T5 UNDER-CABINET LIGHT DURABILITY TEST

FINAL REPORT

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ABBREVIATIONS AND ACRONYMS

CRI	Color Rendering Index
F8T5	8 watt T5 Fluorescent Lamp
F13T5	13 watt T5 Fluorescent Lamp
IESNA	Illuminating Engineering Society of North America
SCE	Southern California Edison
SCLTC	Southern California Lighting Technology Center
T5	5/8 Inch Tubular Fluorescent Lamp

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INTRODUCTION

This project investigates the premature failure of small, under-cabinet T5 systems. The project was initiated by Jack Melnyk and Henry Lau in September 2003 and transferred to Vireak Ly in March 2005. The project was funded by Codes and Standards in 2003 and concluded with a final report in December 2005.

BACKGROUND

It had been noticed that many small, T5 under-cabinet fluorescent systems were failing prematurely after installing them in the mock kitchen at the Southern California Lighting Technology Center (SCLTC). The typical rated life of 8-Watt and 13-Watt T5 lamps (F8T5 and F13T5) usually ranges from 5000 hours to 7500 hours. Out of the 24 installed, two failures were noticed within the first 300 hours of operation. The systems were purchased off the shelf at an electric wholesale store frequented by contractors and customers. These lighting systems are typically used for kitchen under-cabinet and valence-lighting applications.

ACCELERATED LIFE CYCLE ANALYSIS

The life of the T-5 lamps was investigated by conducting an accelerated life cycle test. The test protocol, as delineated by The Illuminating Engineering Society of North America (IESNA) requires that lamps be cycled at three hours of operation per start at room temperatures. The IESNA defines the rated life of the lamp as the number of hours at which 50% of the population fails, as seen in Figure ES-1. The orange lines in the figure show that there are 50% failures at 100% of the rated life.

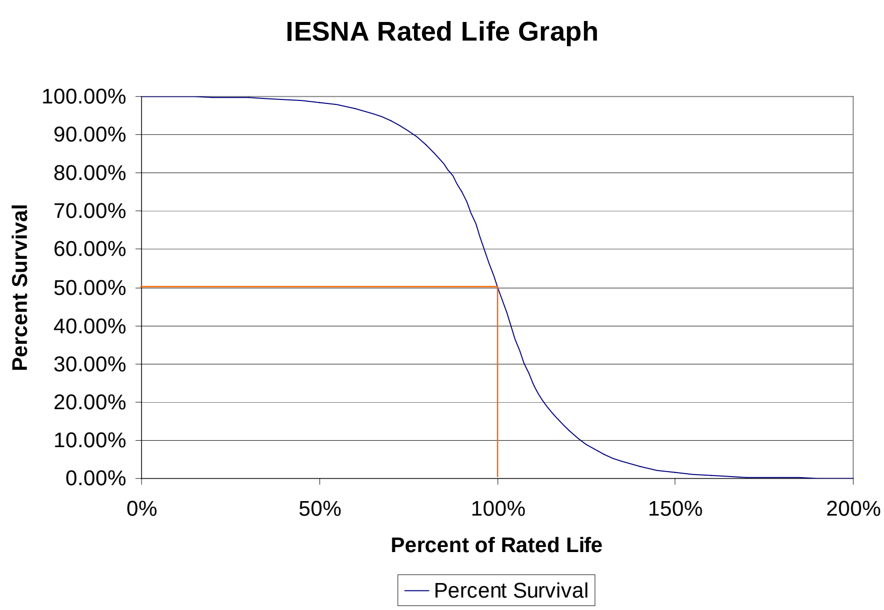


Figure ES-1: IESNA Rated Life Graph

The accelerated rated life test was conducted on the F8T5 and F13T5 lamps at the 3 hours on and 20 minutes off to allow the lamps to cool back to room temperatures. A number of the F8T5 and F13T5 systems were left continuously on as a control group. The actual measured rated life is shown in Figure ES-2.

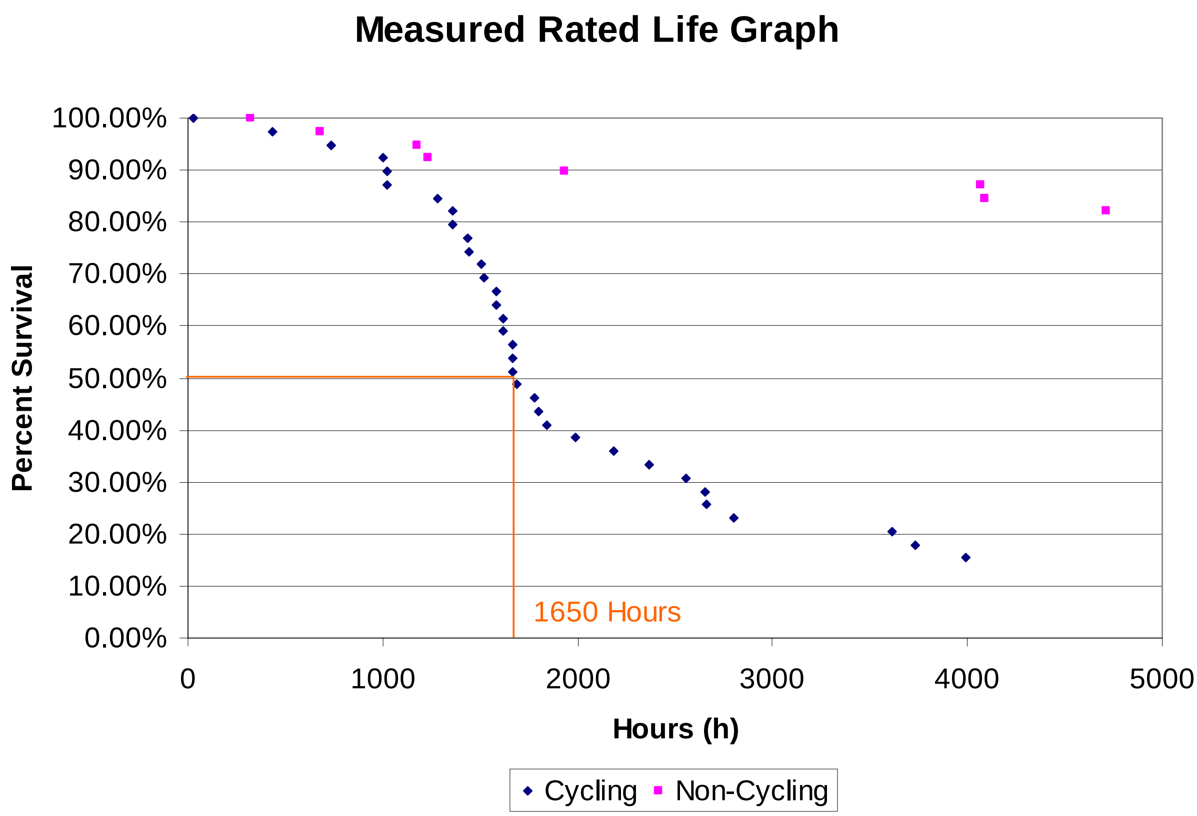


Figure ES-2: Actual Measured Rated Life Graph

As seen in the graph, 50% of the cycling lamp population failed at about 1650 hours. The expected typical rated life was 5000 to 7000 hours, 22% to 33% of the average rated life of the typical T5 lamps.

It was noticed that of all the cycling lamp failures, all were F8T5s and none were F13T5s, regardless of the ballast type. Figure ES-3 shows a graph of the cycling system failures after 4729 hours.

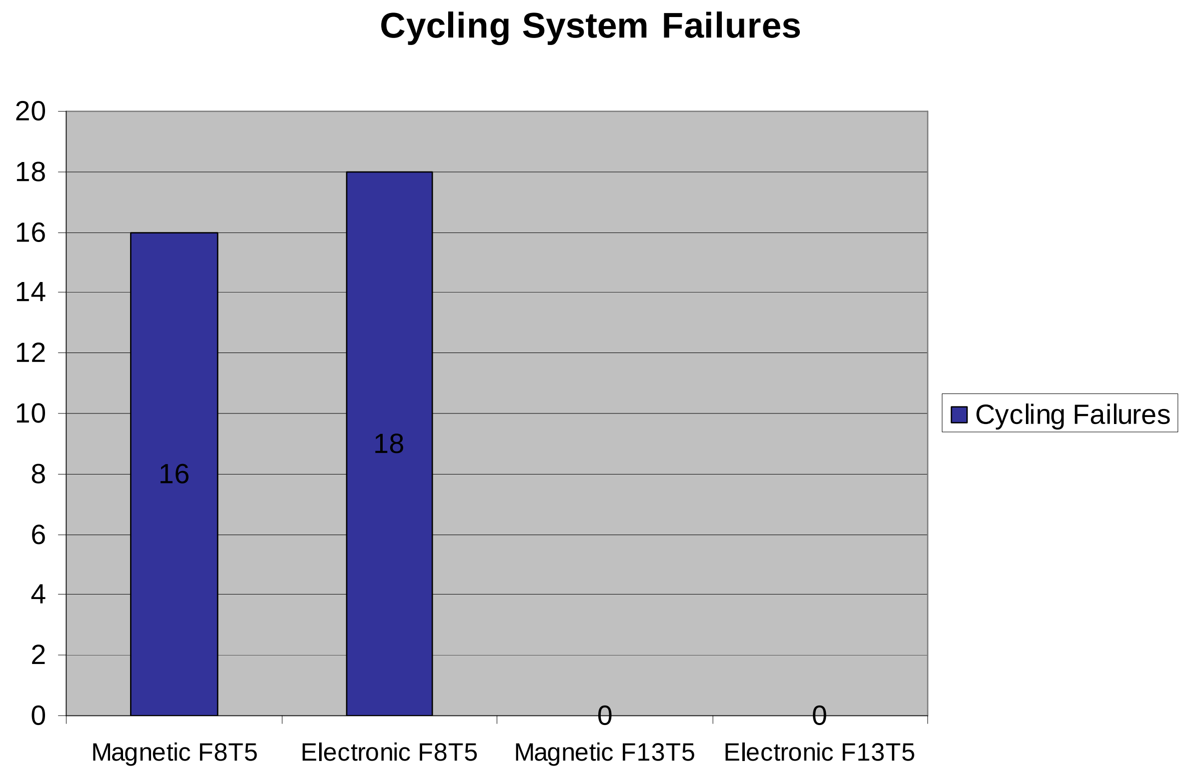


Figure ES-3: Cycling System Failures After 4729 Hours

LAMP OR BALLAST FAILURE TEST

After the conclusion of the accelerated life cycle test, the fixtures were checked to see whether it was the lamps or the ballasts that failed.

The ballast operation was verified by inserting a working lamp into each fixture, and each lamp was verified by inserting it into a working fixture.

All of the system failures were caused by lamp failures and not ballast failures. Of all the failed systems, none of the ballasts were found to be defective and all of the lamps were found to be defective.

IN-DEPTH LAMP AND BALLAST ANALYSIS

Ballast specifications were checked to see if they properly matched the installed lamps. For a lamp and ballast system to be properly matched, mainly two criteria must be met. The ballast must support the lamp's starting mechanism and the lamp wattage must be within the supporting range of the ballast.

The lamp and ballast analysis showed that there was a mismatch between the lamps and the ballasts. The preheat F8T5 and F13T5 lamps were found to be driven by instant start ballasts.

The cathodes of preheat lamps are designed to warm up before striking. The preheat starting method initially warms up the cathodes by running current through them before striking the lamp. The instant start starting method does not preheat the cathodes. The instant start starting method lights up the lamp by striking it with a higher voltage and causes the filament material to sputter off more rapidly.

CONCLUSION

The premature failure of small under-cabinet T5 systems was investigated. The main cause of premature failure in the system was the mismatched components.

It is believed that the driving factor behind the mismatched components is the combination of the customers' desire to have the lights instantly turn on when the switch is turned on and the lack of instant start F8T5 and F13T5 lamps.

It is recommended that manufacturers be notified of the problem to see what solutions are available. For codes and standards, it is recommended that additional language be to introduced to "Title 24 Section 150 – Mandatory Features and Devices" to require matching lamp and ballast for fluorescent residential lighting systems. Not requiring matching components would allow such mismatched systems and premature failures to occur.

OBJECTIVE

The objective of this project was to investigate the premature failure of small under-cabinet T5 systems. The small 8-Watt T5 (F8T5) and 13-Watt T5 (F13T5) lamps are rated at about 5,000 to 7,500 hours, but failures have been noticed in the mock kitchen in the SCLTC in much shorter times. In less than 300 hours, there were two failures out of the installed 24 units. This shows a failure rate of 8.3% within 300 hours. Determining the cause of the failures would provide us with the necessary information to determine a possible solution to the problem.

BACKGROUND

For under-cabinet lighting, fluorescent systems save much more energy over their traditional halogen or xenon counterparts. Fluorescent systems also have much longer life than the incandescent systems. For instance, the typical rated life of the fluorescent F8T5 and F13T5 lamps is 5000 to 7500 hours and the typical life of an incandescent is 2000 hours. Even with these positive points, halogen and xenon systems are still the more popular choice for customers due to their low cost, warm color, high color rendering index (CRI), and dimming capability.

MARKET SIZE

Out of all the rooms in a home, the kitchen uses the most energy for lighting. According to the Department of Energy's "Residential Lighting Use and Potential Savings" report, the bedrooms have the most lights, but the lighting in the kitchen is used more. Figure I-1 shows the number of lights and hours used by each room.

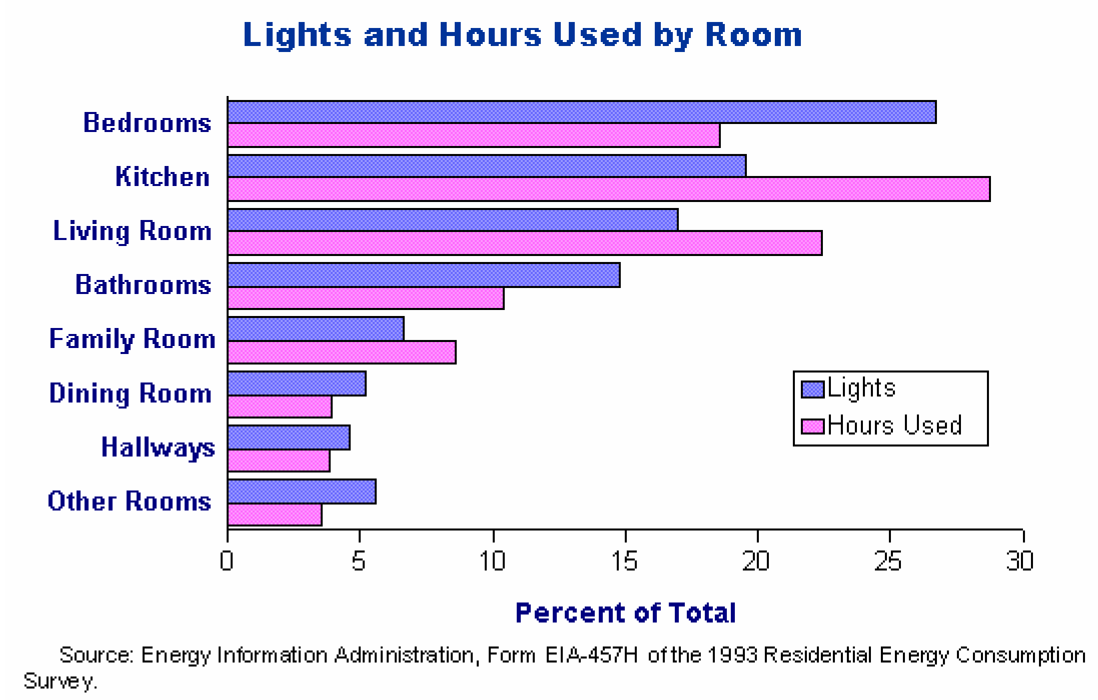


Figure I-1: Lights and Hours Used by Room

The lighting systems in the kitchen are typically comprised of ambient lighting, task lighting, and valence lighting. Downlights or other ceiling mounted lights are considered to be ambient lighting for the kitchen. Under-cabinet lighting is considered to be task lighting since it lights up the countertops directly. If the fixtures are mounted on top of the higher cabinets, then they are considered to be valence lighting.

The under-cabinet and valence lighting systems can use more energy than the ambient lighting systems, even though ambient lighting produces more light for the energy it uses. This is because ambient lighting systems are typically more efficacious than task lighting systems. This may change as new technologies are introduced.

Currently, most of the fluorescent under-cabinet systems in use today are the F8T5 and F13T5 systems. These systems are fairly inexpensive compared to the more uncommon systems, such as the T4 and T2 systems. Table I-1 shows general specifications and the cost difference of the various fluorescent technologies from an internet lamp retail supplier.

General Specifications and Cost Differences

Technology	Designation	Nominal Power	Length	Cost	Cost Difference
T5	F4T5	4 Watts	6 inches	$3.95	**45%**
	F6T5	6 Watts	9 inches	$3.95	**45%**
	F8T5	8 Watts	12 inches	$3.95	**45%**
	F13T5	13 Watts	21 inches	$3.95	**45%**
T4	F8T4	8 Watts	13 1/8 inches	$8.75	**100%**
	F12T4	12 Watts	17 1/8 inches	$8.75	**100%**
	F16T4	16 Watts	18 7/8 inches	$8.75	**100%**
	F20T4	20 Watts	20 5/8 inches	$8.75	**100%**
	F24T4	24 Watts	34 inches	$12.95	**148%**
	F28T4	28 Watts	45 13/16 inches	$12.95	**148%**
T2	FM11	11 Watts	16.6 inches	$18.95	**217%**
	FM13	13 Watts	20.6 inches	$18.95	**217%**

Table I-1: General Specifications and Cost Differences

TITLE 24

Although there are more incandescent under-cabinet lighting systems in use today, the new 2005 California Building Energy Efficiency Standards (Title 24) of the California Code of Regulations will bring about an increase in fluorescent lighting in residential kitchens. Figure I-2 shows Section 150 (k) 1 and 2 of Title 24.

Title 24 *SECTION 150 – MANDATORY FEATURES AND DEVICES*

(k) **Residential Lighting.**

1. **High Efficacy Luminaires.** High Efficacy Luminaires for residential lighting shall contain only high efficacy lamps and shall not contain a medium screw base socket (E24/E26). A high efficacy lamp has a lamp efficacy that is no lower than the efficacies contained in TABLE 150-C. Ballasts for lamps rated 13 Watts or greater shall be electronic and shall have an output frequency no less than 20 kHz.

   EXCEPTION to Section 150 (k) 1: High intensity discharge luminaires containing hardwired electromagnetic ballasts in medium screw base sockets shall be considered high efficacy luminaires for the purposes of meeting Section 150 (k) 6, provided they meet the efficacies contained in TABLE 150-C.

NOTE: To determine the minimum lamp efficacy category only the watts of the lamp (not the ballast) are to be considered.

2. **Lighting in Kitchens.** Permanently installed luminaires in kitchens shall be high efficacy luminaires.

   EXCEPTION to Section 150 (k) 2 Up to 50 percent of the total rated wattage of permanently installed luminaires in kitchens may be in luminaires that are not high efficacy luminaires, provided that these luminaires are controlled by switches separate from those controlling the high efficacy luminaires. The wattage of high efficacy luminaires shall be the total nominal rated wattage of the installed high efficacy lamp(s). The wattage of luminaires shall be determined as specified by Section 130 (c).

Figure I-2: Title 24 Section 150 – Mandatory Features and Devices

This requires that at least 50 percent of the lighting wattage of permanently installed luminaires come from high efficacy luminaires. Under-cabinet lighting systems are typically hard-wired and not plugged in, so this must be considered when designing the lighting system for the kitchen. The T5 lamps and fixtures are considered to be high efficacy luminaires and are alternatives to the less efficient incandescent systems.

SUMMARY

More efficient under-cabinet lighting systems are being both pushed and pulled into the residential market by utilities, governmental agencies, and consumers. The under-cabinet lighting system's usage hours, demand, market availability, and new codes make it the best system to look at in terms of overall residential energy savings potential.

The durability of residential fluorescent under-cabinet lighting systems will have significant impact on future residential energy savings. If the fluorescent under-cabinet light fixtures are failing more than or even as much as the incandescent counterparts, then there is a possibility of increased use of much less energy efficient lighting, such as incandescents, as consumers grow frustrated with replacing failed fluorescents. The premature failure mechanisms must be determined and understood in order to find a solution to the problem. The sustainability of the residential fluorescent under-cabinet and valence lighting market is dependent on the customers' reactions and whether there is a solution to the premature failures.

PROCEDURE AND FINDINGS

OVERVIEW

An accelerated rated life test, which consisted of cycling 78 lamps on for 3 hours and off for 20 minutes at room temperature, was conducted to detect premature failures of T5 under-cabinet systems. The actual measured rated life of the system was compared to the average rated life in order to demonstrate the premature failure. The process yielded the failed units for analysis. The components of the failed systems were examined to see whether it the lamps or ballasts had failed and to determine the cause of failure.

Procurement

In order to represent what is out in the market and what customers would typically buy for their homes, we went to electrical wholesalers for their high-selling under-cabinet fluorescent systems. The fixtures came off the shelf with brand name lamps and all the mounting and wiring hardware as well. Figure PF-1 shows a picture of the typical 12” fixture.

Figure PF-1: Typical Under-Cabinet Fixture

Varieties

The fixtures come in various configurations as described in Table PF-1.

Table PF-1: Available Fixture Varieties

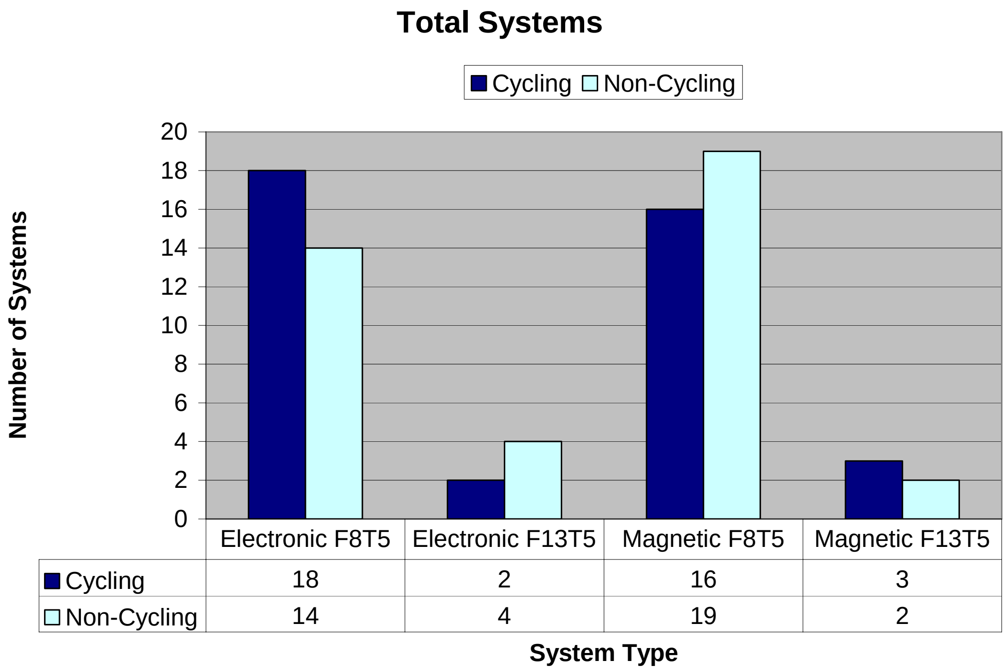
	Ballast Type	**Lamp(s)**	**Lamp Size(s)**
Variety 1	Magnetic	1-Lamp	8-Watt
Variety 2	Magnetic	2-Lamp	8-Watt (2)
Variety 3	Magnetic	2-Lamp	8-Watt, 13-Watt
Variety 4	Electronic	1-Lamp	8-Watt
Variety 5	Electronic	2-Lamp	8-Watt (2)
Variety 6	Electronic	2-Lamp	8-Watt, 13-Watt

Set-Up

A two-sided under-cabinet test rack was constructed to simulate under-cabinet conditions. A picture of the test rack and instrumentation system is shown in Figure PF-2.

Figure PF-2: T5 Under-Cabinet Test Rack and Instrumentation System

A total of 48 various fixtures and 78 lamps were used for the test. Each side of the test rack housed half of the total number of fixtures and lamps. Figure PF-3 shows the location and number of different lamp and ballast systems that were installed.



	Electronic F8T5	Electronic F13T5	Magnetic F8T5	Magnetic F13T5
Cycling	18	2	16	3
Non-Cycling	14	4	19	2

Figure PF-3: Total Number of Systems

ACCELERATED LIFE CYCLE ANALYSIS

Procedure

The lamp life was investigated by conducting an accelerated life cycle test using the standard 3 hours on, 20 minutes off cycling rate. An actual life cycle test would be prohibitive in the time-frame of the project. The Illuminating Engineering Society of North America (IESNA) defines the rated life of the lamp as the number of hours at which 50% of the population fails at 3 hours of operation per start at room temperatures. Figure PF-4 shows a rated life graph for fluorescent lamps. The orange lines in the figure show that there are 50% failures at 100% of the rated life. In other words, half of the lamps would fail before the rated life and half would fail after the rated life.

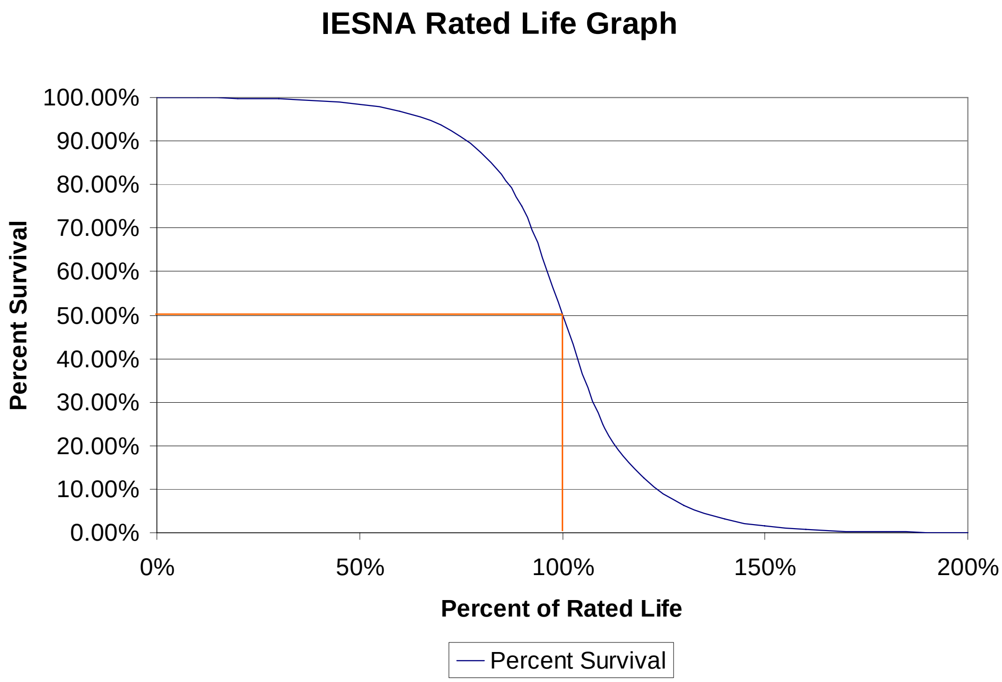


Figure PF-4: IESNA Rated Life Graph

The lamp base temperature was measured to indicate the status of the lamp. If the lamp has electric current in it, then it is consuming power and producing heat. A “hot” lamp indicates that a lamp is on, and a “cold” lamp indicates that a lamp is off. The term hot and cold is used relatively to show the state of the lamps. The actual exact value of the lamp base is not important in this case, but its relative value is. It is also used to help determine the failure mechanism of the lamp in cases where temperature may be a factor. Figure PF-5 shows the lamp base temperatures for three lamps over about ten cycles.

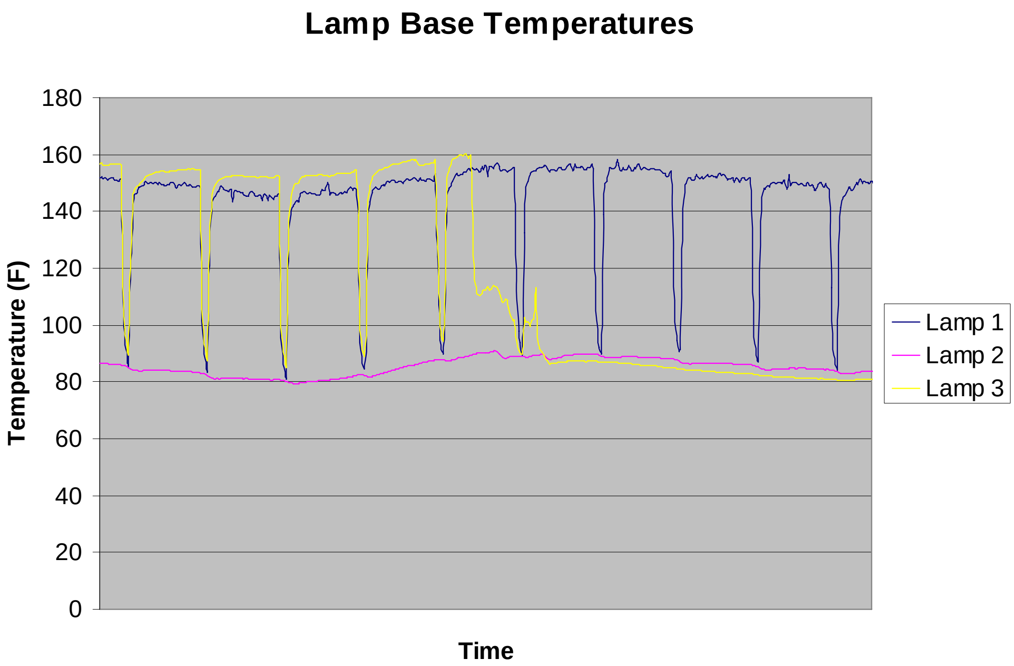


Figure PF-5: T5 Lamp Base Temperatures

Lamp 1 shows a typical cycling lamp which cycles between the "hot" and "cold" states every 3 hours on and 20 minutes off. Lamp 2 shows a failed lamp which remains in the "cold" state. Lamp 3 shows a failing lamp which failed and stopped cycling at about the fifth cycle.

The slow rise and fall of the failed lamp is caused by the changes in the room's ambient temperature. This can also be seen on the cycling and failing lamps.

Equipment

Temperature Measurement
The temperature data for all 78 lamps was recorded using calibrated thermocouples and computer virtual instrumentation software and hardware.

Cycling Device
An industrial-grade timer was used to constantly switch the lamps on and off at the 3 hours on and 20 minutes off cycling rate.

Findings

The results of the accelerated life cycle test showed failure trends among the systems.

Lamp Life
Figure PF-6 illustrates the actual measured failure rates of the T5 systems. The curve very closely follows the IESNA rated life graph in PF-4.

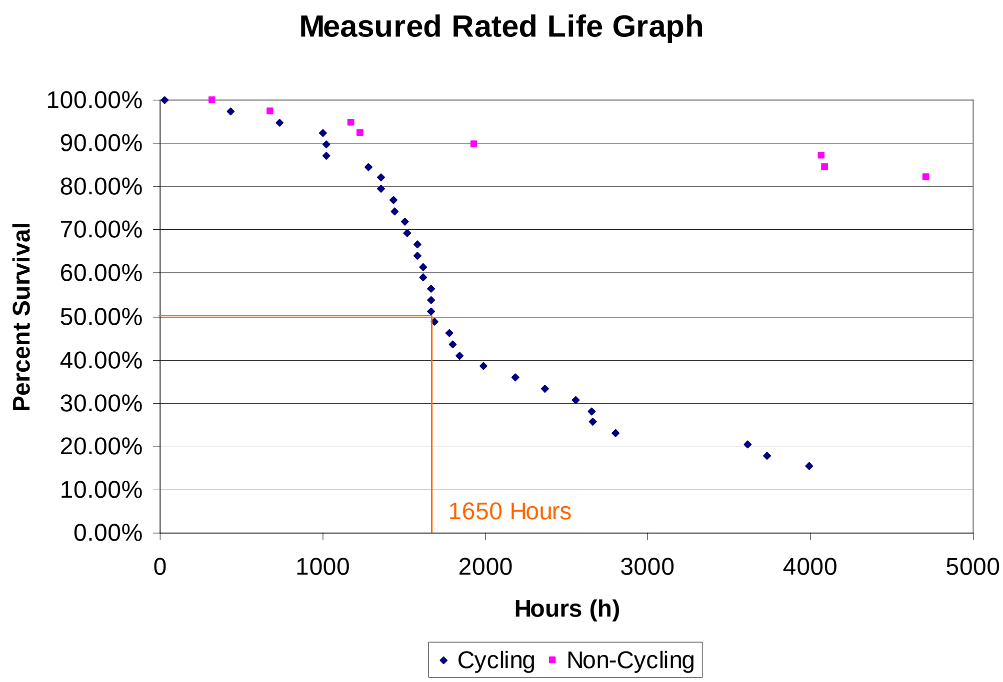


Figure PF-6: Measured Rated Life Graph

As indicated by the data, 50% of the cycling lamp population failed at about 1650 hours, which is shown by the orange line in the graph. This is much less than the 5000 to 7000 hours that was expected of the system. The measured rated life is only 22% to 33% of the average rated life of typical T5 lamps.

Cycling vs. Non-Cycling
One of the obvious trends that was noticed from the Measured Rated Life Graph in Figure PF-6 was the difference in the failure rates between the cycling and non-cycling systems. The cycling systems had many more failures compared to the non-cycling systems in the duration of the test. Figure PF-7 shows the total number of failures for both systems at the conclusion of the test.

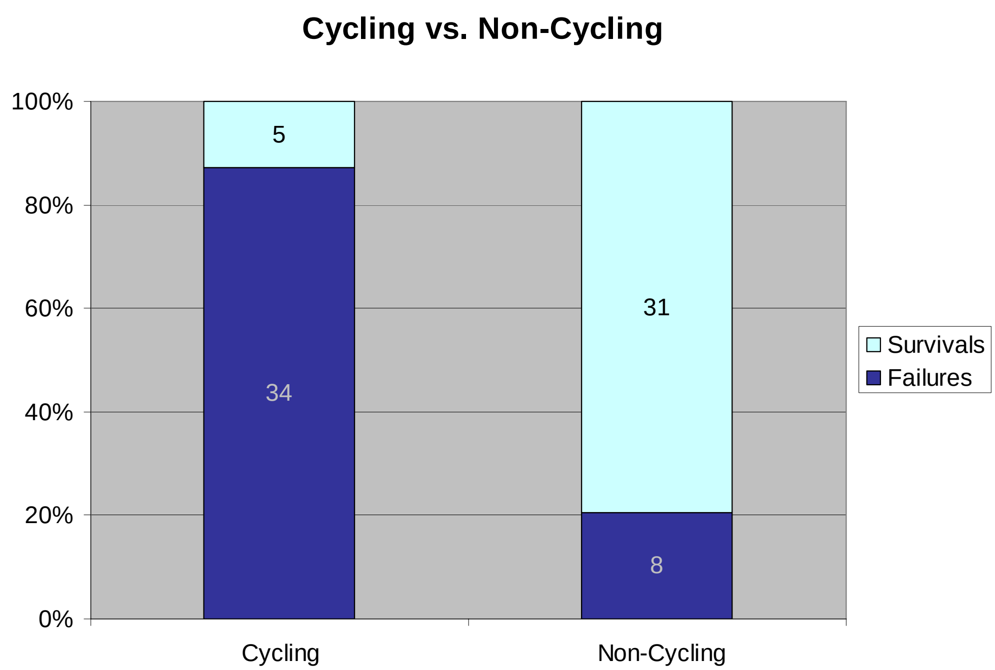


Figure PF-7: Cycling Versus Non-Cycling Systems

The higher failure rate of the cycling systems was expected due to the increased number of starts. The life of fluorescent lamps is directly related to the number of starts that the fluorescent lamp experiences. Starting the lamps involves a high voltage spike, which deteriorates the cathode inside the lamp by sputtering off the cathode material onto the inside of the tube. Figure PF-8 shows the blackened ends of the lamps caused by the sputtered cathode material deposited on the inside of the lamp.

Figure PF-8: Blackened Ends of Failed F8T5 and F13T5 Lamps

8-Watt vs. 13-Watt

Another apparent trend was the number of failures of the cycling F8T5 and F13T5 systems. Figure PF-9 shows a graph of the failed cycling systems.

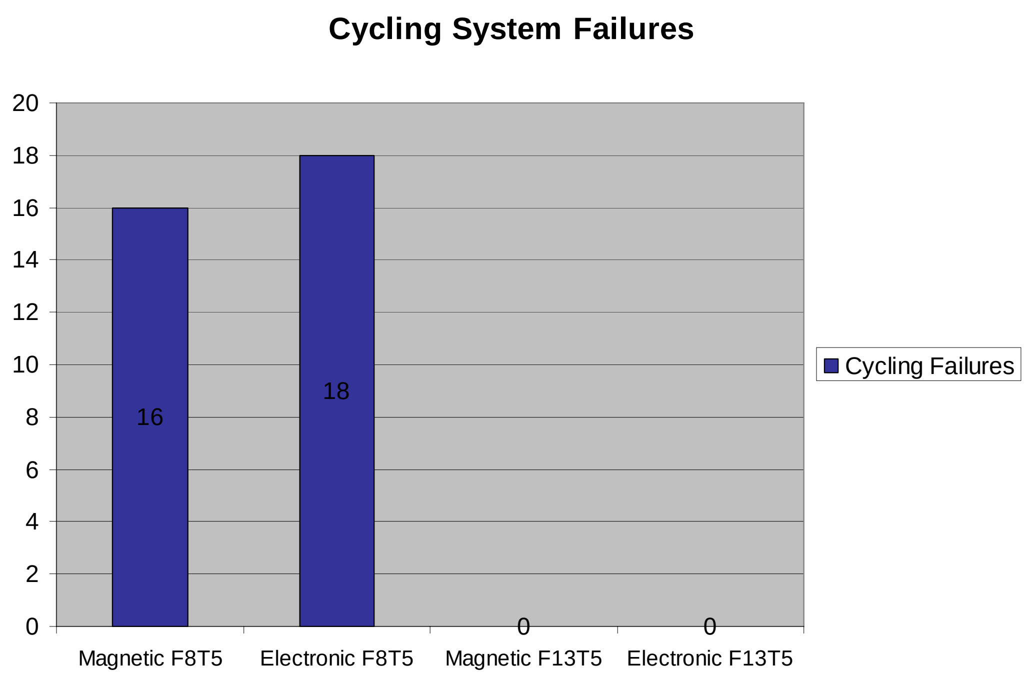


Figure PF-9: F8T5 versus F13T5 Cycling System Failures

One hundred percent of the cycling F8T5 lamps failed at the conclusion of the test while none of the cycling F13T5 systems failed. The ballast technology, whether electronic or magnetic, did not make a difference. At this point in the test, it was not clear why the cycling F8T5 and F13T5 systems were failing in this manner. The cause of the 100% F8T5 failures and 0% F13T5 failures was later determined after the in-depth lamp and ballast analysis.

LAMP OR BALLAST FAILURE TEST

Procedure

After the accelerated life cycle test, the components of the systems were examined to see which component caused the system failure. The lamps of failed systems were replaced with working lamps. If the system lights up normally, then the ballast is in order. If the working lamp does not light up, then the system failure was due to a ballast failure. The failed lamps were placed in working ballasts to verify the cause of failure.

Findings

It was found that none of the ballasts failed. The systems lit up fine when the failed lamps were replaced with working lamps. This test was significant in showing that all the system failures were caused by lamp failures and not ballast failures.

IN-DEPTH LAMP AND BALLAST ANALYSIS

Procedure

In order for a system to work, the components must all work individually as well as a system. Once it was determined that the lamps were the failing components of the system, the ballasts specifications were studied for compatibility with the lamps.

There were a variety of ballasts in the population. Every fixture was opened in order to see the labeling for each of the ballasts. Figure PF-10 shows the test rack with the fixtures opened for individual lamp and ballast analysis.

Figure PF-10: T5 Under-Cabinet Test Rack Lamp and Ballast Analysis

Findings

The lamp and ballast analysis revealed that there was a mismatch between the components of the system. It was found that the ballasts were instant start type ballasts and the F8T5 and F13T5 lamps were preheat lamps. This mismatch explains the cause of the premature failures.

The cathodes of preheat lamps are designed to warm up before striking. The preheat start method initially warms up the cathodes by running current through them before striking them with high voltage to turn the lamp on. Warming up the cathode reduces the amount of cathode material sputter during the voltage spike of the preheat starting mechanism.

The instant start starting method does not preheat the cathodes. The instant start starting mechanism lights up the lamp by striking it with a much higher voltage without preheating the cathodes and causes the cathode material to sputter off more rapidly. Therefore, the life of the lamp suffers drastically compared to the preheat starting method.

The instant start starting method is more damaging to the smaller 12” F8T5 lamps than the larger 21” F13T5 lamps. There is a higher arc resistance in the F13T5 lamp due to the larger distance between the two cathodes. The larger resistance reduces the cathode material sputter during the voltage spike. Applying the 13-Watt starting voltage on the smaller F8T5 lamp creates a much larger spark from the cathode which sputters more material off the cathode, drastically increasing the deterioration rate of the cathode, and causing it to fail prematurely.

Lamp & Ballast Mismatch

The premature failure of small under-cabinet T5 systems was investigated. The investigation demonstrated that the premature failures were caused by lamp failures due to lamp and ballast mismatch. The 8-Watt and 13-Watt T5 lamps are preheat lamps. The ballasts in the system are instant start ballasts. Preheat lamps were not designed for instant start operation. The instant start starting mechanism causes the lamps' cathode to deteriorate more rapidly than designed, causing the premature failure.

Instant-On Feature Driving Instant Start

The main drive behind the lamp and ballast mismatch is the customers' desire to have the instant-on feature of instant start systems and the lack of instant start T5 lamps. Customers prefer the instant-on feature of instant start lamps and ballasts. Once the wall switch is flipped on, the lights are instantly on. Preheat systems take about a second or two to become fully on. Other similar systems like the cold-weather compact fluorescent lamps take up to a couple minutes to reach their full brilliancy were disliked because of their long start-up times.

Recommendation

It is recommended that manufacturers be notified of the problem to see what solutions are available on their side regarding the lack of instant start solutions to F8T5 and F13T5 systems. The market potential for properly matched fluorescent T5 systems will play a large role in the manufacturer's interest in the solution to the problem.

On the codes and standards side, it is recommended that additional language be to introduced to "Title 24 Section 150 – Mandatory Features and Devices" to require matching lamp and ballasts for fluorescent residential lighting systems. This requirement would help manufacturers bring about instant start solutions for the lower wattage T5 systems.