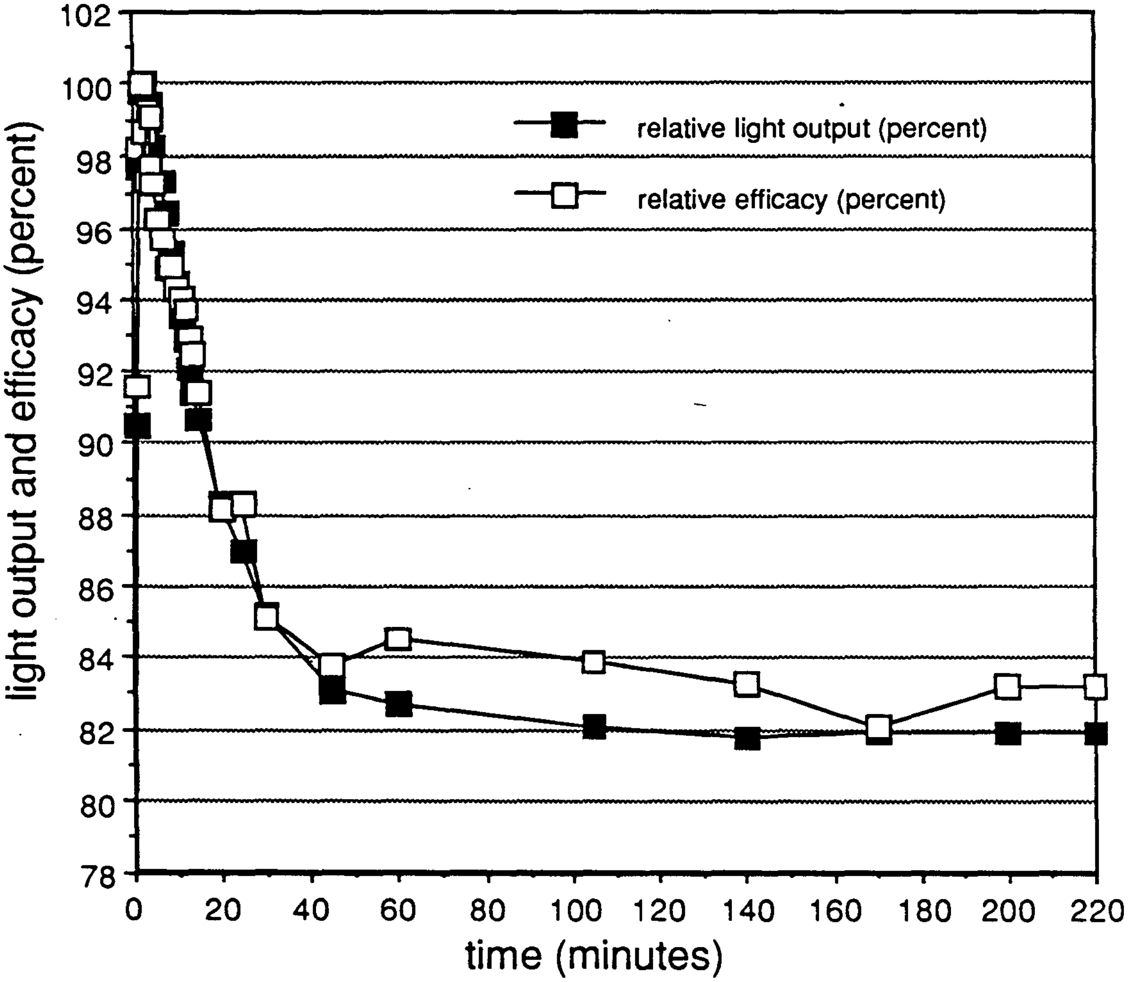


Figure 6. Light output and efficacy for double 13 watt fixture

The same fixture was modified to incorporate a venting configuration. This consisted of two small inlet apertures located diametrically at the base of the fixture, aligned with the two ends of each lamp. A single outlet aperture is located at the top of the fixture. This venting configuration promotes a convection through the compartment allowing cool ambient air to enter the fixture directly onto the cold spot of the lamp. Figure 7 shows a cross section of the fixture indicating the convection pattern through the lamp compartment.

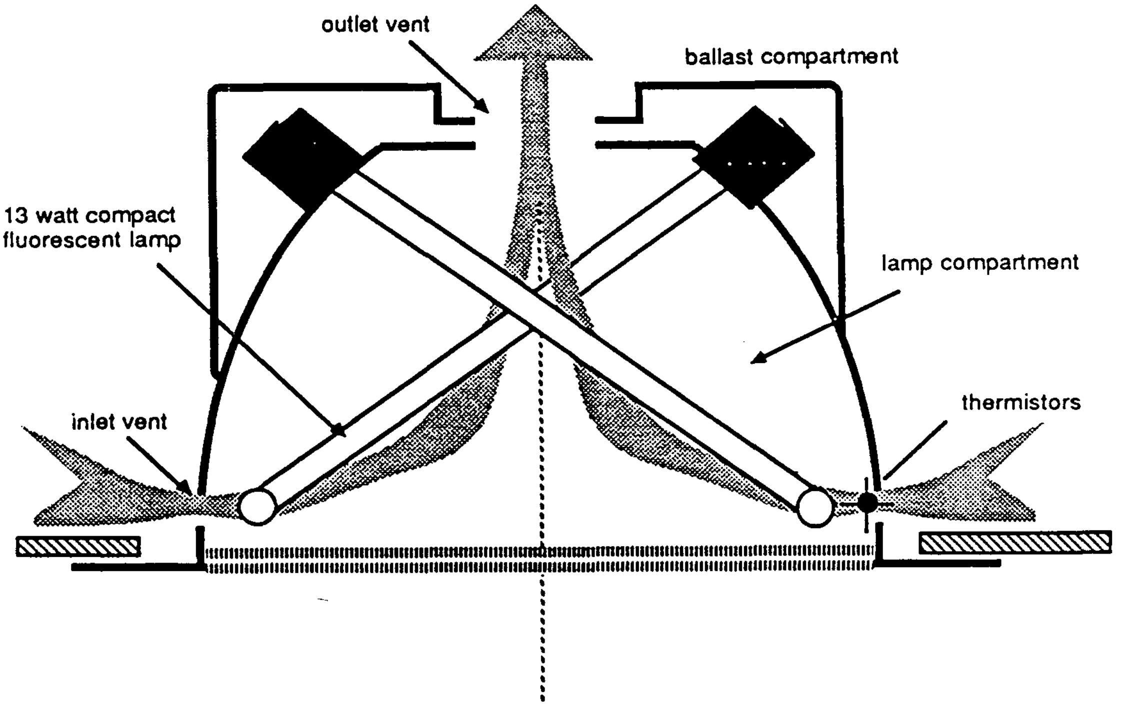


Figure 7. Cross section of recessed fixture with convective venting

Figure 8 shows the changes in light output for the fixture operating with convective venting through the lamp compartment. The light output variations for the standard fixture without venting are included for comparison purposes. For the vented fixture light output reaches a maximum a few minutes after it it is energized then reduces to approximately 90% as the lamp and coldspot temperature heats up over its optimum. As the fixture heats up, the increased temperature gradient between the top and bottom of the fixture causes increased air flow through the apertures. This increased air flow lowers the MLWT and restores the light output to 98-99% of maximum. The temperature of the ambient air surrounding the lamp as it circulates through the fixture was measured at 20-25C° approximately 20C° cooler than the the unvented configuration. The convective venting strategy results in a 18- 20% increase in light output in comparison with the unvented fixture.

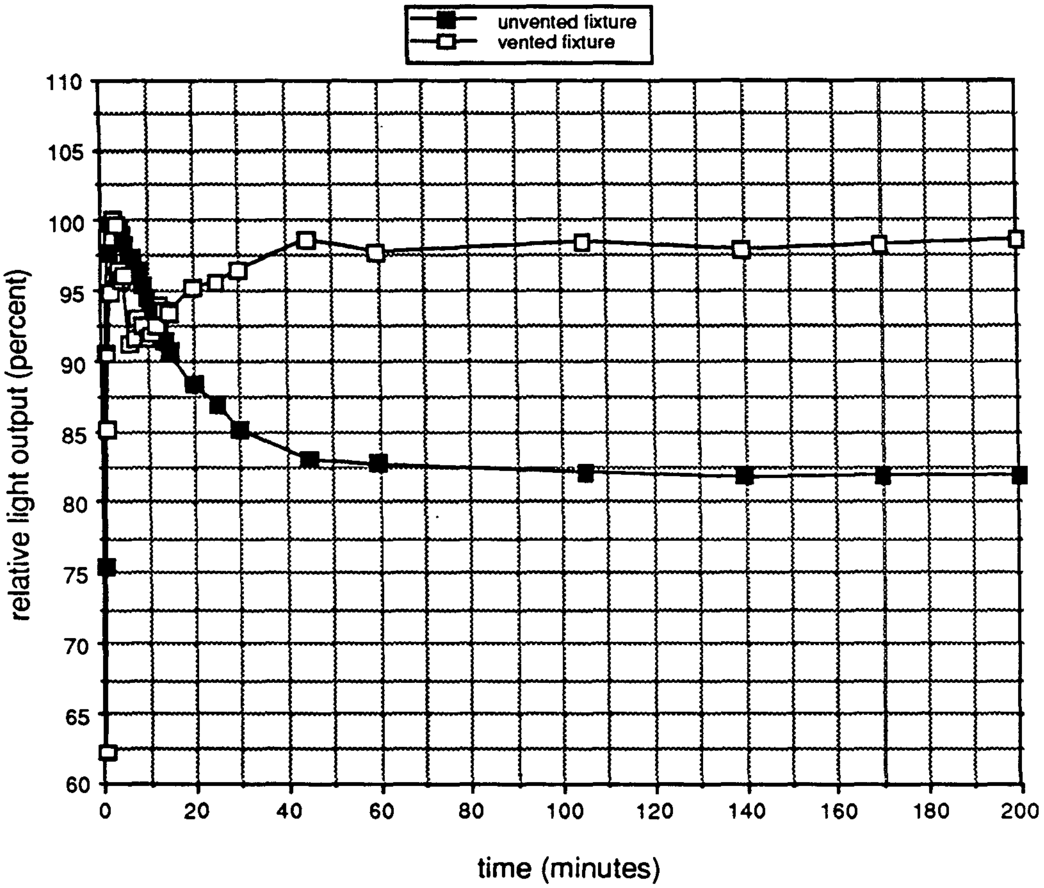


Figure 8. Light output for vented and unvented fixture

2) Recessed double 7 watt compact fluorescent fixture using a thermal bridge system

A recessed two lamp enclosed fixture was tested operating with and without a thermal bridge system. The fixture has the same basic geometry as the enclosed fixture previously described, except it uses two 7 watt lamps with the same diagonal mounting configuration. The thermal bridge consisted of a small conductive spring assembly that contacts a small portion of the ends of the lamp. The bridge is connected to the wall of the fixture directly adjacent to the lamp. The envelop of the fixture then conducts heat from the bridge where it is convected to the surrounding plenum environment.

Figure 9 shows a cross section of the double 7 watt fixture showing the fixture and the thermal bridges positioned at the ends of each twin tube lamp. A detail of the springable bridge is included showing the connection with the lamp and the wall of the fixture. Figure 10 shows the light output variations over time for the fixture operating with and without the thermal bridge system. For the standard fixture light output reaches a maximum shortly after its energized and then reduces to a minimum of approximately 85% after 3 hours of operation. The same fixture with the thermal bridge systems maintains approximately 98% relative light output over the duration of the experiment. This represents approximately 15% increase in lumen output due to the cooling action of the thermal bridge system.

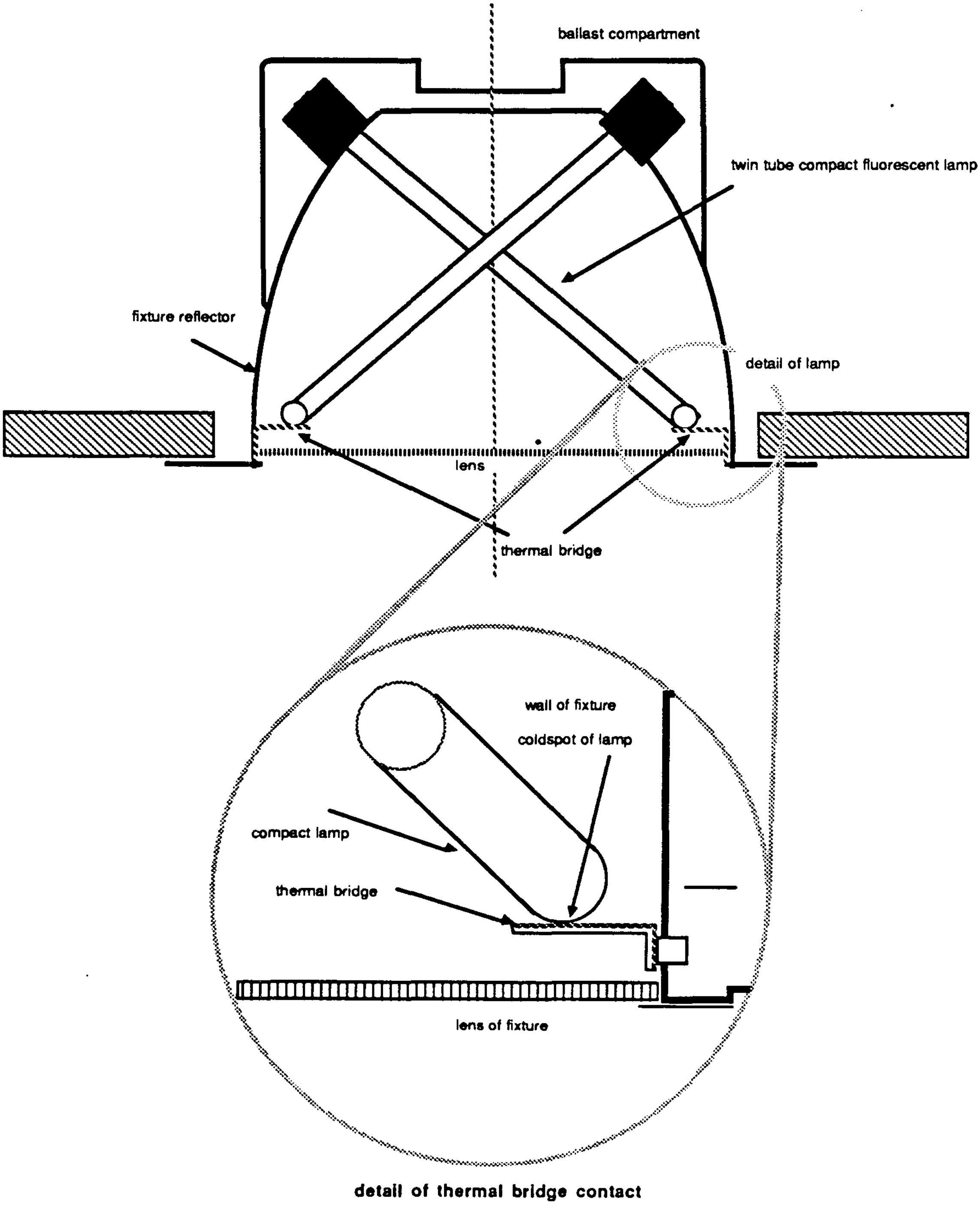


Figure 9 Cross section of 7 watt fixture with thermal bridge

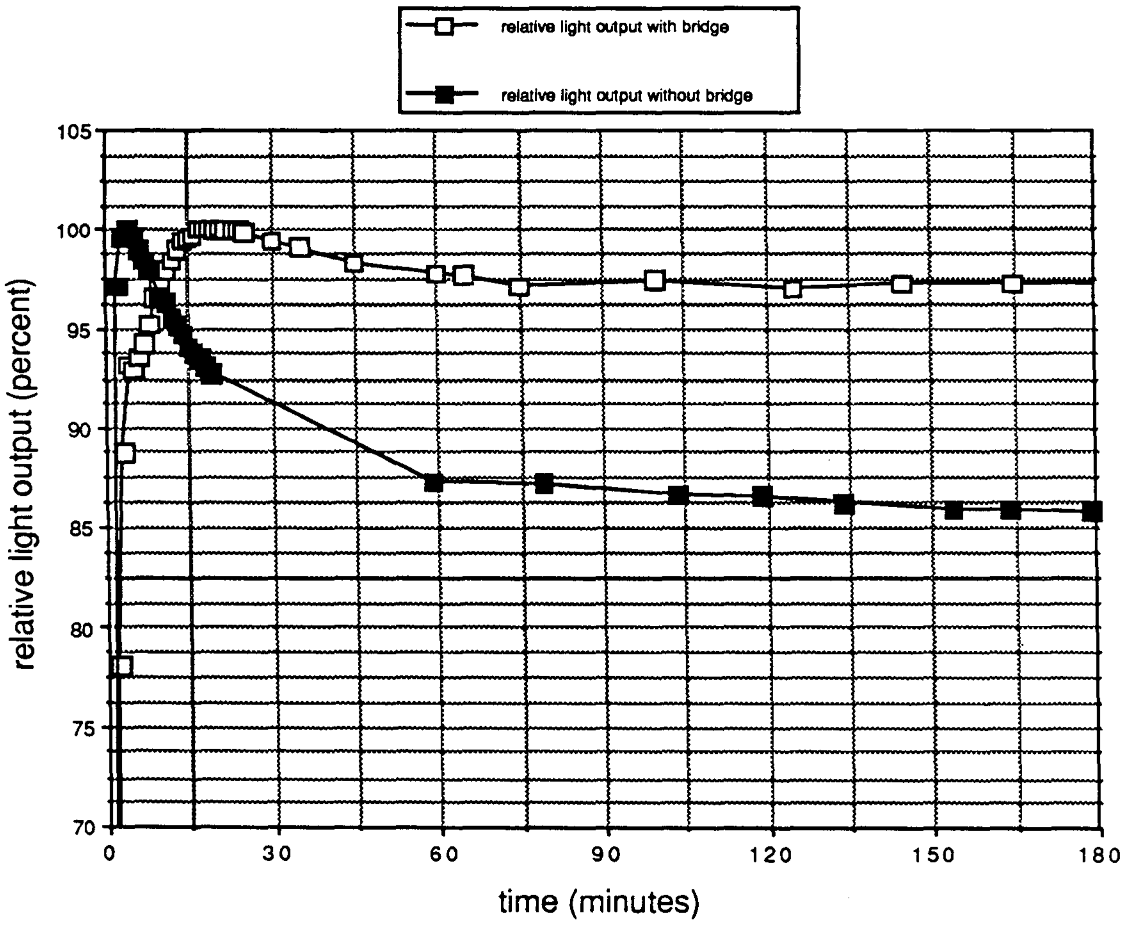


Figure 10. Light output variations operating with and without a thermal bridge

SUMMARY

The experimental data and prototype studies indicate that significant potential exists in terms of enhancing the efficiency of fluorescent fixtures by thermal management. These thermal management systems involve direct approaches to cool small portions on the lamp wall and could be easily integrated within the manufacturing process of the fixture without incurring a significant increase in added cost.

Increasing the efficiency of the fixture presents some significant conservation benefits. These included both energy saving from direct increases in efficacy and capital cost savings due to the reduced number of fixtures required to maintain a specified illuminance level. Secondly increasing the lumen output of compact fluorescent fixture systems will promote the increased utilization of this technology as a replacement for the incandescent. With increasing application of the compact fluorescent it is becoming important to realize the full lumen output potential of these systems and thermal management through appropriate lamp wall temperature control is one technique that can provide increased efficiency.

ACKNOWLEDGEMENT

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