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M. Siminovitch, A. Hamilton, C. Zhang, and R. Verderber

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Michael Siminovitch, Andrew Hamilton, Chin Zhang and Rudy Verderber

Lighting Research Group
Energy and Environment Division
Lawrence Berkeley Laboratory
Berkeley, California 94720

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Lighting Research Group
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Abstract: An experimental protocol and apparatus was developed to assess the relative differences in dirt depreciation between vented and unvented compact fluorescent recessed downlights under simulated conditions. A simulated plenum/ceiling chamber is designed to expose both vented and unvented fixtures simultaneously to a controlled dust environment over an extended period of time. Experimental data shows that the unvented fixture depreciated faster over time due to dust exposure than the vented fixture.

I. INTRODUCTION

Compact fluorescent fixtures are seeing increased application in the lighting of commercial interiors. The increased application is due to the higher efficacy and the potential for increased lamp life relative to incandescent sources. However, most compact fluorescent downlight fixtures present a highly constricted thermal environment to the temperature sensitive compact fluorescent lamp. According to previous studies the losses in lumen output can be as high as 20% [1-3]. One of the emerging techniques for mitigating the thermal losses is convective venting. This technique involves the use of strategically located apertures in the recessed downlight to promote passive ventilation through the lamp compartment into the plenum. This passive ventilation removes heat from the lamp compartment allowing the lamp to operate in a significant cooler environment. The increases in lumen output can approach 20%. Fig. 1 shows a schematic cross section of a compact fluorescent fixture with the convective venting pattern to cool the lamps.

One of the major concerns associated with the application of convective venting is the potential for increased dirt depreciation as room air is drawn into the fixture. Increased ventilation through the fixture may cause particulate matter to settle on the reflector and lamp surfaces, reducing the output of the fixture over time possibly negating some of the potential benefits associated with convective venting.

To address this concern, an experimental approach and apparatus were developed to qualitatively assess the relative dirt deprecation rate of convectively vented compact fluorescent fixtures compared to that of the standard unvented fixtures.

This paper describes the apparatus and methodology and presents data on the relative performance of two identical fixtures operating with and without convective venting in a simulated dust chamber.

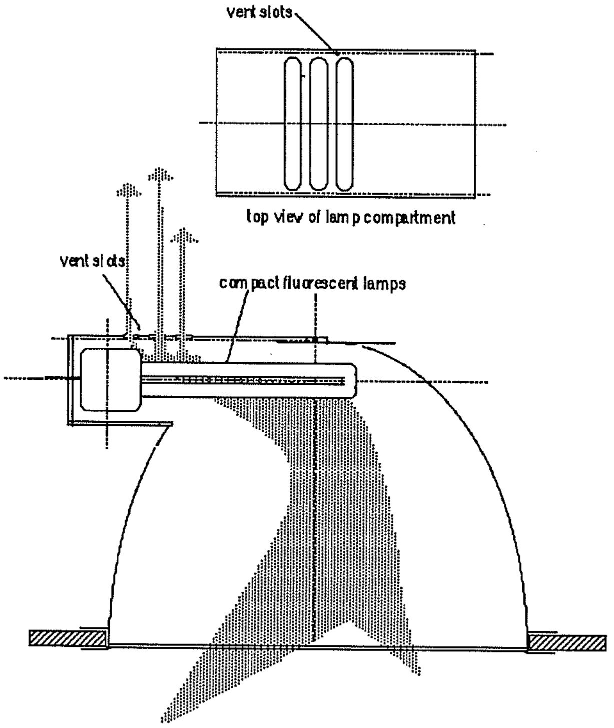

Fig. 1 Cross section of compact fluorescent fixture with convective venting

II. BACKGROUND

The dirt depreciation curves for fixtures found in the IES Handbook [4] were compiled from theory and measurements collected prior to 1970. Nearly all of the work was based on on-site dirt depreciation experiments in offices and industrial spaces [5-11]. There are two reports discussing laboratory measurements using different dust materials [8,15] and two applied calculations of dirt depreciation curves [13,14]. Two studies [7,9], showed that open, vented fixtures have less dirt depreciation than unvented fixtures: one [9] studied fixtures in the T-12 family and the other [7] studied high intensity discharge luminaires. Since then, there has been little experimental data published on dirt depreciation of fixtures and little, if any, was collected for CFL fixtures.

From the literature search, it was determined that no protocols or apparatus currently exists that would allow for an assessment of the relative dirt depreciation associated with convectively vented compact fluorescent fixtures; therefore a new apparatus and protocol would have to be developed. The objective of this protocol was to assess the relative differences in dirt depreciation between vented and unvented compact fluorescent fixtures using a simulated dust environment. The hypothesis in this work is that the relative potential for accelerated dirt depreciation due to venting can be estimated by exposing a pair of vented and unvented fixture simultaneously to a dust concentrated environment over a specific period of time.

III. EXPERIMENTAL APPARATUS

A simulated plenum and ceiling surface were constructed within a dust proof chamber to evaluate the relative dirt depreciation for vented and unvented compact downlights. Fig. 2 shows a schematic of the dirt depreciation chamber. The rectangular chamber measures 5' x 5' x 6'. The front face is a transparent Plexiglas door that allows observation of the process. The horizontal ceiling plane, which divides the chamber into two spaces, contains two apertures to mount the fixtures and four ceiling vents in the corners to prevent any pressure build up during the operation. On the top of the chamber, there are eight air filters evenly distributed on each side. The filters were designed to prevent pressure build up in the plenum (space above the ceiling plane) and dust escaping to the outside as air is injected or during the dust exposure period.

The bottom of the chamber contains a dust box that holds the particulate material (dust) to be circulated in the chamber.

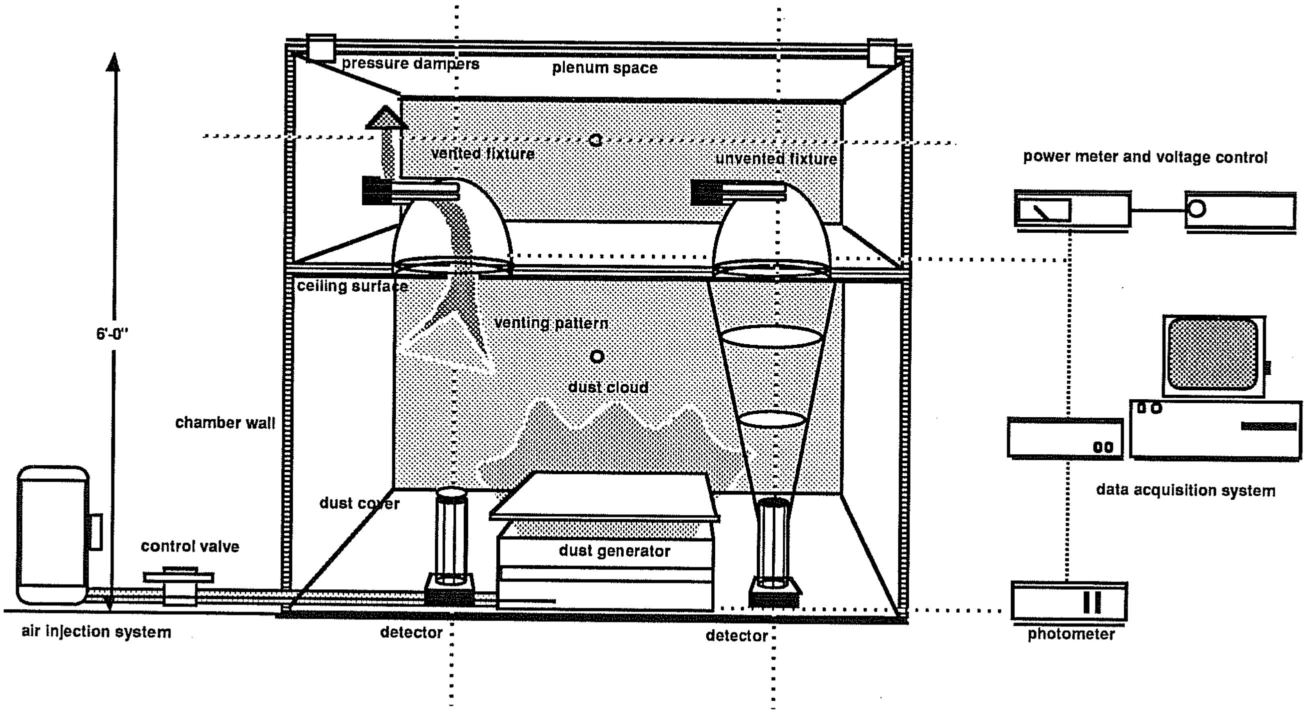

Fig. 2. Dirt Depreciation Chamber; Dust Box; and the Acceptance Cone for Light Sensor

The dust is introduced into the air volume by a very slight pulse of air through a specially designed air supply system. A blower is connected to two valves, one letting air exit the system and the other feeding air into the dust box. This valve arrangement allows for fine tuning of the air injection system. The injected air enters into the box and exits through the pipes to agitate the dust into the air volume. To assure a more uniform distribution of dust throughout the bottom chamber, a dust mask is placed about an inch above the opening of the box, and numerous holes are evenly placed on the pipe underneath the dust. The ceiling vents are opened when the blower is on and closed during the exposure period to reduce pressure differentials. The particulate matter was a finely powered Portland cement that is easily taken up within the air volume inside the chamber.

Two Tektronix J6511 illuminance heads are mounted directly below the fixtures to measure the changes in the light output *in-situ.* The illuminance heads are color and cosine corrected and positioned three feet below the ceiling plane. Each photocell has a tube that restricts the solid angle to prevent the photocell from viewing any area other than the light emitted directly from the open area of the light fixture above it. Light rays reflected from the chamber walls will not be measured since the tube wall is black and will absorb all light entering the tube outside the acceptance cone. See Fig. 2. A movable cap on top of the restrictor tube prevents any dust from entering the photocell system during dust exposures, and allow light output to be measured when removed. The output of the photocells are fed into a Tektronix J-16 photometer to read the light levels. Because the distance between the photo-head and the fixture aperture is more than five times the fixture aperture diameter, the photometer readings can be multiplied by the distance squared to obtain the nadir candlepower for each fixture.

IV. EXPERIMENTAL METHODOLOGY

The experiment used two identical, commercially available recessed downlight fixtures with two horizontally mounted 13-watt compact fluorescent lamps each. The lamps were all seasoned for a period of at least 100 hours. Both fixtures employed a convective venting geometry, which consisted of a series of linear apertures situated on the back of the lamp compartment assembly, to reduce lamp temperatures. The linear apertures of one unit were sealed to replicate a standard unvented fixture geometry.

Figure 3 shows an overview of the procedure. During each experiment both fixtures were exposed simultaneously to a controlled dusty environment over an extended period of time. After an initial calibration, light output was measured at periodic intervals throughout the experiment to assess the relative changes in light output. Any differences in the relative light output over time would occur due only to the difference from the convective venting.

For each experiment, both fixtures were energized for one hour prior to the beginning of dust injections; this is to allow a steady state thermal equilibrium to be established. Each dust injecting consisted of a pulse of air lasting about five seconds. One such pulse is sufficient for a four-hour dust exposure after which the dust tended to settle completely out of the air volume surrounding the fixtures. Then another five second air burst would be applied to provide a suitable dense dust environment. The injections of dust filled the lower part the bottom chamber and slowly diffused, uniformly filling the entire bottom chamber. The dust would then slowly rise and enter both fixture openings, but only exit through the top vents in the vented fixture. The flow of dust-laden air through the convectively vented fixture was observed to be near laminar and continuous. Each interval between light output readings consists of several dust injections, and resulted in a net exposure of approximately 10-12 hours between each light measurement. However, there was no way to determine how much dirt was consistently introduced during each injection.

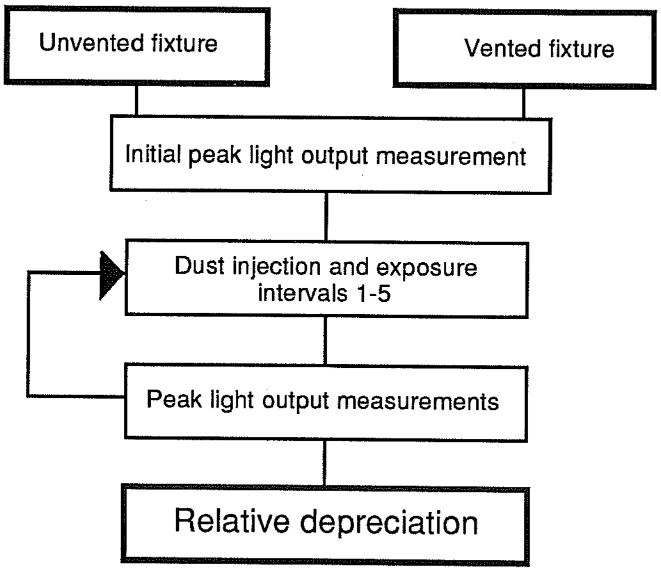

Fig. 3. Overview of experimental procedure

For each light output measurement, the lamps are turned off to cool completely and to allow for the dust to settle within the chamber. One at time, the caps covering the photocells are removed, and fixtures were turned on to measure the relative light output. As each fixture is energized, the light output increases to a peak within the first few minutes, and then starts to decrease due to overheating within the lamp compartment. The peak light output is recorded. This procedure was repeated (after a cooling period) three times for each fixture to ensure the peak light level reading is consistent. Except for the initial readings, these measurements are taken after roughly twelve hours of dust exposure. The initial light levels (no dirt exposure) serve as a base case for comparison to later peak light output measurements. The ratio of the current peak value over the initial, times 100%, is considered the relative light output (RLO), and is an indicator of the relative dirt depreciation.

The complete experiment with the dust injections was conducted twice for a period of approximately 45 and 60 hours respectively. The second experiment was run over a longer period time with added dust injections at each interval. Between each experiment, the fixtures were completely removed and cleaned. The chamber was also completely cleaned and reset. After the chamber was cleaned and fixtures were reinstalled, the experiment was repeated using a new set of initial values for light output. The fixtures were interchanged in terms of position within the chamber in case there was an asymmetry within the dust chamber.

V. EXPERIMENTAL RESULTS

Fig. 4 and 5 shows the variations in relative light output over the duration of 45 and 60 hour experiments. The X-axis gives the interval number. At each interval, the light output for both fixtures was determined after an injection of particulate matter within the chamber (excluding the initial reading).

Fig. 4 shows the reduction in light output corresponding to the 45-hour experiment. The light output for the unvented fixture in the 45 hour run shows an increased rate of deprecation over time reaching a maximum of 11%. The vented fixture also shows a depreciation over time but at the slower rate reaching the final deprecation of approximately 8%. Thus the light depreciation of the vented fixture was about 3% less than for the unvented fixture.

Fig. 5 shows the reduction in light output for the second experiment which was run for approximately 60 hours with more dust injections at each interval. The unvented fixture shows a final reduction in light output of approximately 17%. Again, the vented fixture shows a similar but slower rate of dirt depreciation reaching a final value of approximately 14%. The difference between the two was again approximately 3% providing some evidence that the methodology used is reproducible.

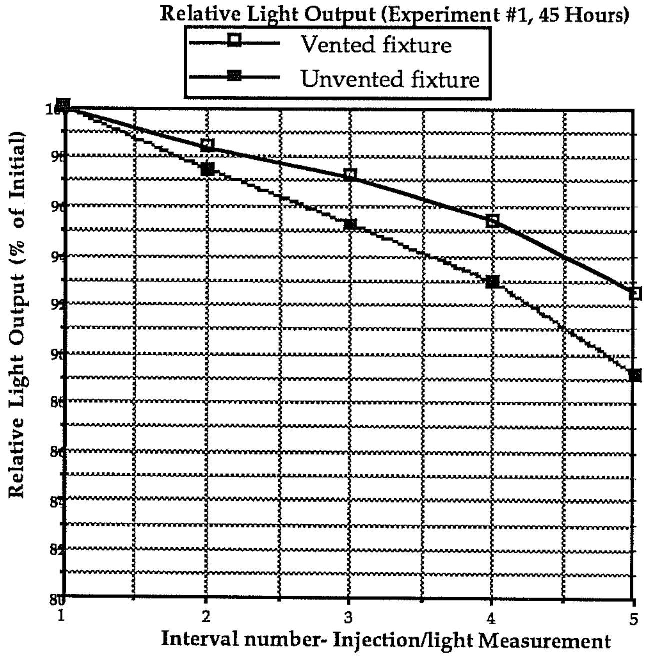

Fig. 4. Light output losses for vented and unvented fixtures over 45 hours

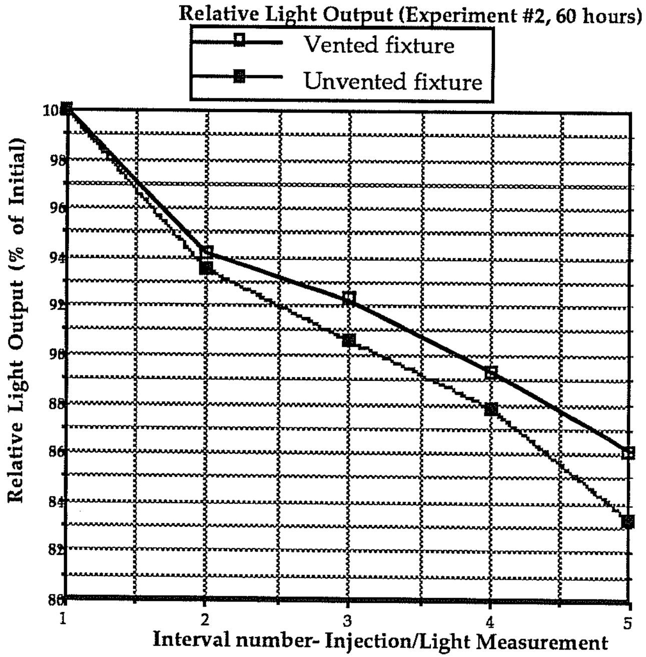

Fig. 5. Light output losses for vented and unvented fixtures over 60 hours

VI. DISCUSSION

The experimental data indicates that the rate of dirt depreciation is slightly reduced with the use of convective venting. For both series of experiments, the vented fixture shows slightly reduced rates of depreciation in comparison to the standard unvented fixture configuration. These data are in agreement with the results of previous published claims for vented fixtures [7,9]. The air flow through the vented fixtures prevents the rising, dust-laden air from stratifying in the luminaire and depositing dust on the fixture internal surfaces. During the experiments, the convection patterns through the ventilated fixture could be easily observed as the air stream leaving the fixture contained particulate matter that was removed from the fixture compartment. Observed convection patterns within the unvented fixture indicated a stratification within the lamp compartment, potentially leading to the increase in dust accumulation on the lamp and the internal reflecting surfaces.

After each experiment, the fixtures were removed from the chamber, inspected, photographed and then cleaned. Inspection of the fixtures revealed that the unvented fixture had visibly more dust build up on the internal components of the reflector and lamp compartment housing. This dirt accumulation on the internal surfaces reduced the reflectance of the fixture surfaces resulting in the observed loss in light output.

The light output assessment was based on a single measurement below the fixture at nadir. We have used the candlepower directly below the luminaire (nadir candlepower) as the estimate of the fixtures relative light output. However, if dirt is deposited non-uniformly over the lamp and interior fixture surfaces, the relative candlepower distribution may change slightly, reducing the accuracy of nadir candlepower alone as an indicator of the fixture's changing lumen output. Candlepower distribution measurements with a goniophometer are required before nadir candlepower can be adopted as the basis of developing dirt depreciation functions. Nonetheless, the simple method used is sufficient to demonstrate that convectively venting compact fluorescent downlights to improve energy efficiency can be achieved without suffering a penalty in increased dirt depreciation.

This approach does not assess the potential for changes in specularity of the reflector or the potential changes in the candlepower distribution due to dust build up at different part of the reflector. In order to conduct a complete assessment of the changes in lumen output and distribution characteristics, additional photometric measurements would be required, i.e., additional light measurement off the central axis. The protocol developed is based on the hypotheses that the simultaneous exposure of the vented and unvented fixtures will represent an estimate of the relative depreciation rates. It allows only for the assessment of convection with regard to depreciation. The experiment does not replicate all of the different types of air borne material or the time rates of exposure.

VII. CONCLUSION

Convective venting strategies do not appear to adversely accelerate the rate of dirt depreciation; in fact, the convection patterns tend to reduce dirt depreciation by removing particulate matter from the lamp compartment. This conclusion is important in the development and acceptance of convective venting strategies to minimize the thermal losses with constricted thermal environments for compact fluorescent lamp. Additionally, the experimental approach represents a potentially useful technique for the relative testing of small compact fluorescent fixtures under simulated conditions.

VIII. ACKNOWLEDGEMENTS

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