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Convective Venting in Compact Fluorescent Fixtures

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Abstract---Many compact fluorescent fixture systems present a highly constricted thermal environment to the lamp. This results in elevated lamp wall temperatures causing reduced light output and efficiency of the fixture system. Dissipating heat from the interior of the fixture to the surrounding plenum can increase the fixture's light output and efficacy by more than 15%, allowing the light output and efficacy to reach 98%-99% of maximum. One way of achieving this thermal dissipation is through the convective venting of the fixture; this inhibits thermal stratification within the fixture housing and permits upward convective flows to cool the lamp. In an enclosed fixture, minimum lamp wall temperature (MLWT) can exceed 50°C; the proper venting configuration can reduce this temperature to 40-45°C.

INTRODUCTION

Fluorescent lamps are greatly affected by ambient temperature. The mercury inside the lamp condenses at the coldest spot on the lamp. This minimum lamp wall temperature (MLWT) therefore controls the mercury vapor pressure which, in turn, affects the light output and efficacy characteristics of the lamp. Due to their constricted thermal environments, many typical compact fluorescent fixtures are operated at elevated temperatures, and because of this, suffer light output and efficacy losses of up to 20%. One thermal management technique currently being investigated to cool the lamp compartment and spot-cool the lamp surface is convective venting. By placing vents in the proper configuration, convective air flows are created that draw cool, external air over the cold spots of the lamps and through the fixture's internal compartment, thereby preventing thermal stratification and cooling the lamp. This results in increased light output and lamp efficacy.

PROCEDURE

Three fixture systems that incorporate vents in the lamp compartment are tested. Each fixture system is run for a 24-hour period prior to any experimentation to ensure the establishment of a specific cold spot. The fixtures are mounted in a simulated plenum and powered through a voltage stabilizer. Temperature readings are taken with thermistors attached to various fixture components or suspended in the lamp's internal compartment or in the external plenum. Data are collected on a data acquisition unit over a period of at least three hours. Light output is monitored by a photometer placed below the fixture and aligned with its center axis. Power and voltage readings are taken with a power meter. Figure 1 shows the general experimental set-up used for all of the fixtures tested.

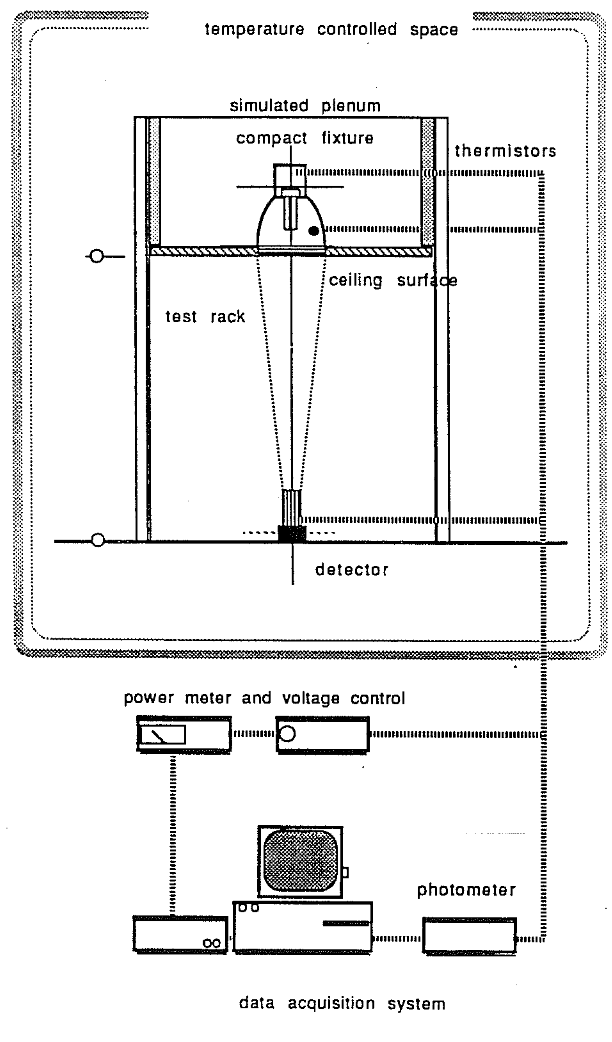

Fig. 1. Schematic of experimental set-up for measuring performance of fixture systems.

The first test is conducted on an open, recessed downlight, housing two, 26-watt, quad-tube, compact fluorescent lamps. Temperature readings are taken with thermistors located at various places in both the lamp compartment and the external plenum. Readings on this first fixture are taken every minute for the first ten minutes, then every ten minutes thereafter over a period of three hours.

A control experiment of the unvented fixture is initially run, and temperature and light output readings are taken for the open fixture. The fixture is then modified to allow vents to be placed in the upper portion of the lamp compartment, above the lamp cold spots. Five removable plates, each incorporating a different aperture, are designed to fit the fixture's upper housing. The apertures are rectangular: 3.25 inches long with varying widths of 0.25 inch, 0.5 inch, 0.75 inch, 1.0 inch, and 1.5 inches. All vents have rounded corners and bevelled edges to allow for a smoother convective air flow out of the fixture. The length and location of the vents are restricted by the upper diameter of the fixture's reflector. The center of the leading edge of each vent is placed one-half inch from the edge of the reflector; the leading edge of the vent is thereby directly over the tips of the lamps, and widths are measured back from the fixed position of the leading edge. This placement of the vent allows for a maximum vent length of 3.25 inches so that the vent will not overlap the edge of the reflector. Temperature and light output readings are then taken for the five configurations of this vented fixture to determine the optimum aperture size. Figure 2 illustrates the venting geometry of this fixture. A side view of the open, recessed downlight, as well as the convective flow pattern through the vented fixture, are provided in Figure 3.

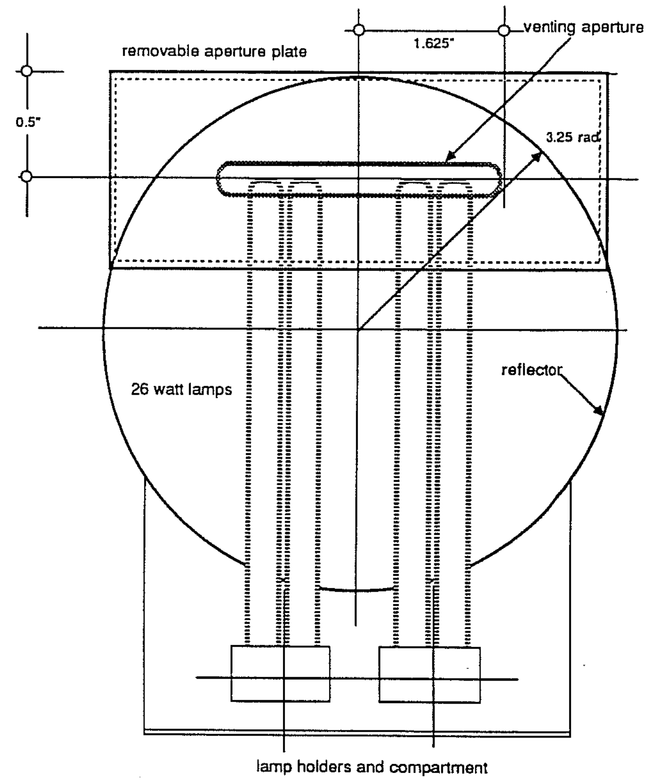

Fig. 2. Top view of recessed fixture showing geometry of venting aperture plates relative to lamp geometry.

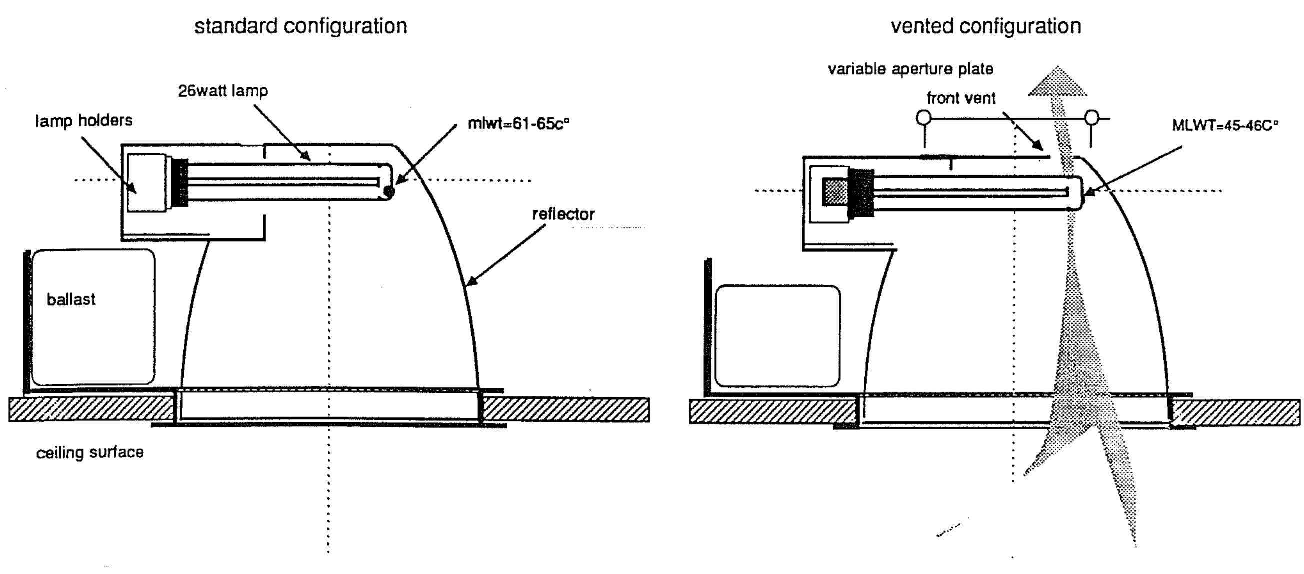

Fig. 3. Cross section of vented and unvented fixture configuration illustrating the convention pattern.

RESULTS AND DISCUSSION

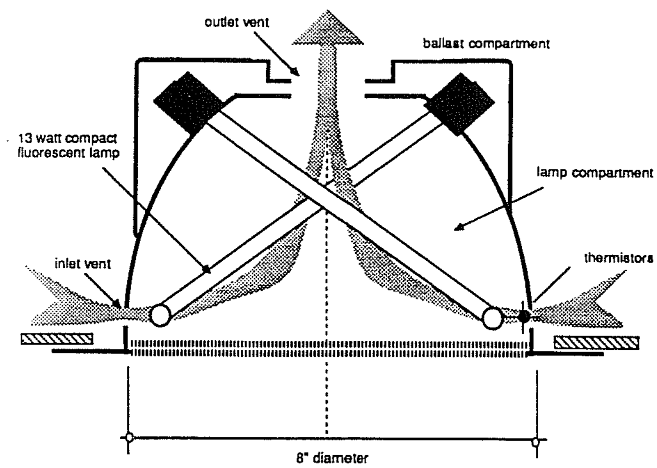

Fig. 4. Cross section of enclosed fixture showing convection pattern through the lamp compartment.

2X26-Watt Open Recessed Downlight

The open, recessed fixture is initially unvented, although having no lens cover, it is exposed to the external plenum. This, however, seems to have little impact on lamp performance. After a running-time of approximately 1.5 hours, the minimum lamp wall temperature (MLWT) of this fixture stabilized at about 58°C, resulting in a decrease in light output of over 15%. Figure 5 shows the temperature and light output results of this control experiment with no vents present in the open, recessed downlight. Vents 3.25 inches long of varying widths--0.25 inch, 0.5 inch, 0.75 inch, 1.0 inch, and 1.5 inches--were then introduced to the top of the fixture housing, and data was taken for each of the five vents tested. The effects of vent width on the optical and thermal performance of the lamp are displayed in Figure 6. Thermal efficiencies are calculated by taking the ratio of the stabilized light output to the maximum light output for each particular vent. Optical efficiencies are the ratios of each lamp's maximum light output to the maximum light output obtained with no vent present. Therefore, the absence of vents results in maximum optical performance, but poor thermal performance, while a very large vent results in poor optical performance, but near-perfect thermal performance.

A second experiment is conducted on an enclosed, recessed downlight, housing two, 13-watt, twin-tube, compact fluorescent bulbs in a crossed configuration. Two small vents, each approximately 0.5 inch in diameter, are inserted into the fixture housing opposite to each lamp's cold spot. A third, larger vent, approximately 1.5 inches in diameter, is placed at the top of the fixture housing. Air flow into the fixture is initialized by heat stratifying inside the fixture so that the hot air, which has a lower density, rises upward and out through the top vent; cold air is thereby drawn in through the lower vents and across the lamp cold spots, convectively cooling the lamp. Figure 4 provides a schematic of the convective air flow through the lamp compartment.

Experiments are conducted on this enclosed fixture with the vents first sealed, and then open, to determine increases in light output and efficacy as a result of this venting configuration. Light output, temperature, and power data are recorded every thirty seconds for the first five minutes (to note when convective flow is initialized), every minute for the next ten minutes, and every fifteen minutes thereafter for the remainder of the three hour experiment. Ambient temperatures immediately surrounding the lamp cold spots are measured by inserting a thermistor through the vent opening to within close proximity of the lamp tip.

The third and final venting experiment is conducted on an enclosed, recessed ceiling fixture, housing two 7-watt twin-tube compact fluorescent lamps. The procedure for this experiment follows the steps outlined above for the 2x13-watt recessed downlight.

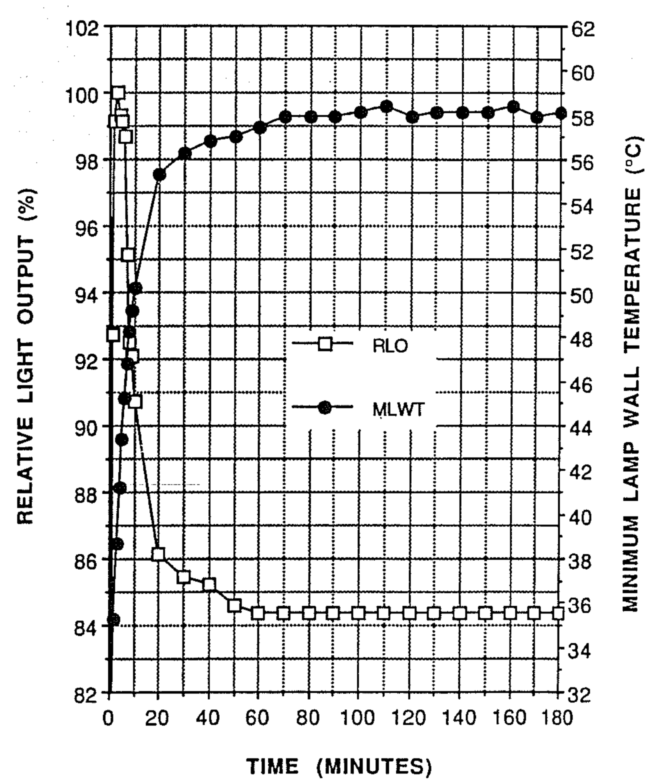

Fig. 5. Lamp temperature and light output for standard fixture operating without vents.

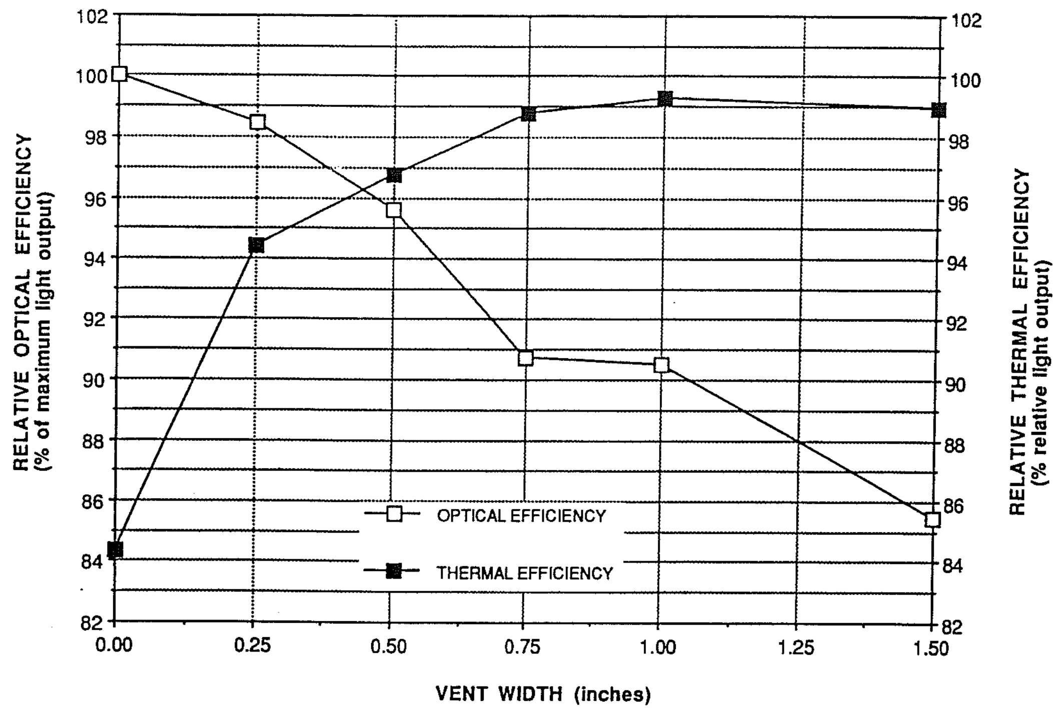

Fig. 6. Optical and thermal efficiency as functions of vent width for the recessed fixture.

Vents of widths greater than one inch were immediately disqualified, as the amount of light lost through the aperture was nearly 10% of the total light output. The stabilized light output increased as the vents got smaller because these smaller apertures minimized direct light loss to the plenum while still allowing enough hot air to flow out of the lamp compartment to maintain a cooler internal ambient. However, vents 0.25 inch wide or narrower were too small to allow the lamp to reach the desired operating MLWT, which is between 40°C and 45°C. As indicated in Figure 6, the best performance characteristics were obtained with a vent width approaching 0.5 inch. For this half-inch vent, the MLWT stabilized at 45°C, and light output reached 97% of maximum. Figure 7 provides a comparison between the relative light output of the 0.5-inch vented fixture and that of the original, unvented fixture, displaying an increase in light output of 12%-14% using this venting geometry.

The results of this experiment were applied to a venting-damper experiment on the same fixture to determine whether using a highly reflective damper above the half-inch vent would decrease direct light loss through the vent while maintaining lamp cooling by convective air flows. An instantaneous increase in light output of nearly 10% was noted when the reflective damper was dropped over the vent; however, these improvements were short-lived as the lamp soon returned to its original, unvented conditions. The damper was then placed at 0.25 inch above the vent, and finally, at 0.5 inch above the vent. Although there were slight instantaneous increases in light output, the overall improvement in the fixture's light output was negligible.

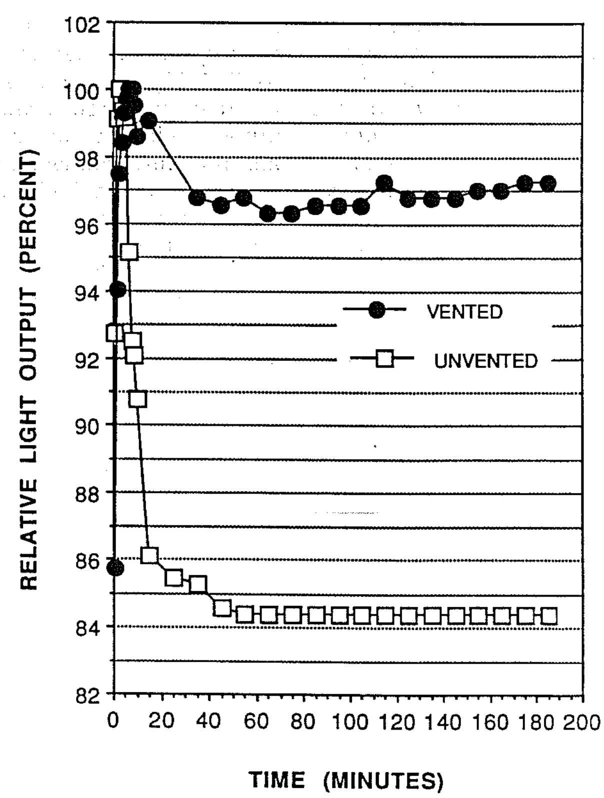

Fig. 7. Comparison of relative light output between the unvented and vented fixture configuration.

2X13-Watt Enclosed Recessed Downlight

Changes in light output and system efficacy for the unvented, enclosed, recessed, 2X13-watt fixture are depicted in Figure 8. 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 over a period of three hours due to the constricted thermal environment surrounding the lamps. Ambient temperature inside the fixture reaches approximately 45°C.

This same fixture is again tested after being modified to incorporate a venting configuration. Three vents are introduced to the fixture housing: two small apertures, each approximately 0.5 inch in diameter, are located diametrically at the base of the fixture and aligned with the cold spots of each lamp; a larger aperture, approximately 1.25 inches in diameter, is located at the top of the fixture. This venting configuration promotes convection through the compartment by allowing the low-density heated air to escape through the top of the fixture, thereby drawing cool external air through the lower apertures. This cool air is drawn into the fixture compartment directly onto the cold spots of the lamps, resulting in both convective cooling of the fixture compartment, and spot-cooling of the lamps.

Figure 9 shows the changes in light output for the fixture operating with convective venting through the lamp compartment. The light output variations for the enclosed fixture without venting are included for comparison purposes. For the vented fixture, light output reaches a maximum at approximately three minutes after the fixture is energized; light output then drops to about 91% of maximum as the lamp and cold spot temperatures heat up over 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 light output to 98%-99% of maximum. The temperature of the ambient air surrounding the lamp as it circulates through the fixture is measured at approximately 25°C, about 20°C cooler than the unvented configuration. The convective venting strategy results in a 16%-18% increase in light output in comparison with the unvented fixture.

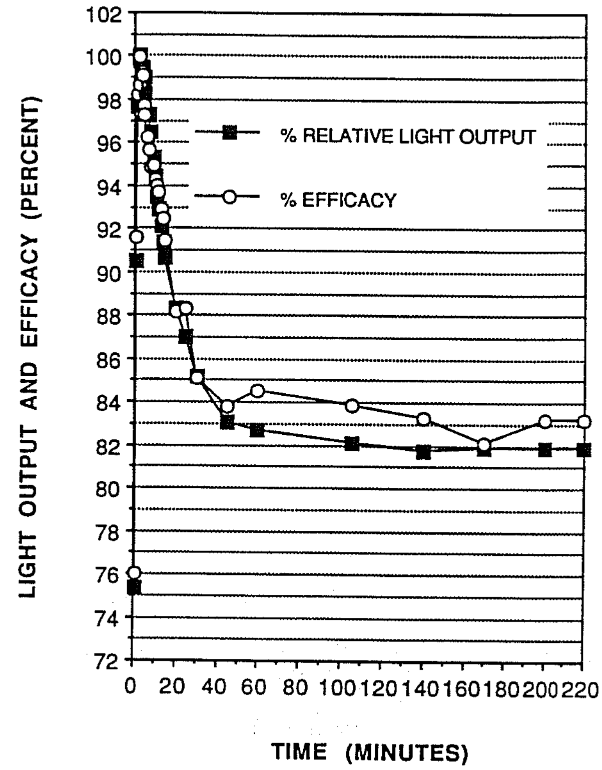

Fig. 8. Relative light output and efficacy for standard enclosed fixture.

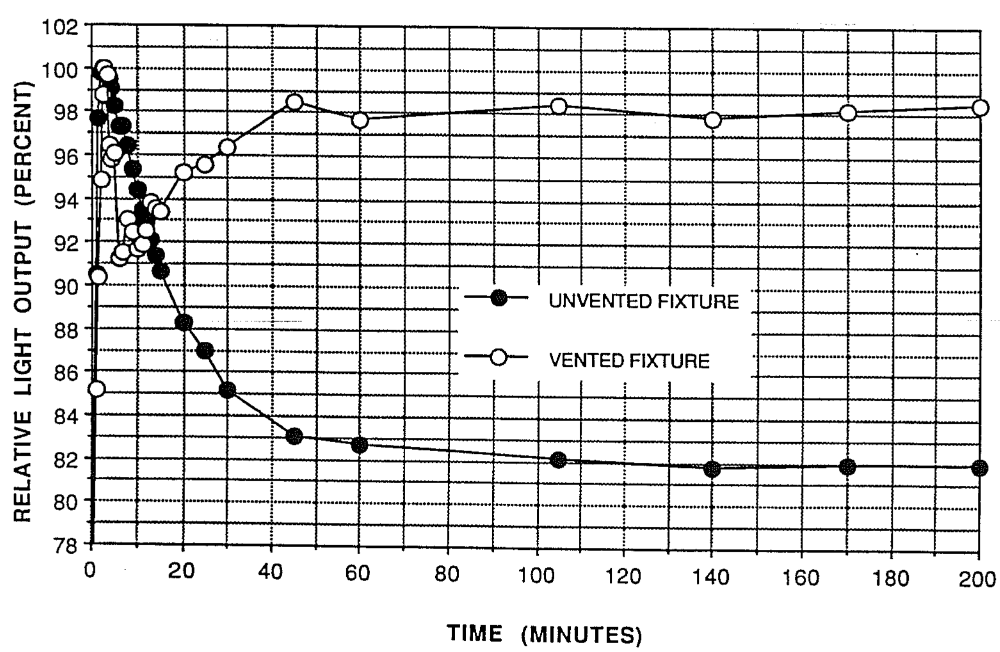

Fig. 9. Relative light output for vented and unvented fixture configuration (2x13 watt fixture)

2X7-Watt Enclosed Recessed Downlight

Results similar to those obtained for the 2X13-watt enclosed downlight were obtained for the 2X7-watt recessed, enclosed fixture. The unvented fixture exhibited light output and efficacy losses in the range of 12%-14%. A venting configuration identical to that used on the 2X13-watt fixture, which included two lower apertures opening onto the lamp cold spots, and one larger aperture at the top of the fixture, reduced these light output and efficacy losses to only 2%-4% below maximum. Figure 10 displays the light output results of the vented 2X7-watt fixture. Light output reaches a maximum shortly after the fixture is energized, then drops to the low point of approximately 96%. As in the 2X13-watt fixture, light output again increases to within 98% of maximum. The light output results of the unvented fixture are provided for comparison purposes.

Vents introduced to any enclosed fixture, however, pose the problem of dust and particulate debris getting trapped within the fixture and settling on the lens, thereby blocking output light. The air current created through the fixture, as well as the larger vent in the upper portion of the lamp, could mitigate this possible problem. Ideal venting use would be in open downlights, such as the 26-watt open recessed fixture studied in this experiment, as dust or particles entering the upper vent would not be trapped on the lens, but would simply traverse the fixture and float out the bottom.

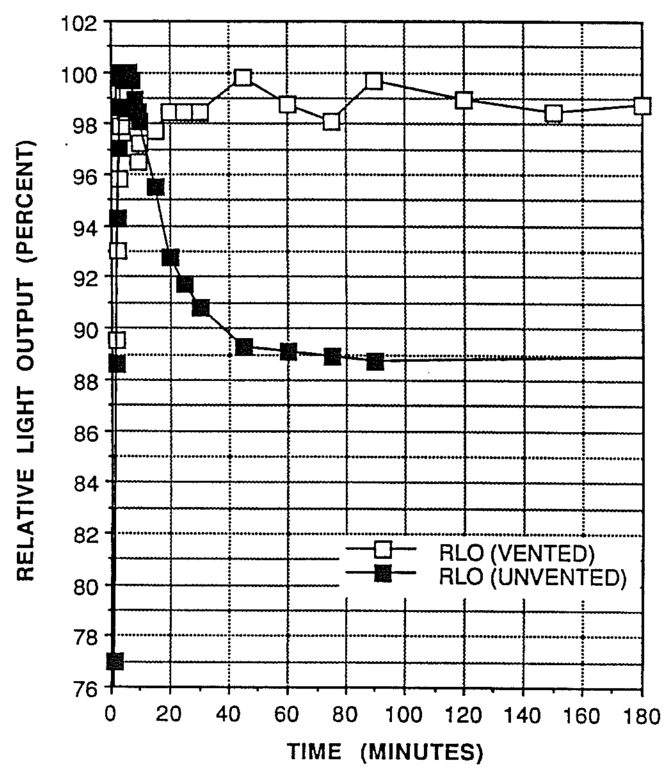

Fig. 10. Relative light output for vented and unvented fixture configuration (2x7 watt fixture)

CONCLUSION

Convective venting studies done on three different compact fluorescent fixtures indicate that the reduction in light output and efficacy caused by a highly constricted thermal environment can be nearly eliminated with a proper venting configuration. Experiments conducted on an open, recessed ceiling fixture housing two, 26-watt, quad-tube, compact fluorescent bulbs indicate a light output loss of 15% for an unvented fixture; with an aperture area of approximately 1.5 square inches (a 0.5" X 3.25" vent) placed in the top of the fixture, thermally-induced light output losses are reduced to about 3%, while optical losses due to the aperture's size are only about 4%. In an enclosed recessed fixture, housing two, 13-watt, twin-tube bulbs, light output and efficacy losses are noted at 18%; both of these decrease to only 2% losses with two, small, lower vents and a larger, upper vent introduced to the fixture. In a smaller, enclosed, recessed downlight, housing two 7-watt bulbs, losses for both the light output and efficacy of the fixture are originally noted at 10%; with three vents introduced to the fixture (in the same configuration as the other enclosed fixture), light output reached 98% of maximum, and lamp efficacy reached 96% of maximum.

These experiments indicate that significant increases in both light output and efficacy in thermally-constricted compact fluorescent fixture systems can be achieved through the use of convective venting.

ACKNOWLEDGMENTS

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