Durability Testing

for

ENERGY STAR® Residential Light Fixtures

Final Project Report

(Public Version)

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Introduction

During the past few years, there has been increasing concern about the quality and the reliability of residential fluorescent light fixtures with the ENERGY STAR label. One of the expected advantages of residential light fixtures with the ENERGY STAR label is product durability. The term "durable" is generally used to describe how long something will last without deteriorating or failing. Consumers expect high durability of energy-efficient products, and early failures can introduce barriers to the penetration of these products in the market, as well as create a poor impression of the ENERGY STAR label.

Anecdotal reports of early failures of ENERGY STAR residential light fixtures and the need to guarantee high quality of ENERGY STAR labeled products, have led the US Environmental Protection Agency (EPA) to support the Lighting Research Center (LRC) in the development of a durability testing method. In the case of residential light fixtures, durability is associated with different parts, such as the lamp, ballast, wiring, lamp socket, diffuser, or reflector. Of these components, the lamp and the ballast have been the focus of much research because product failure is generally observed when either the lamp or the ballast or both fail. If the lamp fails prematurely, even though it is somewhat annoying, replacement is easier. If the ballast fails early, however, replacement of the fixture is generally required and customer dissatisfaction increases. Ballast replacement requires, at a minimum, a specialized person, likely resulting in additional cost.

The main focus of this project was to establish an industry-approved testing method that would help identify products that were likely to fail prematurely. In order to develop a durability testing method, it was first necessary to identify issues likely to cause the premature failure of lamps and ballasts, based on existing research and on an understanding of lamp/ballast starting and operating characteristics. Once these issues were identified, it was important to conduct limited testing to validate these assumptions. The limited testing had two foci: verify the assumptions identified earlier as being possible causes of premature failures of fixtures; and pilot test the proposed methodology. Based on these tests, a durability testing method would be proposed to the EPA to help identify poor quality products.

The following report details the efforts of the ENERGY STAR durability testing method project at the LRC, encompassing background, testing, results, and recommendations.

Background

A fluorescent lighting system is comprised of a particular lamp and ballast combination. The lamp is designed to operate at a specific current, called lamp current, and emits a certain amount of light, called rated light output. The ballast is designed to start and operate a specific lamp type by supplying a specific starting voltage and running the lamp at its rated lamp current. The lamp and ballast form a complicated system that is affected by the environment in which it is operated. In order to better understand issues associated with premature failure of fluorescent lamp light fixtures, the LRC conducted a literature review on lamp and ballast failure mechanisms.

Lamp failure

The lamp usually does not last as long as the ballast. The failure of fluorescent lamps is caused mainly by the loss of the electron emissive coating of the lamp electrodes.[1] Fluorescent lamps operated on alternating current have two identical electrodes that serve alternately as the anode and the cathode. The electrode at the negative end of the tube (the cathode) and its associated discharge region (the negative glow) serve the function of injecting the necessary electron current into the discharge column. The positive electrode (the anode), on other hand, must extract electrons from the discharge column at the other lamp end. The majority of the electrons emitted by the cathode result from the process of thermionic emission, whereby thermally excited electrons have enough energy to free themselves from the material. Fluorescent lamp electrode filaments are coated with an emission mix, made from calcium (Ca), barium (Ba), and strontium (Sr) oxides, that has a very low work function, ranging from 0.9 to 1.1 eV, compared to that of the bare tungsten filament whose work function would be about 4.5 eV. The work function is a property of a material that determines the energy needed for an electron to escape the material. For coated filaments, temperatures of about 900°C are high enough to create thermionic emission of electrons sufficient for the discharge current. Without the emissive coating, thermionic emission is insufficient for the discharge current, which, if maintained, would lead to the destruction of the electrode and lamp failure.

The function of the emissive coating on the electrode is to keep the work function low, so that thermionic emission occurs. The emissive coating on the electrodes is removed, however, by two processes: evaporation and sputtering. Electrode temperature directly affects the evaporation and erosion of the emitting material and thus the lamp life. Evaporation is the continual, temperature dependent removal of material into the low pressure atmosphere inside the lamp envelope. The removed material is deposited on nearby cooler surfaces, such as the lamp wall, that results in lamp end-darkening. Sputtering is the removal of material by the impact of positively charged ions accelerated toward the cathode. Sputtered material also gets re-deposited on nearby surfaces, including the electrode. A very high electrode temperature (greater than 1000°C) will reduce lamp life due to evaporation of the emitting material, and a low electrode temperature (less than 700°C) will reduce lamp life due to erosion of the emitting material by sputtering.[2]

Operating life, therefore, is limited by evaporation and sputtering of electrode coating. If the electrode temperature is too high, lamp life is reduced by evaporation of the emissive coating. While a low electrode temperature will reduce the evaporation of the emissive coating, it may increase lamp electrode sputtering. Sputtering increases at low electrode temperatures because alternate processes take the place of thermionic emission for generating the supply of electrons for the discharge. These processes require a drop in electric potential adjacent to the electrode, which is responsible for accelerating ions, which impact the electrode. This drop in electric potential is called cathode fall voltage. Near end of life, when the emission mix is depleted from the electrode filament, the work function of the electrode material increases up to about 4.5 eV, that of bare tungsten. To sustain the discharge, the sharp drop in electric potential at the cathode increases dramatically to aid in extracting electrons. Large increases in cathode fall voltage result in either catastrophic sputtering of the electrode, or the ballast failing to sustain or initiate the discharge due to the higher overall lamp voltage.

Ballast operating effects on fluorescent lamp life

There are three operating parameters that may affect fluorescent lamp life: lamp current crest factor (CCF), supplemental electrode heating voltage, and lamp operating current. The ballast that operates the lamp mainly determines these three parameters.

Lamp CCF is the ratio of peak lamp current to the root mean square lamp current. A higher CCF indicates a distorted wave shape with the potential for high peak current, which can damage the lamp electrode and reduce lamp life. Fortunately, most electronic ballasts have satisfactory CCF of less than 1.7, which is regarded as an acceptable limit by the American National Standards

Institute (ANSI) ballast performance standards. However, this limit is based on 60 Hz operation; therefore, the validity of applying it to high frequency operation is questionable. Perhaps higher CCF values are acceptable for high frequency operation due to the more efficient heating of the electrodes under high frequency operation.

Supplemental lamp electrode voltage is the voltage across the electrode filament at each lamp end that is supplied by certain ballast types to heat the electrodes during lamp operation. For instant start and modified rapid start ballasts, this voltage is 0 V (non-existent), but some electronic rapid start ballasts, and most magnetic rapid start ballasts continue to provide about 3.5 V across the electrodes during lamp operation. Although this increases the active power of the system, it can diminish or possibly avoid the sputtering of the electrode emissive material that occurs if the electrode temperature drops below 700°C.

Lamp operating current is the current flowing through the lamp during operation. The ballast factor (BF) is the ratio of the luminous flux emitted by a lamp operated on a given ballast to the flux emitted by the same lamp when operated on a reference ballast. These two parameters are directly related in that reducing the lamp operating current reduces the light output of the lamp and therefore reduces the BF. ANSI sets maximum limits on lamp operating current to minimize the evaporation of the electrode emissive coating and minimum limits to avoid electrode sputtering.

Ballast failure

Ballasts provide the appropriate circuit conditions (voltage, current, and waveform) to start and operate fluorescent lamps. Among other variables, ballast life depends on supply voltage, ambient temperature, and the operating temperature. For electronic ballasts, life is dependent upon the quality of the electronic components (the electrolytic capacitor being one of the most important), and the degree to which the ballast is protected from line voltage surges and electrical transients.

High temperature can damage electronic components inside the ballasts, especially the electrolytic capacitors in electronic ballasts. The major parameters of the electrolytic capacitors are capacitance, working voltage, maximum operating temperature, and load life. Load life is the period (in hours) in which the capacitor will be expected to perform within the stated specification of rated capacitance when operated at rated voltage and rated operating temperature. Load life is a critical parameter affecting the life of the ballast, but it does not mean that the ballast will fail to start the lamp at the end of the rated load life of the capacitor. In other words, even though the capacitor is performing beyond the stated specification of rated capacitance, the ballast may still be able to start the lamp. However, it is the interaction between the maximum operating temperature and the load life that indicates how long the capacitor will be performing within the stated specification of rated capacitance, enabling the ballast to provide the appropriate starting voltage and operating characteristics required by the lamp.

In general, the rated operating temperature of electrolytic capacitors is 105°C. Load life expectancy of a capacitor when operated at different temperatures is approximately 1000 hours at 105°C, 2000 hours at 95°C, and 4000 hours at 85°C. Load life expectancy can act in reverse, however, when the ambient temperature is higher than the maximum rated operating temperature, i.e., 500 hours at 115°C, 250 hours at 125°C, etc. In general, for each 10°C decrease in operating temperature, the load life of the capacitor is doubled; similarly, for each 10°C increase in operating temperature, the load life of the capacitor is halved. This rule of thumb applies to aluminum electrolytic capacitors, which is the typical type of capacitor used in electronic ballasts.

For safety reasons, Underwriters Laboratory (UL) specifies the maximum ballast case operating temperature as 90°C. Some manufacturers also specify a maximum ballast case operating temperature to assure good product performance. In general, maximum allowable temperature for performance is lower than for UL requirements. When placed inside certain types of fixtures (e.g., recessed downlights and close-to-ceiling fixtures), the ballast case temperature can reach very high temperatures, which can, not only become a fire hazard if the temperature is above 90°C, but also reduce the load life of the capacitor, compromising performance of ballasts and causing premature failure of these types of fixtures.

With regard to the degree to which the ballast is protected from line voltage surges and electrical transients, electronic ballasts use semiconductor devices such as transistors and rectifiers that are more sensitive than magnetic components to supply voltage surges. Elevated supply voltage translates to an increase in component temperature, which in turn will reduce the life of the electrolytic capacitor of the electronic ballast.[3,4,5] Reduced supply voltage does not affect the life of a ballast, but will cause sputtering of the emissive coating of the lamp electrode, thus reducing lamp life and impacting lumen depreciation.[6,7,8] To protect these electronic components from electrical line surges, electronic ballast designs can employ filters and voltage limiters at the ballast input. Ballast life depends on the design and quality of these components and the degree to which the ballast is exposed to transient fluctuations. The rated life of electronic ballasts assumes a supply voltage variation range of 10%-20%.

Approach

The greatest challenge of this project was the development of a durability testing method that would be able to predict early failure of lamps and ballasts without adding too much onus on manufacturers. Three issues were identified to be associated with early failure of residential light fixtures:

- Elevated temperature inside the fixture results in elevated ballast case operating temperature, causing failure of electrolytic capacitors in electronic ballasts.
- Starting and operating electrical characteristics of the ballasts may damage lamps.
- Supply voltage variation may impact the ballast starting and operating electrical characteristics.

The LRC proposed to investigate each of these issues separately, so that it was possible to have a better understanding of the impacts of each on premature failure of ENERGY STAR fixtures. Three sets of testing were developed and pilot studies to validate the assumptions described above were performed. The procedures used for each testing are detailed in the Method Section. In summary, the proposed sets of testing were:

Rapid-cycle testing. The goal of this proposed test was to rapidly identify any starting and operating electrical characteristics of ballasts that may damage lamps by stressing the lamp/ballast system. The lamps and ballasts systems were placed on racks using a switching cycle of 5 minutes on/ 5 minutes off to subject the lamp/ballast combinations to a stress test. To control for heat, the lamp/ballast systems were placed on racks outside the fixtures. In order to control for voltage variation, a power supply was used to maintain constant rated voltage to the ballast.

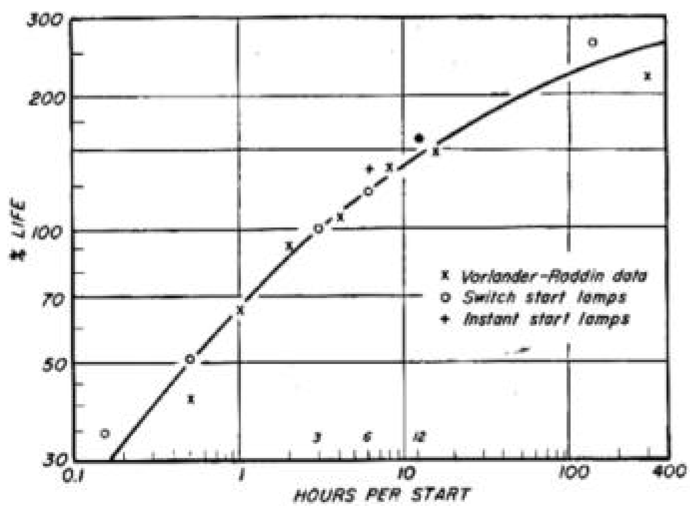
Life testing of lamps follows a standard method that was developed by the Illuminating Engineering Society of North America (IESNA) and ANSI. These organizations are comprised of many constituents from the lighting industry, ranging from manufacturers to lighting specifiers and end-users. Rated life of both compact and linear fluorescent lamps is defined as the time when 50% of a large number of lamps operating on a 3-hour on/20-minute off cycle have failed. This life test is carried out under controlled conditions, such as input voltage, lamp operating position, lamp spacing, and room ambient temperature. The lamps and ballast are usually tested on a rack where all the lamps are operated in an open-air environment. Currently there are no standard life tests for ballasts.

Accelerated life tests are short-term tests that should be predictive of lamp life. There are approved procedures of accelerated life testing for incandescent lamps. The results obtained with these accelerated life tests are highly correlated with the standard life test for incandescent lamps.

Currently, there is no accelerated life testing for fluorescent lighting systems, although attempts to determine an acceptable accelerated life testing has been conducted in the past. Vorlander and Raddin (1950) conducted a study to determine the effects of various operating cycles on life and performance characteristics of T-12 preheat, hot-cathode fluorescent lamps.[9] Their study generated a curve of average life in thousands of hours vs. burning cycles in hours for linear fluorescent lamps. Although the rated life (3-hour on/20-minute off) of those products was only 4000 to 6000 hours (compared to more than 20,000 hours today), Vorlander and Raddin clearly illustrated that lamp life is shortened when lamps are operated on shorter cycles. Because of the significant improvement in lamp life and performance characteristics of linear fluorescent lamps, this curve cannot be used to predict life for today's lamps.

Another study (Thayer, 1954) was conducted to determine the effects of design and operating variables on the life of fluorescent lamps.[10] That study provided data for rapid-start and instant-start lamps, which was added to the 1950 curve. Figure 1 shows this relationship between different on-times and lamp life.

Figure 1. Lamp life vs. on time

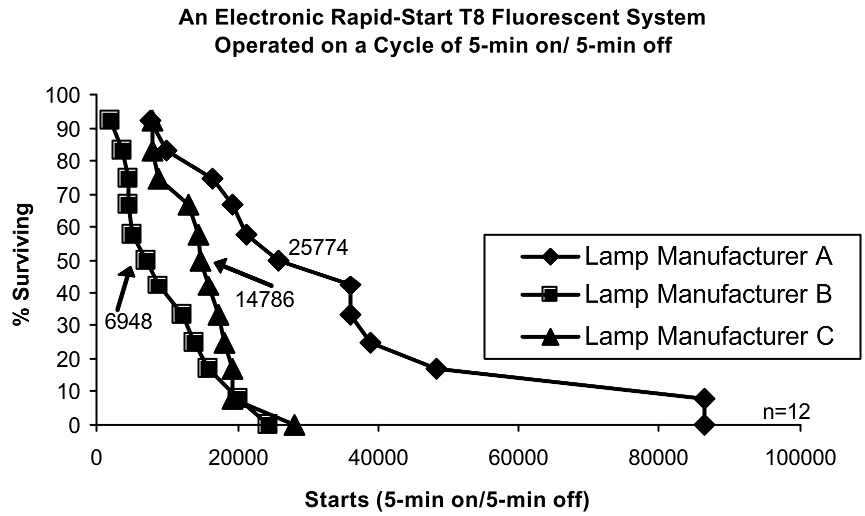


Source: Vorlander, F.J. and Raddin, E.H. 1950. The effect of operating cycles on fluorescent lamp performance, *Illuminating Engineering, January: 21:2.*

As mentioned above, the lamp electrodes are damaged during starting and operation. The ballast controls the starting and the operation of the lamp, and different ballasts operating the same lamp may result in different lamp life, even if the same operating cycle is being used. The same is true for lamps from different manufacturers that are being operated on the same ballast. This is shown in Figure 2. Manufacturers claim, however, that this problem is minimized when lamps and ballasts are ANSI compliant.

The number of lamp/ballast combinations using the components currently available in the market can be overwhelming. Establishing the correlation between accelerated and standard life tests for the various lamp/ballast combinations requires extensive research. For this reason, the rapid cycle test used in this study was meant to stress the lamp, but passing this test did not necessarily guarantee that the same lamp would achieve its rated life.

Figure 2. Rapid cycle testing of a ballast operating three different lamps



Source: O'Rourke, C., and Figueiro, M.G. Long term performance of screw-base compact fluorescent lamps. *J. Illum. Eng. Soc.* In press

The LRC has conducted a series of tests using various lamp/ballast combinations that could, in a near future, lead to a model for predicting lamp life using a rapid-cycle test. For the purpose of this pilot study, however, rapid cycling was used only as a means to stress the lamp, and the effects of various lamp/ballast combinations was not tested.

Heat testing. The goal of this proposed test was to easily measure the ballast case operating temperature inside the fixture. Although single ended fluorescent light fixtures are not required to undergo UL testing for safety, many manufacturers have the capability to perform UL testing in-house because of other product lines that require testing for UL labeling. In order to reduce the onus on the manufacturers, UL testing apparatus was used to measure the ballast case operating temperature. It is important to note, however, that, even though the apparatus was the same, this testing was done to measure ballast case operating temperature for performance, not safety. In other words, the location of the thermal probes and the maximum allowable ballast case operating temperatures were different than those required in the UL testing. The LRC contacted ballast manufacturers to identify location on the ballast where the thermal probes should be placed and maximum allowable temperature prior to conducting the heat test. In addition to measuring operating ballast case temperature of the lamp/ballast systems inside the fixture, it was also important to conduct the measurements of the operating ballast case temperature of the lamp/ballast systems outside the fixture in order to verify the ballast case operating temperature before the lamp/ballast system was placed inside the fixture.

Voltage testing. The goal of this pilot test was to measure the impact of high and low supply voltage on premature failure of ENERGY STAR light fixtures. An extensive literature review was conducted to establish the high and low supply voltage levels typically found in residential applications. If the fixture was equipped with a diffuser, it was removed for heat control. To eliminate switching as a cause of failure, constant power was used and the lamps were on 24 hours a day.

To standardize electric equipment manufacturing across the country, ANSI and NEMA have established voluntary standards[11] for acceptable supply voltage ranges at the customer's meter. Most utilities are required to provide service for typical residential lighting loads at least as strict as ANSI Range A (110V to 127V). Range B (106V to 127V) has been established as the acceptable range for lighting loads. Informal interviews with utility representatives confirmed that ANSI Ranges A and B are reasonable expectations for residential service.

ENERGY STAR fixtures are probably subjected to other supply voltage stresses beyond control of the electric utility. Electronic equipment (such as unprotected electronic ballasts) can be damaged or destroyed by short bursts of high supply voltage, known as "surges," "spikes," or "transients." Some surges are generated *before* service to the residential meter due to lightning strikes or car accidents at substations or transformers. However, utilities across the country report that 80% of power quality problems such as supply voltage surges are due to devices switching on within the home, such as air conditioners, refrigerators, sump pumps, washing machines, dishwashers, and vacuum cleaners.[12,13]

These types of switching surges can occur many times a day in a typical American home. Electronic rust (damage to electronic circuitry due to surges) is cumulative in its wear and tear on unprotected electronic components.[14,15] Over time, exposure to normal surges will cause unprotected electronic circuitry to fail. Electronic rust can be prevented with the use of surge protection devices.

For this reason, surge suppression capability ("transient protection") is required by ballasts used in ENERGY STAR fixtures.[16,17] As with other requirements in the ENERGY STAR specification, it may be valuable to confirm that these requirements are being met. Projects such as the PEARL program can perform spot checking of surge protection of ENERGY STAR products.[18]

For the purpose of this project, it was important to verify whether high and low supply voltage is associated with premature failure, so that a recommendation for additional protection is required prior to qualifying for the ENERGY STAR label.

Methods and Results

Roundtable Discussion, 31 October 2001

In fall 2001, the LRC hosted a roundtable discussion concerning durability testing for ENERGY STAR fixtures. Participants at the roundtable made the overwhelming prediction that elevated temperatures were the cause of premature failures in some ENERGY STAR fixtures. Other research has shown that ENERGY STAR fixtures are returned because of premature failure, and that elevated temperature is a likely cause of such failure.[19] Electronic ballasts are particularly susceptible to failure due to elevated temperatures, and since the ENERGY STAR program is gradually eliminating magnetic ballasts, temperature testing will become increasingly important.

Additional, secondary causes addressed at the roundtable included ballast/lamp mismatch, poor electrical connection, inappropriate ballast/lamp starting characteristics, high current crest factor, and defective design or usage of components used within a product.

Roundtable participants indicated that beyond basic temperature testing, it may also be valuable to "weed out" poor quality products from the ENERGY STAR list. The NEMA/ALA (American Lighting Association) matrix (http://www.nema.org/lampballastmatrix) lists lamps and ballasts that are pre-approved for use in ENERGY STAR fixtures, because they are considered high quality. The products on the list will not require other life testing because these products follow ANSI standards.

Roundtable Discussion, 20 September 2002

A second roundtable discussion, again arranged by the LRC, was held in fall 2002. Compelling evidence was shown that heat, indeed, is a likely cause of premature failure in fluorescent fixtures (see Pilot Studies section below). In addition to presentation of the methodology and results for sample selection of pilot temperature and stress testing, an interaction study was suggested, as a follow-up, to investigate interaction such as heat vs. stress, heat vs. stress vs. low voltage, and heat vs. stress vs. high voltage.

Voltage variation was targeted as a possible cause of failure. As a result, the LRC interviewed industry experts and conducted a literature review of typical voltage variation in residences. The LRC also conducted a third pilot study to measure the impact of high and low supply voltage on premature failure of ENERGY STAR light fixtures.

Pilot Studies

Temperature Testing

Consistent with the literature review and as pointed out in the roundtable held in October 2001 (and also in the subsequent roundtable held in September 2002), it is in the best interest of any manufacturer to test the temperatures within their products, since this will identify overheating conditions that will undermine product durability and long-term performance. Many manufacturers have the capability to perform this testing in-house because of other product lines that require testing for UL labeling.

Following the roundtable, contacts at the ALA[20] reported that many types of fluorescent fixtures are not required to have temperature testing in order to earn UL approval. As a result, fluorescent lighting products may be commercialized without any temperature testing whatsoever. Since UL exempts many fluorescent lighting products from temperature testing, and since UL testing is aimed not at product performance but product safety, a modified temperature testing procedure should be developed for the ENERGY STAR durability specification.

To follow up on these recommendations, the LRC has performed temperature pilot testing on ENERGY STAR fixtures (figure 3). One purpose of this pilot testing was to sample actual temperature conditions in operating fixtures. The second purpose of this pilot testing was to develop the testing procedure for manufacturers to follow before putting an ENERGY STAR fixture on the market.

Figure 3. Temperature testing of ceiling mounted and recessed light fixtures

Sample Selection

Based on the experience of the roundtable participants, recessed and ceiling-mounted compact fluorescent fixtures were predicted to be the most likely to overheat. Focusing on these product types, the LRC sought one sample from each of the manufacturers participating in the ENERGY STAR program at the end of 2001. A total of 29 products were tested, of which 22 were ceiling-mounted and 7 were recessed. Of the 22 ceiling-mounted samples, 12 were magnetically ballasted, and 10 were electronically ballasted. All 7 of the recessed samples were electronically ballasted.

Once sample products arrived, the LRC consulted ballast engineers wherever possible to determine thermocouple testing locations and maximum acceptable temperature limits.

Testing Setup and Methodology

Refer to Appendix I.

Temperature Pilot Test Results

For many of the tested samples, maximum ballast temperature limits were listed at 90°C. The LRC contacted as many of the ballast engineers as possible to inquire about the basis of these limits. As expected, many engineers indicated that temperature limits were based on safety, not on ballast performance. If "performance" were the basis for temperature limits, it stands to reason that many temperature limits would be reduced from current levels. Indeed, the NEMA/ALA matrix[21] currently lists 135 electronic ballast products — all of which have a maximum temperature of 65-75°C. Only magnetic ballasts on this list (totaling 12 products as of March 2003) are rated for 90°C. See Table 1 for LRC temperature testing results.

Table 2 shows the percentage of pilot test fixtures that would have exceeded the maximum allowable ballast operating case for the following criteria: 90°C, 75°C and 65°C. At the 75°C temperature performance limit, the operating ballast case temperatures of at least half of the ceiling fixtures exceed the limit. If temperature limit for performance is 65°C, the operating ballast case temperatures of at least 90% of the ceiling fixtures exceed the limit. Figure 4 shows the temperature testing results for all the products tested.

Based on the recommendations from industry roundtables and the results of this temperature pilot testing, the LRC recommends that a temperature testing procedure be incorporated into the durability portion of the ENERGY STAR specification. The proposed testing method is included in Appendix I.

It is important to note, however, that the samples tested in this project were just a small representation of what is currently available in the market, but it probably represents typical temperatures inside the fixtures. Even though more research could be done, it is recommended that the EPA immediately take action with regard to heat management inside fixtures.

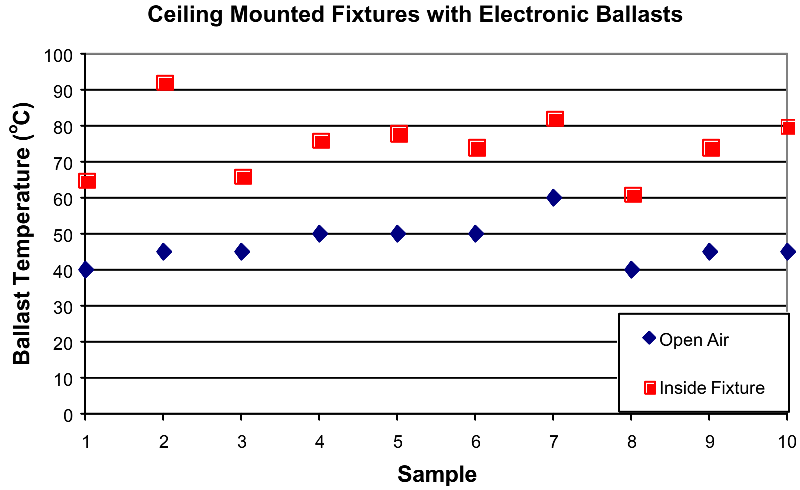
Table 1. Temperature test results

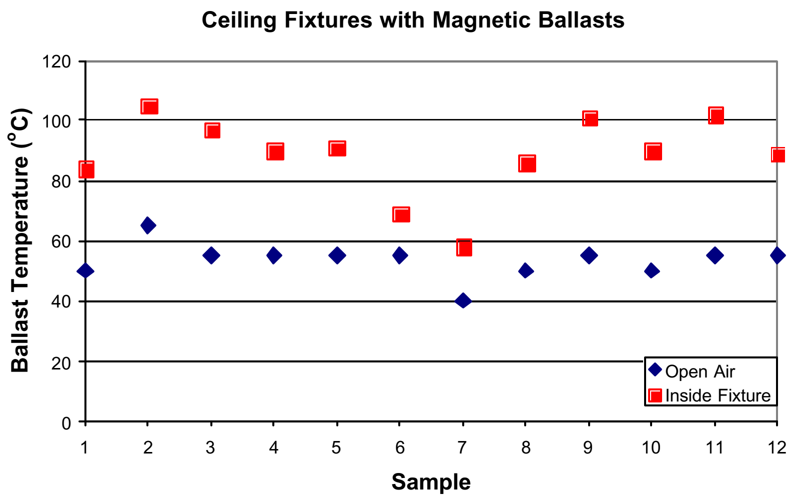
	<64°C	**65-74°C**	**75-89°C**	**90°C+**
Ceiling mounted fixture, magnetic ballast (n=12)	8%	8%	25%	58%
Ceiling mounted fixture, electronic ballast (n=10)	10%	40%	40%	10%
Recessed fixture, electronic ballast (n=7)	71%	14%	0%	14%

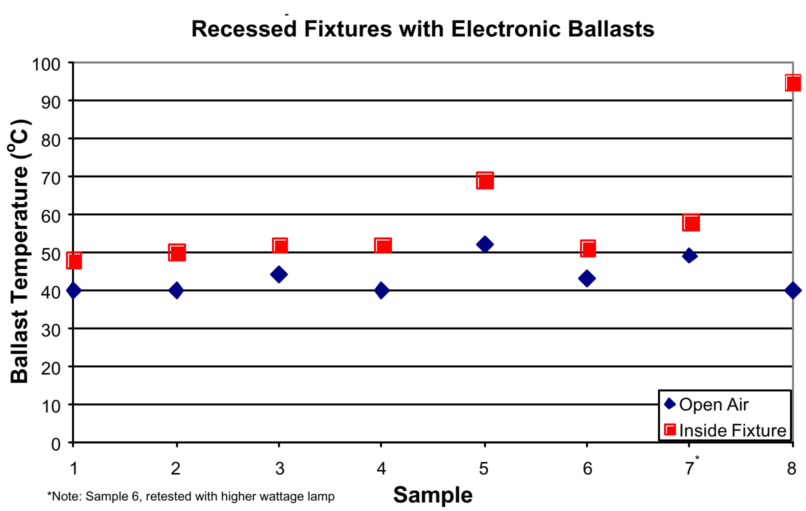
Table 2. As maximum allowable ballast operating case temperature becomes more strict, percentage of samples exceeding limit

	90°C+	**75°C**	**65°C**
Ceiling mounted fixture, magnetic ballast	58%	83%	92%
Ceiling mounted fixture, electronic ballast	10%	50%	90%
Recessed fixture, electronic ballast	14%	14%	29%

Figure 4. Temperature testing results — electronic ceiling, magnetic ceiling, and electronic







Stress Testing

At the time that the LRC proposed to perform stress testing, the ENERGY STAR CFL specification was requiring a rapid-cycle test, with a 5-minutes on/5-minutes off operating cycle. The reason for this requirement was that the standard cycle (3-hours on/20-minutes off) testing time would be too long and did not predict lamp failure when operating on rapid-cycle testing. Furthermore, the lighting industry had been discussing the possibility of using rapid-cycle testing (5-minutes on/5-minutes off operating cycle) as an acceptable alternative to standard life testing. As discussed above, it is important to note that this cycle rate will not necessarily be appropriate for all applications in which the products will be used. A rapid-cycle test does not account for evaporation of emissive coating due to the operation of the lamp and may not have sufficient on-time duration to replicate the heat produced inside some of these fixtures. In addition, different lamp/ballast combinations may result in different lamp life. Finally, passing the durability testing does not guarantee that the same product will achieve its rated life because the failure mechanisms are probably different.

It was important, however, to conduct rapid-cycle testing that would stress the system and quickly identify any starting and operating electrical characteristics of the ballast that may damage the lamps.

Sample Selection

Nine products with typical lamp/ballast combinations found in ENERGY STAR fixtures were tested. Six samples of each product were selected from readily-accessible ENERGY STAR lighting products using the same product types as acquired for temperature testing. Samples were selected to represent a range of lamp wattages, from 13W CFL through high-wattage, Circline® lamps. Samples were not selected based on ANSI or IEC standards, price, nor any other potential indicator of quality.

Testing Setup and Methodology

The LRC conducted the testing in its Watervliet, NY facility. Lamps and ballasts were removed from the fixtures and placed in racks in a base-up position. One lamp rack system was built for this study with five "shelves" that held 32 lamps. A 45 kVA voltage regulator (120V ±0.5%) regulated the power to the lamps. A computer monitored and controlled the testing, ensuring the operating cycle was 5 minutes on/5 minutes off. Ambient temperature in the test lab was 25°C ±10°C. Lamps were "seasoned" for 100 hours before the testing began.

A visual inspection method was selected for measuring lamp failure because it is a simple, inexpensive and effective way of collecting this type of data. Lamps were operated on this rapid cycle test until failure. Lamps that had not failed as of April 30, 2003 were manually turned off.

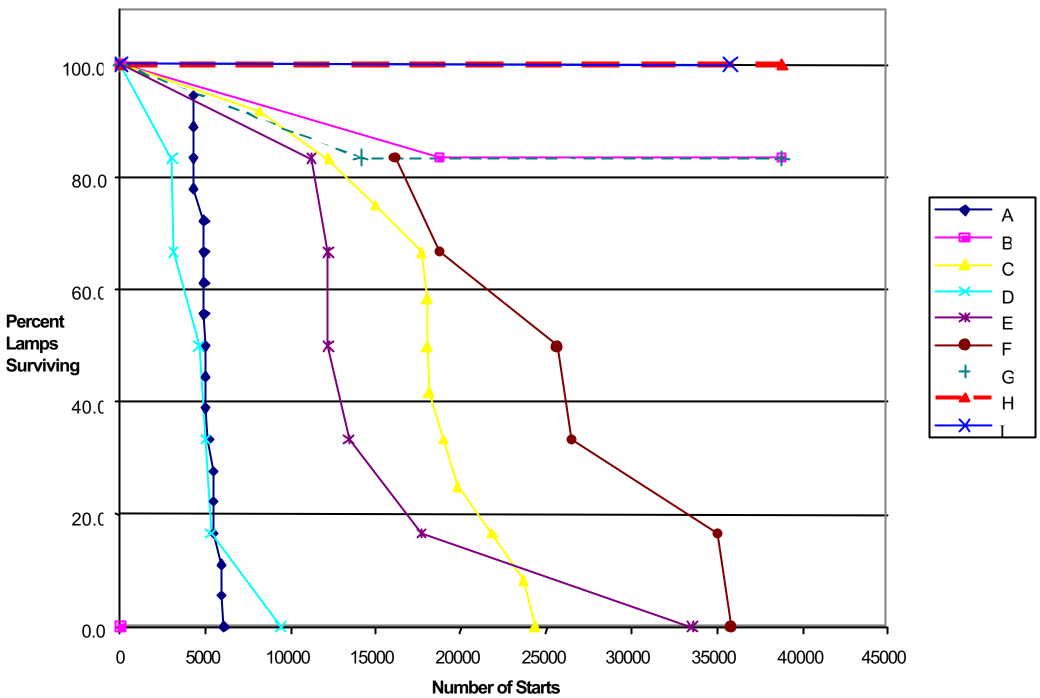
Figure 5. Stress testing apparatus

Stress (Rapid Cycle) Pilot Test Results

Figure 6 shows the total number of starts each product completed until failure. The number of starts varies for each product tested. Two products failed very prematurely, neither achieving 10,000 starts, while the other seven products were still performing after approximately 32,000 starts. At the time this test was initiated, the ENERGY STAR CFL specification was requiring that the lamp had one start for every two hours of rated life. For example, if a lamp rated life was 10,000 hours, 5000 starts were required to pass the rapid-cycle test. Based on the results of this pilot study, the minimum number of starts required could be higher than 5000. The majority of the products tested here (7 out of 9 tested products) had at least 20,000 starts.

Manufacturers claim, however, that conducting this type of testing is very expensive and time consuming because of the various possible lamp/ballast combinations. They assure that, if the lamp and the ballast are ANSI compliant, there is little need to perform this type of testing. The results of this pilot test cannot support or reject this hypothesis because it was not designed to test it. More literature review and possibly testing are needed to confirm this hypothesis.

Figure 6. Pilot stress test lamp failure summary



Supply Voltage Testing

The LRC initiated discussions with participants from the two previous durability roundtables to develop a pilot testing method for measuring the impact of high and low supply voltage on life of typical ENERGY STAR fixtures.

Since surge suppression capability ("transient suppression") is required by ballasts used in ENERGY STAR fixtures, the LRC focused their efforts on investigation of constant under- or over-voltage. The LRC opted to run a pilot test ofcommon ENERGY STAR fixtures to determine whether this type of voltage problem is a likely cause of premature failures.

Sample Selection

In order to make sample selections of products, the LRC sought advice from Meghan Hoye of ICF Consulting for recommendations of most common lamp wattages. In addition, the LRC enumerated entries in ICF's overall product list to determine common lamp and ballast types. The LRC focused on samples using 13W twin tube and double twin tube lamps, 30W Circline lamps, and 40W double-Circline lamps. All samples were electronically ballasted. The LRC identified two examples of products in each of these categories and purchased six samples of each.

Testing Setup and Methodology

Figure 7. Voltage regulators

The LRC used the information gained in the literature search to establish extremes of residential voltage conditions: 104 V and 130 V. Using separate voltage/power regulators (Chroma Programmable AC Source 6408), two samples of each of the six products were subjected to the under voltage condition (104 V). Concurrently, two samples of each product were operated at the over voltage condition (130 V). Control samples were operated at normal voltage (120 V) to allow any voltage failures to be distinguished from failures due to poor quality components.

The samples were operated for 24 hours a day, 7 days a week, at the constant over- or under-voltage conditions. Constant power was used to eliminate switching as a cause of failure. Diffusers were removed from fixtures to eliminate elevated temperature as a cause of failure.

Daily monitoring was done to note any lamp or ballast failures. Replacement lamps were pre-ordered at the start of testing so ballasts could continue to operate in the test condition.

Figure 8. Voltage pilot test apparatus

Voltage Pilot Test Results

After eight weeks of constant operation, the fixture samples modeled residential use equivalent to 64-96 weeks. This projection is based on the assumption that typical residential fixtures are in use for 2-3 hours per day.[22,23]

Over the course of eight weeks, ***no failures*** occurred in any of the samples, neither with lamps nor ballasts. Fixtures were then subjected to three more weeks at even greater voltage extremes, ±30% of nominal (84 V and 156 V). Still, no failures occurred.

Based on this voltage pilot test, it appears likely that constant over-voltage or under-voltage conditions are ***not*** a primary cause of premature failure of ENERGY STAR fixtures. No testing method will be developed for inclusion in the ENERGY STAR specification, at least until the interaction between voltage, temperature, and rapid cycling are further investigated.

Conclusions

The pilot tests presented here were an attempt to investigate whether:

- elevated temperature inside the fixture results in elevated ballast case operating temperature;
- starting and operating electrical characteristics of the ballasts could damage lamps;
- supply voltage variation could impact the ballast starting and operating electrical characteristics.

When shown to have an effect on the premature failure of ENERGY STAR residential light fixtures, appropriate testing methods that would help "weed out" products that are likely to fail prematurely were developed.

Temperature Testing

Based on manufacturers input and literature review, it was established that heat was a key factor associated with premature failure of light fixtures. Pilot studies were then conducted to measure ballast operating base case temperature inside certain types of residential light fixtures. UL testing procedure and apparatus were used as a way to simplify the testing for manufacturers. The results of the pilot tests showed that, indeed, ballast case operating temperature inside some of the fixtures exceeded maximum recommended temperature for performance. After some *a priori* investigation, the LRC had found that maximum recommended ballast operating case temperature associated with performance ranged from 65°C to 75°C. At least half of the ceiling mounted fixtures exceeded 75°C and more than 90% of the tested ceiling fixtures exceeded 65°C. Based on these results and because temperature testing for many single ended fluorescent lamp fixtures is not currently required by UL, the LRC recommends that temperature test be done on ENERGY STAR residential light fixtures according to the proposed durability testing method described in the Appendix I.

Stress Testing

With regard to the stress test, or the rapid cycling test, the results of the pilot study were inconclusive. Manufacturers expressed concerns about having to conduct testing on all possible lamp/ballast combinations, which would be very expensive for them. They claim that as long as lamps and ballasts are ANSI compliant, compatibility should not be a problem. The results of the pilot tests do not support this hypothesis, but are not sufficient to support the opposite conclusion either; the rapid cycling test was not set up to investigate whether ANSI compliant lamp and ballast systems were more or less likely to fail prematurely. Until more research is conducted, the LRC recommends that, as an interim step, all ENERGY STAR lamps and ballasts be ANSI compliant. By no means, however, does this reduce uncertainty as to premature failure(s) or that the products will meet rated life.

Voltage Testing

Transient protection is already included in the ENERGY STAR specification, so no additional requirements are necessary. Protection for constant over-supply voltage or under-supply voltage is not part of the current specification, but does not appear to be a primary cause of premature failure of ENERGY STAR fixtures.

Interaction of Rapid Cycling, Voltage, and Temperature

Despite the fact that voltage alone is not likely to be a cause of premature failure of these systems, it is possible that voltage combined with elevated temperatures or rapid cycling could be problematic. Participants at the second roundtable discussion recommended that future projects investigate these possible interactions.

The LRC has attempted to lay the foundation for this future work. In December 2002, the LRC organized conference calls to discuss procedure for design of experiment ("doe") interaction of temperature and voltage. Attending these conference calls were Jerry Laverdiere and Howard Wolfman of OSRAM SYLVANIA, and Al Rousseau of Philips.

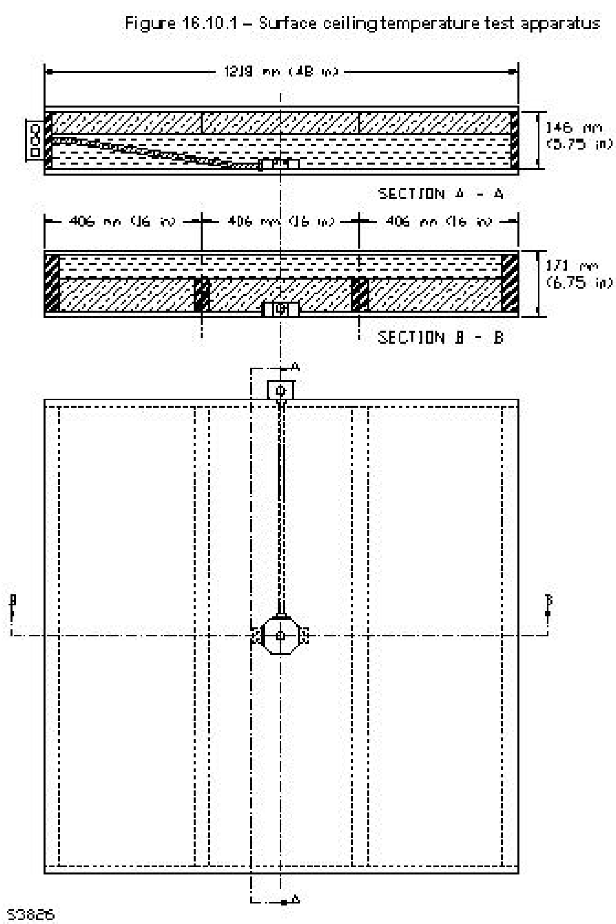
Subsequent to these meetings, Mr. Laverdiere has provided a "Minitab Project Report" to organize experimental design efforts. However, testing for the interaction between these three issues (stress, heat, and voltage) was beyond the scope of work of this project. The design of experiment ("doe") method could be used to determine the most efficient way to design an experiment to test for these interactions in the future.

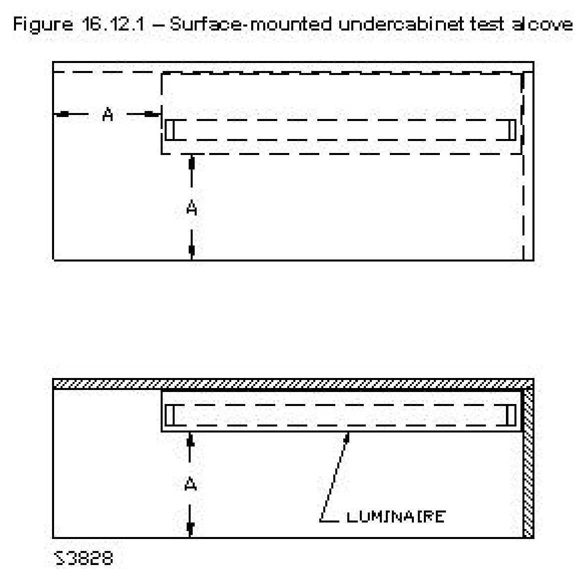
Appendix I

Proposed Durability Testing Method: Temperature

1. Selection of Fixture Types Criteria
   The LRC proposes to require manufacturers to perform the durability testing method for non-IC (not intended for insulation contact) recessed fixtures and surface mounted fixtures. If more than one lamp wattage can be used inside the fixture, testing be conducted using the highest possible wattage. If different ballasts are used inside the fixture, measurements using each ballast are required. Testing is required for every diffuser type and housing material (to be determined).
2. Sample quantity
   Manufacturers will be required to measure one sample of each fixture type and model, according to criteria detailed above.
3. Testing location
   Testing shall be conducted in a room with ambient temperature of 25°C ±5°C.

Figure 9. UL testing apparatus for surface-mounted luminaires, "normal" conditions

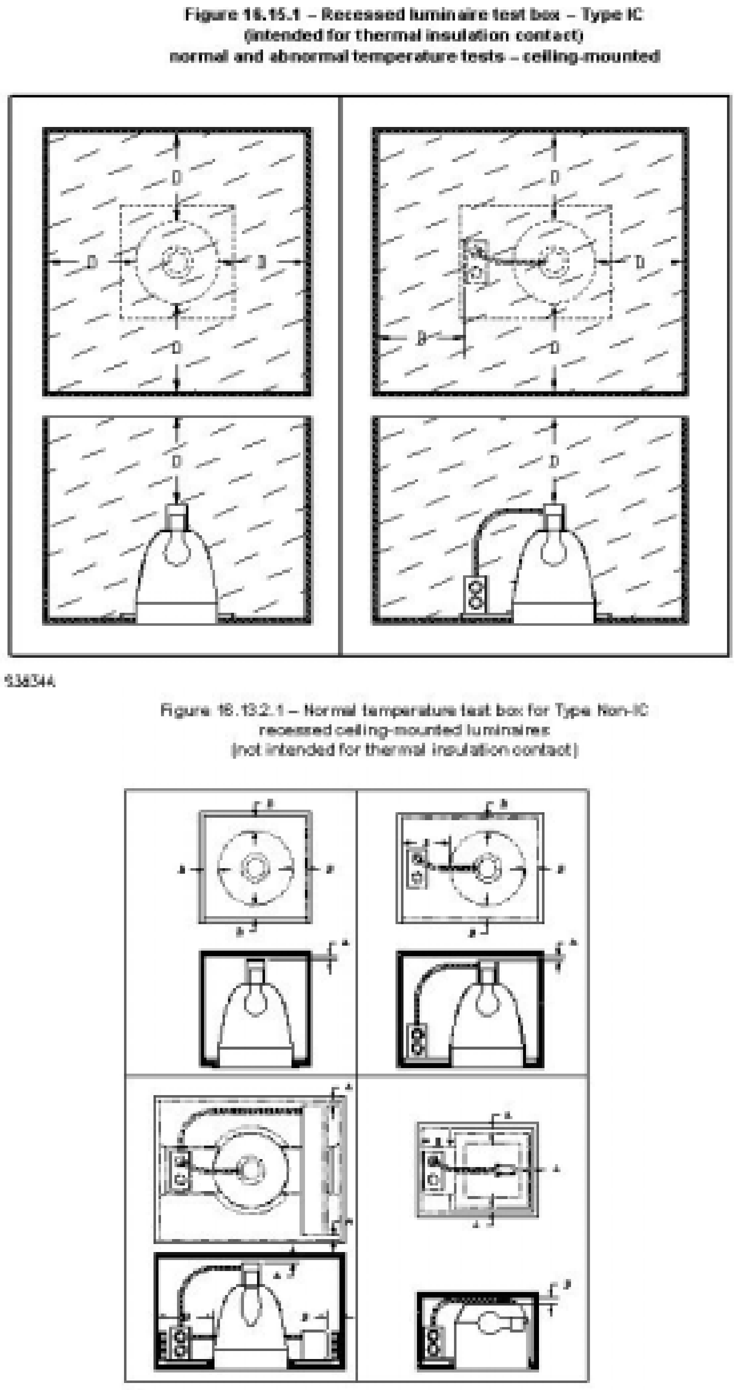




Source: UL Standard for Safety for Luminaires, UL 1598. 1st Ed., January 31, 2000

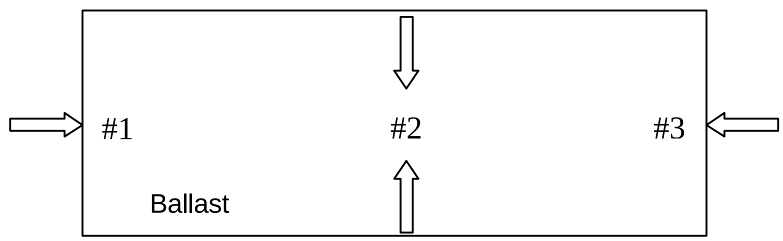
4. Apparatus
   Underwriters Laboratory (UL) has established a thermal testing procedure and apparatus for safe operation of electric fixtures. The apparatus construction techniques for ENERGY STAR durability testing should follow those described in UL 1598 for normal temperature testing, but thermocouple locations will be different than the ones required by UL.

Figure 10. UL testing apparatus for IC-rated and non-IC-rated recessed luminaires, "normal" conditions



Source: UL Standard for Safety for Luminaires,
UL 1598. 1st Ed., January 31, 2000

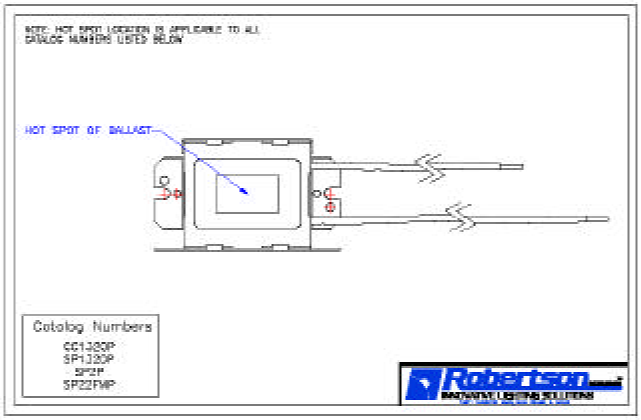
5. Procedure
    a. Fixtures shall be connected to the apparatus in the manner described in UL 1598.
    b. Thermocouples will be placed on the ballast in the locations indicated by the ballast manufacturer. This information should be listed in the NEMA/ALA matrix, and/or clearly marked on the ballast, and/or clearly stated in the ballast manufacturer's literature (printed or web site). If more than one location is indicated, temperature measurements are to be made in every location. If none of the sources cite this information, thermocouples must be placed in three locations on the ballast: one on each edge of the ballast (# 1 and # 3) and one on the center of the ballast (# 2). See sketch below.

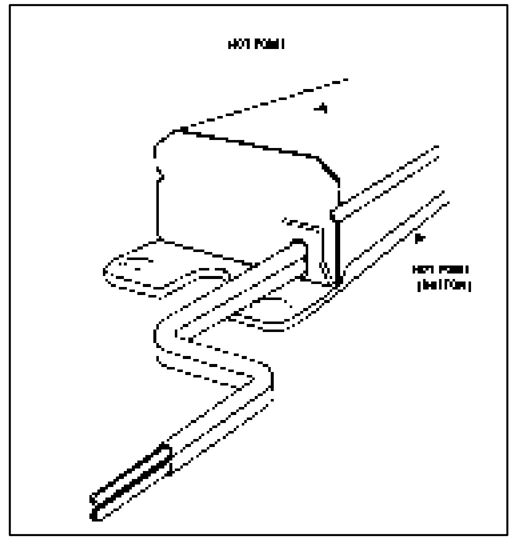


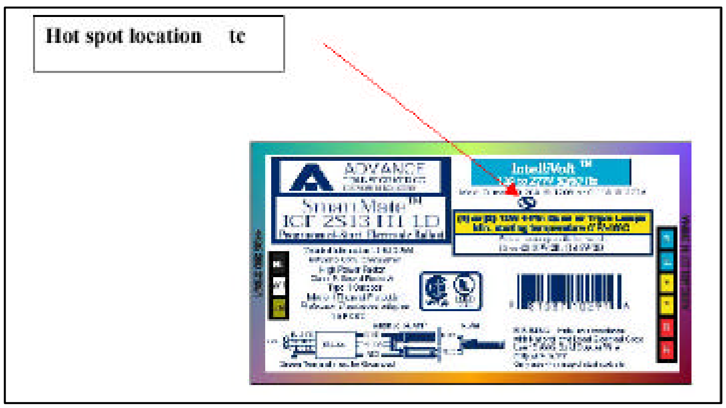
Locations on the ballast (1, 2, 3) where thermocouples should be placed only IF no sources cite locations on the ballast where measurements should be made.

    c. In addition to thermocouple location, ballast manufacturers shall also indicate the maximum allowable ballast case operating temperature for optimum performance. This information shall be listed in the NEMA/ALA matrix, and/or clearly marked on the ballast, and/or clearly stated in the ballast manufacturer's literature (print or web site). If none of the sources cite this information, the fixture manufacturer should assume that the maximum allowable ballast case operating temperature is 65°C at the indicated location or, if not indicated, at any of the 3 locations shown in the diagram above.
    d. Stabilization time shall be a minimum of 7.5 hours. Fixtures must be operating inside the testing box for a minimum of 7.5 hours before any measurements are taken.
6. Documentation
   The LRC recommends that the EPA request the following documentation from each manufacturer:
    a. Photograph(s) of testing apparatus mounted on the testing apparatus
    b. Documentation from ballast manufacturer indicating location and maximum allowable temperature for ballast performance. If this information is included in the NEMA/ALA matrix, no other documentation is required.
    c. Temperature at the start of testing and after 7.5 hours of stabilization.

Figure 11. Examples of temperature testing locations to be provided by ballast manufacturer







Courtesy: Robertson, Magnetek/Universal and Advance Transformer

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