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VARIATIONS IN CONVECTIVE VENTING TO INCREASE THE EFFICIENCY OF COMPACT FLUORESCENT DOWNLIGHTS

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Abstract--**In most compact fluorescent recessed downlights, hot air stratifies within the fixture, causing the lamps to overheat and lose up to 25% of light output and efficacy. Thermal management techniques, including passive venting of the fixture, are being developed to mitigate these losses in fixture efficiency. This paper demonstrates a sequence of venting configurations and techniques, from an unmodified compact fluorescent downlight as a control fixture, through a series of venting strategies, to the development of a highly efficient downlight that incorporates a new angular concept in convective venting. With this new venting design, an increase in light output of nearly 25% can be attained without the optical losses generally associated with some venting geometries.**

I. INTRODUCTION

Compact fluorescent fixtures are rapidly gaining acceptance in commercial lighting applications. These systems are used primarily to replace incandescent sources in both new construction and as retrofits in existing buildings. The principal advantages of compact fluorescents are the energy savings associated with their increased efficiency and the reduced maintenance costs associated with their longer life. However, compact fluorescent lamps are often used in fixtures that have been originally designed for incandescent sources. Unlike incandescents, fluorescents are highly sensitive to ambient temperature, and the highly constrictive thermal environment typical of most downlight fixtures can generate significant losses in the light output and efficacy of fluorescent downlights.

The light output of a fluorescent lamp is determined by the mercury vapor pressure within the lamp. The mercury typically condenses at the coldest spot on the lamp wall. Since the minimum lamp wall temperature (MLWT) at this coldspot controls the mercury vapor pressure within the lamp, the thermal environment surrounding the lamp has a great effect on the system efficacy and light output. As a fluorescent lamp is operated within a constrictive downlight housing, the ambient air within the fixture heats up and stratifies, so that the warmest air remains near the top of the fixture. In compact fluorescent fixtures, the coldspot is generally at the tips of the lamp, away from the heat-generating ballast and electrodes at the base of the lamp. But in many downlight applications, the lamps are housed horizontally near the top of the fixture, so that the lamp cold spots are located in the warmest ambient of the fixture. The light output is maximum when the optimum MLWT is attained. But in such a constrictive downlight fixture, the MLWT exceeds the optimum, and the lamp loses efficiency, incurring up to a 25% loss in light output. Methods of thermal management are being developed to cool the overheated lamps, thereby increasing the lamp's light output and efficacy. One such method is convective venting.

Convective venting techniques involve inserting apertures in the upper portion of the fixture housing to promote a passive ventilation through the fixture. Warm air is allowed to escape through these upper vents, while cool air is drawn in through the bottom of the fixture, cooling the internal fixture ambient. With proper positioning of the vents and fixture, the convective air flow can be made to pass directly over the lamp's cold spots, further reducing the MLWT at these critical locations and bringing the stabilized light output to within 1%-2% of maximum. Previous work [1,2] has already demonstrated these results, but also aroused some concern regarding the optical losses through the vents. This paper goes one step further in presenting a sequence of convective venting techniques, and demonstrates that with an angular displacement of the lamp compartment within the fixture, this near 100% recovery of lost light output can also be achieved with none of the optical losses generally associated with venting techniques.

II. EXPERIMENTAL METHODOLOGY

A series of four venting experiments is conducted to evaluate various venting geometries. A double, 26-watt, quad-tube recessed downlight is used in these experiments. The fixture system consists of a spun aluminum reflector, horizontal lamp compartment and holders, and side-mounted, core-coil ballasts. The lamps used in the fixtures are initially seasoned for at least 100 hours to minimize any errors caused by lumen depreciation. The fixture is housed in a simulated ceiling and plenum chamber and powered through a voltage stabilizer. Prior to any experimentation, each fixture system is operated in place for a 24-hour period to ensure the establishment of a stable coldspot. The fixture is then allowed to cool completely before beginning the experiment. Experiments are run and data is collected over a minimum of 10 hours. Light output, power input, and fixture and ambient temperatures are monitored over the duration of each experiment. Light output is evaluated by a Licor light sensor placed directly below the fixture and aligned with its center axis. Temperatures are taken with type T thermocouples attached to various fixture components or suspended in either the lamp's internal compartment or the external plenum. Input system wattage is monitored with an Ohiosemitronic watt transducer that converts power wattage to a DC voltage signal. All light, temperature, and power data is collected on a multi-channel data acquisition system with hardware and software from National Instruments. Fig. 1 depicts this experimental set-up.

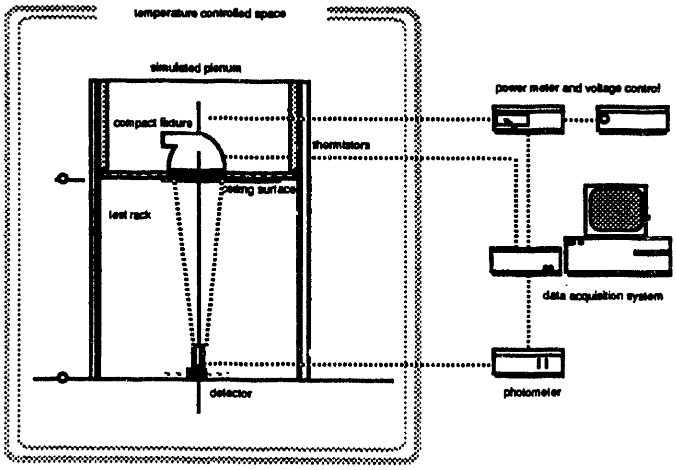

Fig. 1. Experimental set-up featuring a simulated ceiling and plenum system and a data acquisition system.

Experimental results are expressed in terms of changes in light output over time. The maximum light output is generally determined within the first fifteen minutes of the experiment. Light output data is normalized to this maximum and expressed as a percent. By comparing the relative changes in light output for the different venting configurations, the effective venting geometries can be identified.

Tests are initially conducted on an unmodified fixture with no venting apertures. This set of data will serve as the reference or control set for future experimental runs on modified fixtures. Fig. 2 illustrates the fixture's unmodified configuration, featuring the principal components of the fixture assembly and the horizontal positioning of the lamps, as well as the constrictive geometry in the upper portion of the lamp compartment.

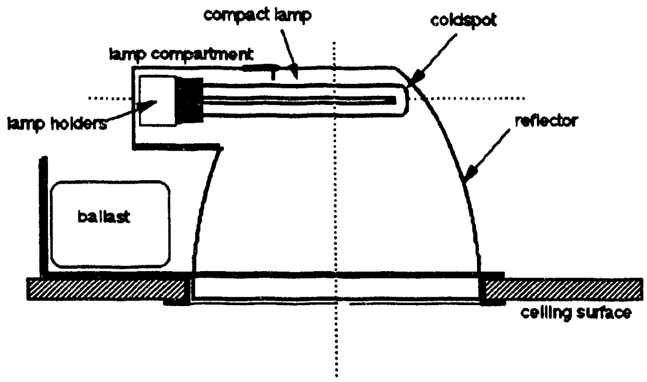

Fig. 2. Cross section of unmodified, double 26-watt, recessed downlight, illustrating the location of the lamp cold spots, and the horizontal placement of the lamps.

The fixture is then modified to incorporate a front and back venting geometry. The front apertures are located directly in front of the ends of the lamp to create an air flow passing directly over the lamp cold spots. The back venting apertures are placed in the upper portion of the lamp compartment above the filament and socket region of the lamps where most of the heat is generated. Fig. 3 shows a cross section of the modified fixture with a front and back venting geometry. The flow pattern through the lamp is also depicted.

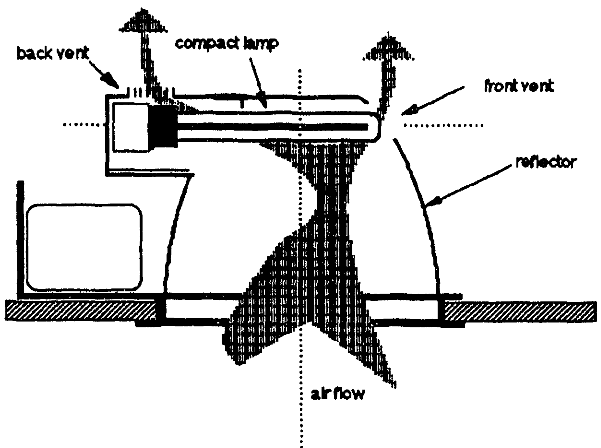

Fig. 3. Cross section of the modified fixture with front and back venting geometry, illustrating the flow pattern through the lamp.

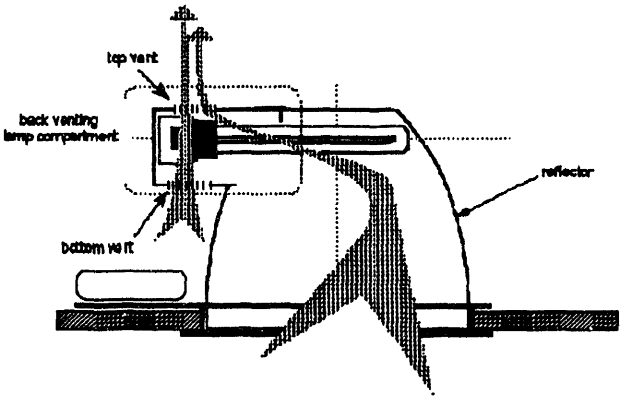

Fig. 4. Cross section of modified fixture featuring an enhanced back venting geometry and two convective flow paths.

One of the advantages of this venting geometry is that the front apertures create an air flow which directly cools the coldspot region. However, these front apertures also allow significant amounts of light to escape into the plenum instead of being reflected to the target area below the fixture.

The third configuration tested is designed to eliminate the optical losses produced by front apertures. In this venting geometry, apertures are placed only in the rear of the fixture, in the lamp holder assembly. The vents are placed in the top and bottom of the lamp holder assembly to promote two convective flows, one directly through the lamp holder assembly, and the other, through the entire fixture compartment. The first path cools the socket and filament area, the warmest area in the fixture, thereby minimizing the heat transfer down the lamps to the cold spots. The second ventilation path cools the whole lamps and the entire fixture compartment, drawing cool external air in through the bottom of the fixture, and allowing the warm air to escape through the upper vent in the lamp holder area. By aggressively venting the back portion of the lamp holder assembly, the enhanced back venting configuration creates a pressure difference between the socket region of the lamp compartment and the rest of the fixture. The small suction force created increases the convective air flow through the whole of the fixture. Fig. 4 illustrates this enhanced back venting geometry with the ventilation paths generated.

The fourth fixture system tested involves a new concept in fixture modification. The previously described enhanced back venting geometry is again employed; but in this new configuration, the lamp compartment is tilted by 5°-10° from the horizontal so that the lamps slope downward and the lamp cold spots are at the lowest point of the lamp. This sloping serves several purposes. First, because the lamps are tilted downward, the lamp cold spots at the tips are lower within the fixture compartment, and are therefore in a cooler ambient, promoting a lower MLWT. Secondly, the downward sloping allows gravity to act on the condensed mercury within the lamp, promoting mercury beading at the lamp tips, which are now the lowest part of the lamp, and further aiding in the establishment of a stable coldspot at the MLWT. The downward sloping of the lamps also means that the venting apertures are now at the highest point of the compartment. The hottest air within the chamber naturally collects at the highest point, so that vents placed in this location will enable the hot air to exit the chamber more easily than in the straight horizontal configuration. The sloped surface at the top of the compartment also ensures a smoother and more efficient air flow through the chamber and out the vent. This new design of enhanced back venting with a lamp compartment tilt combines all of the basic concepts involved in thermal management and convective cooling: establishing a stable coldspot as easily as possible at the lowest possible MLWT, and employing passive ventilation to continually maintain optimum conditions. Fig. 5 illustrates this design and the two ventilation paths created.

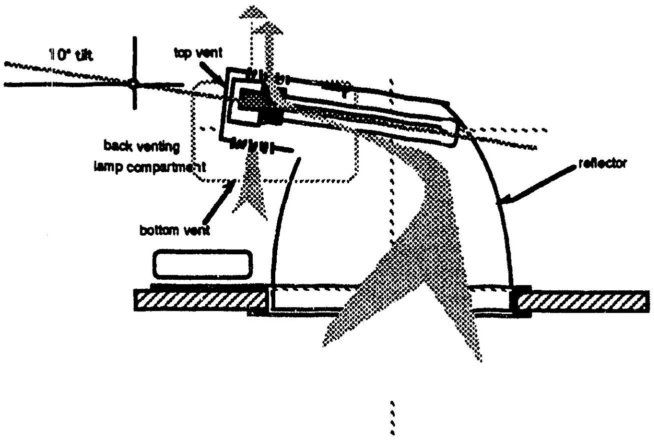

Fig. 5. Cross section of modified fixture with enhanced back venting and a tilted lamp compartment.

III. EXPERIMENTAL RESULTS

The changes in light output for the unmodified, double 26-watt, compact fluorescent recessed downlight are shown in Fig. 6. Light output reaches a maximum within the first few minutes, then drops sharply. Within 30 minutes, the fixture has already lost approximately 25% of its light output.

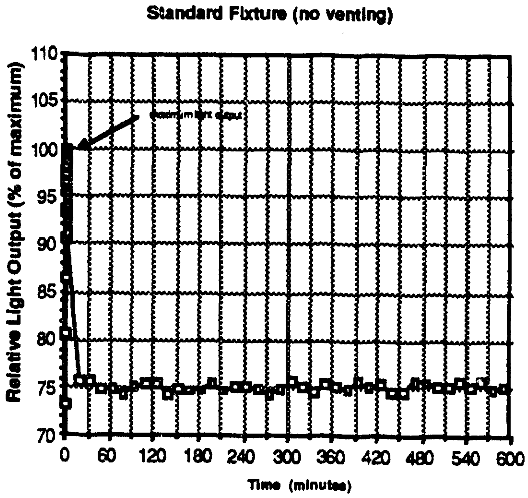

Fig. 6. Changes in light output over time for an unmodified double 26-watt CF recessed downlight.

Fig. 7 illustrates the results obtained with the first fixture modifications involving the insertion of front and back venting apertures in the upper fixture housing. After approximately 30 minutes, the fixture reaches a stabilized light output of 97%-98% of maximum, indicating the strong cooling effects associated with this venting geometry.

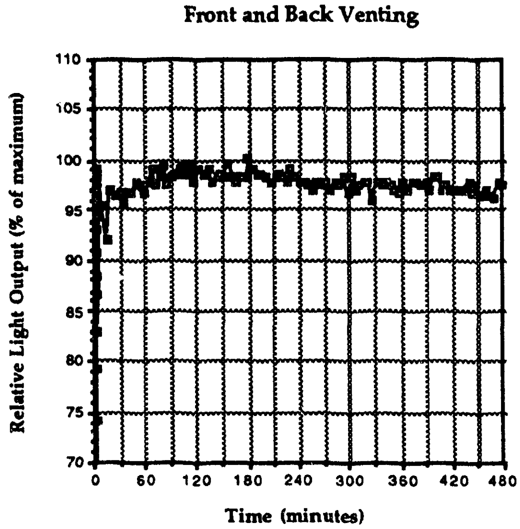

Fig. 7. Light output data obtained with a downlight modified to incorporate front and back vents.

The next series of experiments involves an enhanced back venting configuration. Fig. 8 depicts the experimental results obtained with this modified, vented fixture. After the first 30 minutes, light output stabilizes at approximately 93%-94% of maximum, indicating an increase of nearly 20% in the stabilized light output as compared to the unmodified fixture. Although this configuration is not as thermally efficient as the front and back venting geometry, it eliminates the problem of optical losses incurred with front apertures.

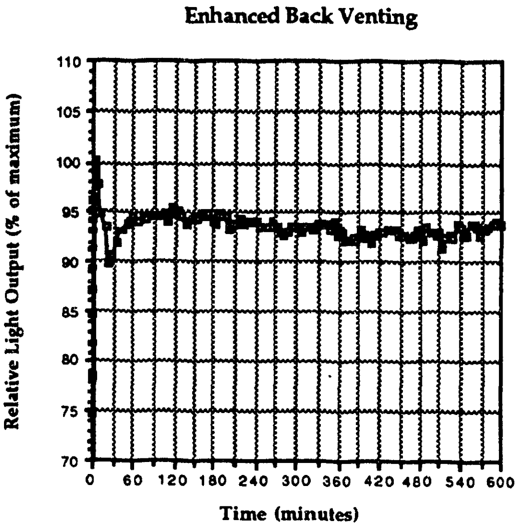

Fig. 8. Light output data obtained with a downlight modified to incorporate an enhanced back venting geometry.

The configuration featuring the enhanced back venting with a tilted lamp compartment is then tested. With the lamp compartment housing at a 5°-10° tilt, the stabilized light output is maintained at 98%-99% of maximum, indicating a 5% increase in light output over the enhanced back venting alone. Fig. 9 illustrates the results obtained with the enhanced back venting and tilted lamp compartment configuration.

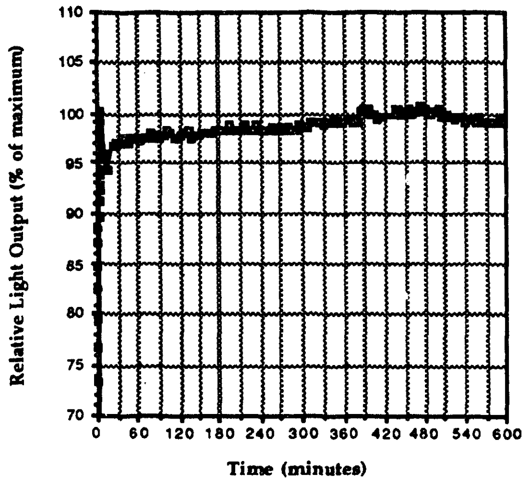

Fig. 9. Light output results from the enhanced back venting with tilted lamp compartment venting configuration.

The results obtained from this tilted and vented geometry represent the most significant improvements in light output recovery, showing an increase in light output of nearly 25% as compared to an unmodified downlight. The thermal performance of the tilted configuration slightly exceeds that of the front and back venting geometry, and additionally, incurs none of the optical losses produced by that geometry.

IV. ANALYSIS AND DISCUSSION

As previous research work has already shown [1,2], convective venting has a marked effect on improving fixture performance, increasing the stabilized light output of a recessed downlight by over 25% as compared to a standard, unvented fixture. These improvements result directly from the lower ambient temperature within the chamber and the lower lamp wall temperatures that enable more sizable and efficacious coldspots to develop. Of the first three geometries tested, the combined front and back venting configuration was the most effective in increasing thermal efficiency. The two convective air flows produced by this venting scheme act directly to cool the areas of the fixture that most influence fixture performance: the heat-generating filament and socket region, and the heat-sensitive lamp tips where the cold spots form. However, using front venting apertures creates the potential for optical losses through the reflector; light may be lost to the plenum space rather than being directed to the target area below the fixture. These optical losses may approach 10%, significantly reducing the efficiency gains associated with convective venting, and making the advantages of this venting geometry questionable.

The enhanced back venting geometry eliminates the potential for optical losses through front venting apertures. The aggressive back venting induces a pressure differential within the compartment, promoting an air flow through the fixture nearly comparable to that produced by the combined front and back venting. Comparatively, an enhanced back venting configuration runs at 94% of maximum light output whereas the combined venting geometry runs at 98% of its maximum light output. Although the gains in light output with enhanced back venting do not appear as significant as those obtained with front and back venting--a 19% gain versus a 23% gain, respectively--the apparent lower thermal efficiency of the enhanced back venting configuration is offset by an increase in optical efficiency since no light is lost through front apertures.

Finally, with the combination of the enhanced back venting and the tilted lamp compartment, nearly all of the light output lost in the standard, unmodified fixture is recovered. The vented fixture operates at 98%-99% of the maximum light output, reaching an optimum thermal and optical efficiency as no light is lost through front apertures and nearly all thermal losses are expiated by the improved convective flow. The additional 5% recovery in light output as compared to the enhanced back venting alone is due to the tilting of the lamp compartment. The tilting lowers the cold spots into a cooler region, facilitates the formation of the cold spots at the tips of the lamp, away from the hot filaments, and promotes a more natural convective flow of the hot air by making the vented area the highest part of the compartment. Back venting in the rear of the lamp compartment over the socket region does not pose the problem of optical losses, as this rear portion is an optically inefficient area for both the lamp and reflector. This back venting and tilting solution therefore optimizes the convective cooling of the fixture while eliminating the risk of optical losses usually associated with venting apertures.

Several issues, however, still need to be addressed with this new venting configuration. Among these are the offset target area of the downlight produced by the 5°-10° tilt of the lamp compartment. Additional studies are needed to measure the changes in the optical distribution of the luminaire incurred with this tilting. An optimum angle has yet to be identified that will maximize the benefits of this design while minimizing the optical distortion produced by the tilting. It is assumed that this angle will vary with fixture type, depending specifically on the fixture's geometry, thermal characteristics, optical design, and application. Also, as the convective flow is improved with a sloped upper housing, part of the fixture assembly will have to be redesigned to make the slope of the upper surface as smooth as possible. Such issues will have to be addressed with more specific goals and limitations in order to successfully implement the concept into an actual working product. These would appear, however, to be only minor design and manufacturing adjustments for such a large improvement in fixture efficiency.

V. CONCLUSION

This paper was intended to present a range of possible venting geometries, and to introduce the new concept of combining lamp compartment tilting with convective venting to further increase the benefits of an enhanced back venting configuration. The use of any of the convective cooling techniques presented in this paper will result in large increases in lamp light output and system efficacy. However, the key issue in using convective venting as an effective thermal management technique is to maximize the thermal advantages of the venting configuration while reducing or eliminating the optical losses produced by openings in the envelope of the fixture or reflector. As it was shown in this paper, with the proper design and positioning of a convective venting geometry within a particular fixture, all of the benefits of a thermally-efficient fixture can be obtained without compromise in optical efficiency.

As recessed downlights have widespread use in commercial applications, such large improvements made in the efficiency of these fixtures would have great repercussions on commercial energy demands. The additional lumens obtained from these fixtures would make fluorescent downlights as or more attractive than their incandescent counterparts in renovation and new construction projects. Not only does this result in a large savings in energy, but the increased light output means that fewer fixtures are required in the initial installation, thereby also producing a large savings in first costs and maintenance.

V. ACKNOWLEDGMENTS

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[2] OSRAM. DULUX Compact Fluorescent Handbook. A4.2, p.11. 1992.

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