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An Investigation of the Effect of Operating Cycles on the Life of Compact Fluorescent Lamps

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Abstract

While compact fluorescent lamps (CFLs) and associated ballasts are undergoing rapid development in the US, and manufacturers and energy advocacy groups promote them as having lifetimes greater than ten times those of incandescent lamps, little public data exist to verify long-term performance characteristics of these products. Furthermore, the standard life testing procedure of 3 hour-on and 20 minute-off cycles requires many months to assess long-term impacts, and may not be representative of the conditions in which the products are actually used.

This paper describes the life testing results for a total of 11 different screwbase CFLs from six different lamp manufacturers. The testing was conducted by using five different operating cycles. The authors analyze the effect of different on and off time on lamp life.

1. Introduction

As direct replacements for incandescent lamps, screwbase compact fluorescent lamps (CFL) provide higher operating efficiencies and longer lamp lifetimes. Previous work by the authors documented many aspects of the initial performance of these products (Davis, Ji and Luan 1994; Ji and Davis 1993). However, the higher cost of the CFL products poses a significant barrier to their widespread use in residences. Economic justification for using CFLs instead of incandescent lamps is very sensitive to the assumptions made for lamp life. Usually, these assumptions are based on manufacturers' life ratings, which may or may not be representative of actual performance in realistic applications. Furthermore, the rapid evolution of these products means accelerated methods for determining lamp life are needed, and so some manufacturers have developed rapid-cycle techniques to predict lamp life.

This paper describes an ongoing project in which CFL products are being tested under different operating cycles, and reports the effect of different on and off time on the lamp life of screwbase CFLs.

2. Life testing methods

Fluorescent lamp life is determined by the loss of the electron-emitting coating on the electrodes (Waymouth 1971). Some of the coating is eroded from the electrodes each time the lamp is started; additional evaporation and erosion also occurs during lamp operation. Electrode temperature directly affects the evaporation and erosion of the emitting material, and so affects lamp life. Very high electrode temperature will reduce lamp life due to evaporation of the emitting material, and a low electrode temperature will reduce lamp life due to erosion of the emitting material by sputtering.

For determining the rated life of fluorescent lamps, the Illuminating Engineering Society of North America (IESNA) specifies a test method of operating a large sample of lamps on a 3 hour-on and 20 minute-off cycle and determining the median time until failure (IESNA 1991). Little has been published on how different operating cycles affect fluorescent lamp life. Vorlander and Raddin (1950) operated groups of fluorescent lamps on seven different cycles and provided data on the relationship between operating hours per cycle and the average life of fluorescent lamps. Figure 1 shows their data, and illustrates that shorter cycles reduce the life of a fluorescent lamp. Figure 1 also shows the potential for establishing a predictive relationship between short-cycle tests and standard tests. However, their data were collected for lamps from the 1940s, and they do not address cycles of less than 0.5 hour-on or 20 minute-off.

Recently, some manufacturers (Garbowicz 1994) have used rapid-cycle methods to reduce the time required for life testing. The methods make use of varying on-off cycles, such as: 10 second-on and 10 second-off; 40 second-on and 20 second-off; 5 minute-on and 5 minute-off; and 15 minute-on and 5 minute-off. However, the nature of the relationship between the rapid cycles and the IESNA method has not been determined.

Rapid-cycle tests with very short off times may be unreliable as a test method because the damage to the lamp electrodes during starting may differ from what would occur in an application, since the lamp electrodes may not cool completely during the time the lamp is off. The authors previously reported data (Davis, Ji and Chen 1996) for determining the appropriate off times for rapid-cycle testing techniques. In this previous study, temporal changes in electrode resistance after extinguishing a lamp were measured for five different compact fluorescent lamps. Since electrode resistance relates directly to electrode temperature, the results also indicate the time required for the electrode temperature to stabilize after a lamp has been turned off. The testing results showed that for fluorescent lamps, electrode temperature took about 5 minutes to stabilize after the lamp was extinguished. Thus, the data from very short off times (less than 5 minute-off time) may not correlate to standard life testing data or to actual use, since the lamp electrodes may not cool completely during the time the lamp is off. Based on these results, the authors decided to use 5 minutes as a minimum off time for rapid-cycle testing.

3. Experimental design

For the current project, 11 different screwbase CFLs from 6 different manufacturers are being tested. Table 1 lists the characteristics of the 11 products being tested. The letter used in the product designations indicates a specific manufacturer: products A1 and A2, for example, are two different products from the same manufacturer.

Data reported here are for lamps are being operated on five different operating cycles, selected to represent possible applications of CFLs:

Cycle 1: 5 minute-on and 5 minute-off (under cabinet)
Cycle 2: 15 minute-on and 5 minute-off (bathrooms)
Cycle 3: 1 hour-on and 5 minute-off (dining room)
Cycle 4: 3 hour-on and 5 minute-off (kitchen/living room)
Cycle 5: 3 hour-on and 20 minute-off (kitchen/living room)

For cycles 1 through 3, 8 of each of the products is being tested; the sample size in cycles 4 and 5 is 4. All the lamps were operated in base-up position, based on prior work (Davis, Ji and Chen 1996) showing that operating position had no significant effect on lamp life for screwbase CFLs. Four 6'x3'x5' (LxWxH) lamp racks were built for this study, each with 5 "shelves"; each shelf holds 32 lamps. A 45 kVA voltage regulator (120V ± 0.5%) powers the 480 lamps in operation plus a computer for testing control and monitoring. Ambient temperatures inside the lab are within 25 ± 10 °C.

Lamp starting and operating parameters were measured for one sample of each of the 11 different products. The lamps were seasoned for 100 hours prior to testing. During testing, a LeCroy digital oscilloscope model 9314L, two

Pearson current monitors Model 411, a LeCroy differential probe model AP032, and a Pacific 4.5 kVA AC power source model 345-AMX were used. For lamp starting characteristics, the parameters measured were starting time, cathode preheat current and lamp starting voltage. For lamp operating characteristics, the parameters measured were lamp operating current and current crest factor. Since many of the products are self-ballasted, the lamps and ballasts were separated before testing by cutting the ballast case open and separating the lamp lead wires from the ballast circuit. The testing results are shown in Table 2. These data are important for explaining possible causes for life differences between the products, as discussed in the results section.

4. Testing results and discussion

While the testing is ongoing, the results to date provide interesting insights into the performance of compact fluorescent products. Table 3 shows the median lamp life in hours for the products; blank cells indicate that a sufficient number of lamps for computing the median in that cell have not yet failed. Table 3 also shows that the total operating hours at the time this paper was written were 8412 hours, 12601 hours, 15514 hours, 16377 hours, and 15159 hours for cycle 1, 2, 3, 4, and 5 respectively. Table 4 also presents median lamp life for the same products as Table 3, but in cycles rather than hours.

Two results are immediately obvious: that shorter operating cycles significantly reduced the median lamp life (for the products with complete data), and that some products tested did not meet their rated lamp life, even at the standard 3 hour-on and 20 minute-off cycle. Both of these observations indicate that economic analyses that simply use rated lamp life regardless of operating cycle and without independent confirmatory data are questionable at best

Figure 2 shows the relationship of lamp life to on time for the four lamps that have already reached median lamp life on all of the cycles. This figure illustrates that the lamp life (in hours) was directly related to on time duration. Specifically, lamp life with 5 minutes, 15 minutes and 1 hour on time was about 15%, 30%, and 80% of the lamp life with 3 hours on-time.

Cycles 4 and 5 provide the opportunity to compare the 5 minute-off time to the standard 20 minute-off time. Table 3 shows that, for the lamps where the median life has been achieved in both these cycles, the differences in the number of cycles is small and does not appear to be systematic. This provides further support for using the 5 minute-off time in order to accelerate life testing of CFLs. Table 3 also shows that most of the products met or exceeded their rated life, although two products did not even achieve 50% of their rated life on the standard 3 hour-on and 20 minute-off cycle.

Comparing the results shown in Table 3 with the electrical parameters shown in Table 2 provides preliminary insights into product design. For example, notice that, although products D1 and D2 had current crest factor (CCF) greater than 1.7, they had very long lamp life. ANSI standards (ANSI 1993) currently limit CCF for fluorescent lamps to a maximum of 1.7, since higher CCFs are expected to reduce lamp life. For products D1 and D2, the low lamp operating current relative to other products limits the peak lamp current (even with a higher CCF); this may explain why the lamp life is maintained. Product B2 had high cathode preheat current and very short starting time, relative to other electronic preheat products; its significantly shorter life may indicate that lower preheat currents for a longer starting time are better for the lamp. The authors have found similar results for lamp starting parameters for four-foot linear T8 fluorescent lamps as well (Ji et. al. 1997)

5. Summary

Results from testing a variety of CFL products on different operating cycles demonstrates that life cycle analyses based on manufacturer life ratings may be flawed without independent confirmation of the actual lamp life when operated by the specific ballast, at the operating cycle of interest. Prelim results provide data for estimating lamp life at different operating cycles provide some guidance to ballast designers as to the important design parameters for assuring long lamp life.

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Figure 1. Average Life vs. Operating Hours Per Cycle
(Vorlander and Raddin, 1950)

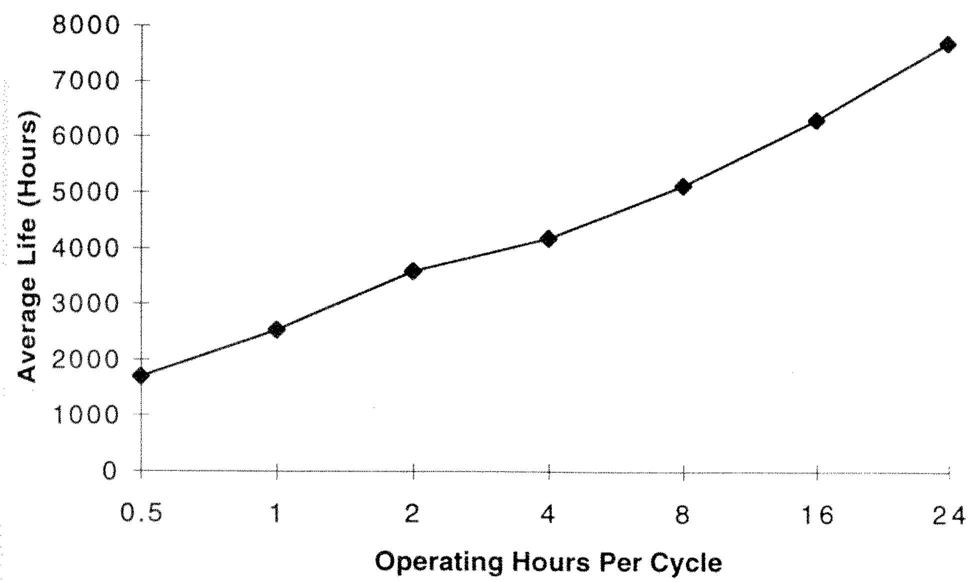
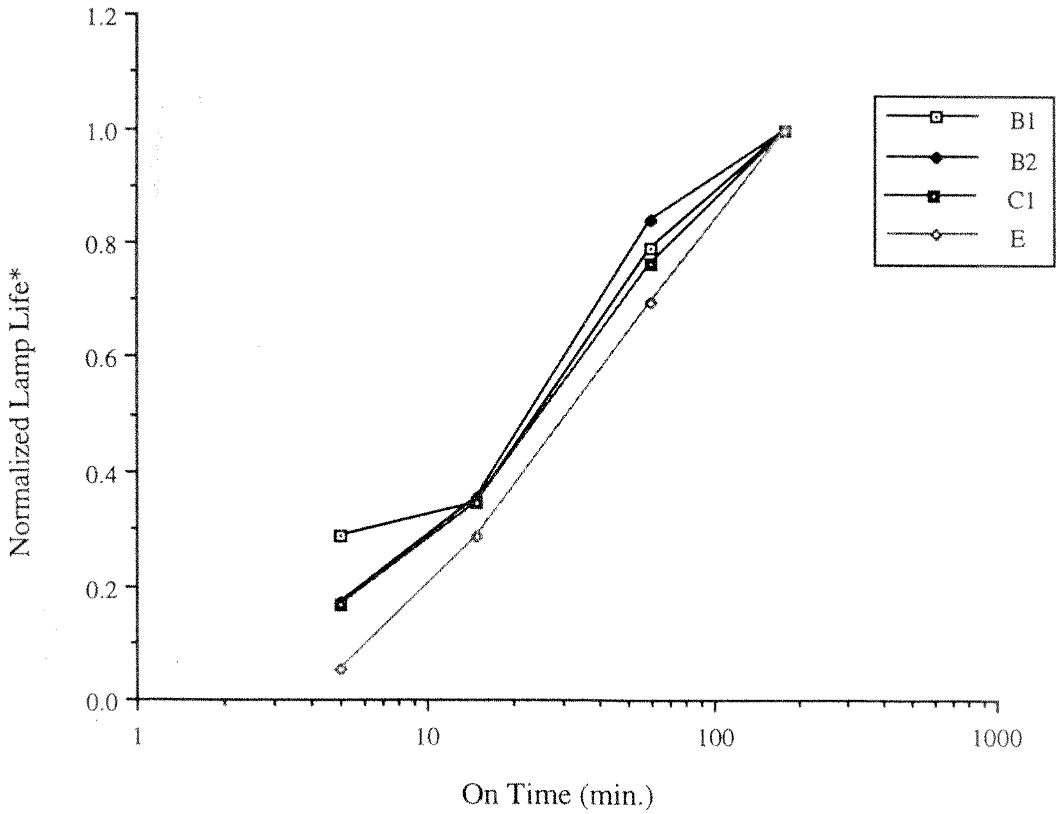


Figure 2. Normalized Lamp Life vs. On Time



* normalized for each product to the 3h/20m lamp life

Table 1. Products Tested

Product Code	Starting Method	Ballast Type	Rated Active Power (W)	Lamp Shape
A1	electronic preheat	electronic	15	triple tube
A2	electronic preheat	electronic	20	triple tube
B1	instant start	electronic	20	circline
B2	electronic preheat	electronic	18	quad tube
C1	preheat	magnetic	17	coil
C2	electronic preheat	electronic	15	double coil
D1	electronic preheat	electronic	15	triple tube
D2	electronic preheat	electronic	23	triple tube
E	instant start	electronic	16	bullet
F1	electronic preheat	electronic	15	triple tube
F2	electronic preheat	electronic	17	bullet

Table 2. Lamp-Ballast Characteristics for Screwbase CFLs

	Starting Parameters			Operating Parameters	
Product Type	Starting Time (s)	Cathode Preheat Current (mA)	Lamp Starting Voltage (V)	Lamp Operating Current (mA)	Current Crest Factor
A1	1.06	232	212	160	1.51
A2	1.08	217	235	171	1.46
B1	0.08	N/A	230	553	1.58
B2	0.5	725	165	275	1.66
C1	1.7	N/A	106	284	1.59
C2	0.98	323	173	160	1.54
D1	1.1	229	178	193	2.14
D2	0.9	265	198	177	1.92
E	0.08	N/A	113	363	1.52
F1	1	266	162	168	1.6
F2	0.88	372	115	223	1.62

Table 3. Median Lamp Life in Hours for Screwbase CFLs
(May 27, 1998)

Product Code	Cycle 1 5m/5m (8412)*	Cycle 2 15m/5m (12601)	Cycle 3 1h/5m (15514)	Cycle 4 3h/5m (16377)	Cycle 5 3h/20m (15159)	Mfr Rated Life 3h/20m
A1	(0)**	(0)	(0)	(1)	(0)	10,000
A2	(4)	3253	13559	(2)	(0)	10,000
B1	1158***	1401	3181	4025	3965	12,000
B2	859	1797	4269	5073	5397	12,000
C1	1236	2557	5628	7364	6341	7,500
C2	1950	5390	12217	12134	(0)	10,000
D1	(1)	(0)	(1)	(0)	(1)	10,000
D2	(2)	(1)	(1)	10356	(1)	10,000
E	533	2753	6704	9618	10212	10,000
F1	(3)	(4)	12962	11103	11966	10,000
F2	4265	(3)	13025	(1)	(1)	10,000

* indicates the cumulative operating hours on each cycle as of May 27, 1998

** If the test lamps have not passed median lamp life, the number in parentheses indicates the total number of lamps failed as of May 27, 1998
(For cycles 1 through 3, 8 samples of each product were tested;
for cycles 4 and 5, 4 samples of each product were tested.)

*** this number indicates the median lamp life in hours

Table 4. Median Lamp Life in Cycles for Screwbase CFLs
(May 27, 1998)

Product Code	Cycle 1 5m/5m (100939)*	Cycle 2 15m/5m (50403)	Cycle 3 1h/5m (15514)	Cycle 4 3h/5m (5459)	Cycle 5 3h/20m (5053)
A1	(0)**	(0)	(0)	(1)	(0)
A2	(4)	13012	13559	(2)	(0)
B1	13893***	5603	3181	1342	1322
B2	10309	7190	4269	1691	1799
C1	14830	10228	5628	2455	2114
C2	23403	21559	12217	4045	(0)
D1	(1)	(0)	(1)	(0)	(1)
D2	(2)	(1)	(1)	3452	(1)
E	6398	11011	6704	3206	3404
F1	(3)	(4)	12962	3701	3989
F2	51180	(3)	13025	(1)	(1)

* indicates the cumulative operating cycles on each cycle as of May 27, 1998

** If the test lamps have not passed median lamp life, the number in parentheses indicates the total number of lamps failed as of May 27, 1998
(For cycles 1 through 3, 8 samples of each product were tested;
for cycles 4 and 5, 4 samples of each product were tested.)

*** this number indicates the median lamp life in cycles