Transitioning from Incandescent to CFL and LED Lighting: As Simple as Changing Bulbs?

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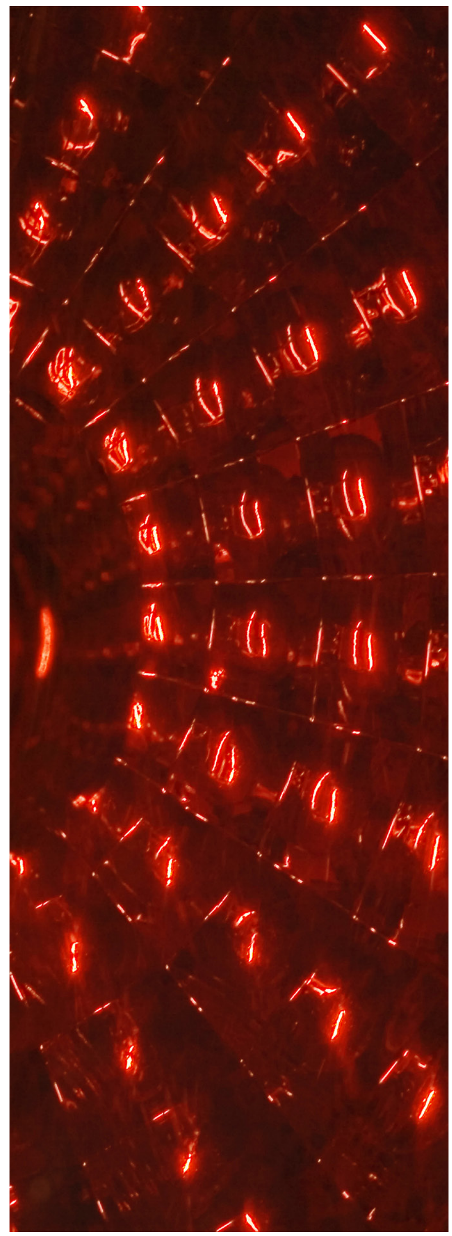

In a move sparked largely by the drive for increased energy efficiency, government legislation and increasingly lower costs, much of the developed world is transitioning away from traditional incandescent lights to more energy-efficient compact fluorescent (cfl) and light-emitting diode (led) lighting. However, questions regarding the proper use and function of these lights, along with related safety concerns, show the need exists to quickly reach manufacturer and consumer consensus on how to most effectively use this new technology to reap its full benefits.

The evolution to CFL and, eventually, LED lighting currently underway is being driven by state and federal energy efficiency initiatives as well as buy-in by retailers and consumers as costs have dropped. These newer lighting technologies differ significantly in their electrical properties from incandescent lighting, yet they are required to function in homes and businesses primarily via hardware and fixtures designed for the older technology. The potential safety impact of the cumulative effect of this transition has not been fully explored in either U.S. safety standards or codes.

The March of History

Incandescent light sources based on Thomas Edison's original patents have been in use for over 125 years, which has made them the standard for artificial lighting for more than a century. The relatively rapid move toward CFL and LED lighting represents the biggest leap forward in this technology since electric bulbs replaced gas lamps and candles.

Fluorescent lighting made its first public appearance at the 1939 World's Fair in New York. It uses a very different technologyfor producing light than the incandescent lamp, namely a gas-discharge where electricity excites a mercury vapor. But even with its added complexity, today's evolved compact fluorescent lighting continues to gain favor because it converts electrical power into light much more efficiently than incandescent.

LED lighting may have an even more promising future as it approaches greater economic and commercial viability. Despite its higher initial costs, installations such as traffic signaling highlight LED's advantages of long life and decreased power usage. Both CFL and LED technologies have the benefits of higher luminous efficiency and reduced power needs when compared with the incandescent technology that preceded them.

In recent years, the escalating push toward greater energy efficiency has placed the newer lighting technologies front-and- center. Additional impetus is now coming from jurisdictions such as the State of California, which encourages the combination of higher efficiency lighting with lighting controls designed to reduce energy use. The country of Australia has taken the further step of mandating the replacement of all incandescent bulbs with CFLs in 2010.

Reliability and Safety Issues

The dramatic growth of CFL technology has resulted in a corresponding increase in complaints from consumers. These complaints largely are related to the unique characteristics of CFLs and lighting controls, and how in combination they may present several potential problems in lighting installations.

Most lighting controls – including solid state switches, motion-detecting switches, occupancy sensors, sound sensors, wireless controls, and dimmers – are designed for use with traditional incandescent lamps. Some CFLs can work effectively with these controls, but many designs are incompatible, with reports of problems ranging from lighting failure to flashing, flickering, unusual noises, poor light output, and reduced product life.

Any of these occurrences alone can be a nuisance to consumers. UL traditionally has not addressed them, since they could be considered performance rather than safety issues. However, further testing seemed relevant to confirm that any incompatibilities between CFLs and lighting controls would not result in fires, shock, or other unsafe conditions.

UL Testing and Results

Following discussions with CFL and lighting controls experts, UL identified four issues for initial studies, including CFL/lighting controls compatibility; potential controller contact damage due to high inrush currents; the substitution of CFLs into light fixtures intended for incandescent lamps; and accurate load modeling.

UL conducted extensive laboratory testing in all four of the areas identified. Testing focused primarily on CFL lamps, with some information gathered on emerging LED technologies, with the following results:

- Substitution into existing fixtures will result in lower temperatures
- CFL lifespan may be reduced when used in fixtures where switches are turned off and on repeatedly
- Contact damage is not significant due to the high inrush currents

In summary, UL's testing and analysis confirmed that current- production CFL lamps are performing well, with no observed safety hazards. Additionally, the study found that consumers may be able to use CFLs more broadly and safely than previously believed.

If a consumer mistakenly places a CFL onto a circuit controlled by a solid-state lighting control a hazardous condition is not likely to result.

No matter what stage your company is in on its journey to safety compliance, UL will help you identify and implement the smartest, most efficient and effective solution based specifically on your company's needs. With a proven track record in product compliance developed over more than 115 years, UL is a respected third-party source to help manufacturers achieve total market access.

This is an introductory paper on materials preselection. This paper is intended for background information and discussion only. This paper should not be relied upon for any purpose other than to gain an overview of this subject area. It is not legal advice and should not be treated as such. If you require specific advice on the subject, you should consult your legal advisors and relevant authorities in your operating jurisdictions.

The Need for Consensus

In the area of CFL/lighting controls compatibility specifically, UL witnessed occurrences of annoying flickering often accompanied by noises. Fortunately, results showed no indications of fire, shock, or casualty hazard from any CFL or controller.

While improvements in technology are leading to improved performance and eliminating end-of-life issues, there is still room for improvement. The potential incompatibility of CFL lamps with incandescent lighting controllers has negative consequences from a marketplace perspective. Consumers expect CFLs and the LEDs that follow to integrate seamlessly with existing technology; anything less may become a steady source of frustration for consumers, retailers and manufacturers alike.

UL favors prompt action on this issue, and proposes forming a consortium along with manufacturers and consumers to forge a consensus that addresses consumers' needs for products that work well together, or are at least clearly marked to explain their intended use.

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Addendum

The following pages provide added technical detail on UL's CFL testing procedures and results.

Selection and Acquisition of Test Samples

Samples of CFL and LED lamps, incandescent lamps, lighting controllers, and light fixtures were purchased from electrical distributors, provided by manufacturers, or ordered from online vendors. All samples were devices that are commercially available (i.e. no prototypes).

Electrical Characteristics of CFL Lamps

Typical Edison-base CFL light sources use a ballast circuit to take AC power (e.g. 120Vac, 60 Hz in North America) and manipulate it by means of electronic circuitry such that the light source is supplied at a design voltage, current, and frequency best for producing light.

Electrical Characteristics of Lighting Controls

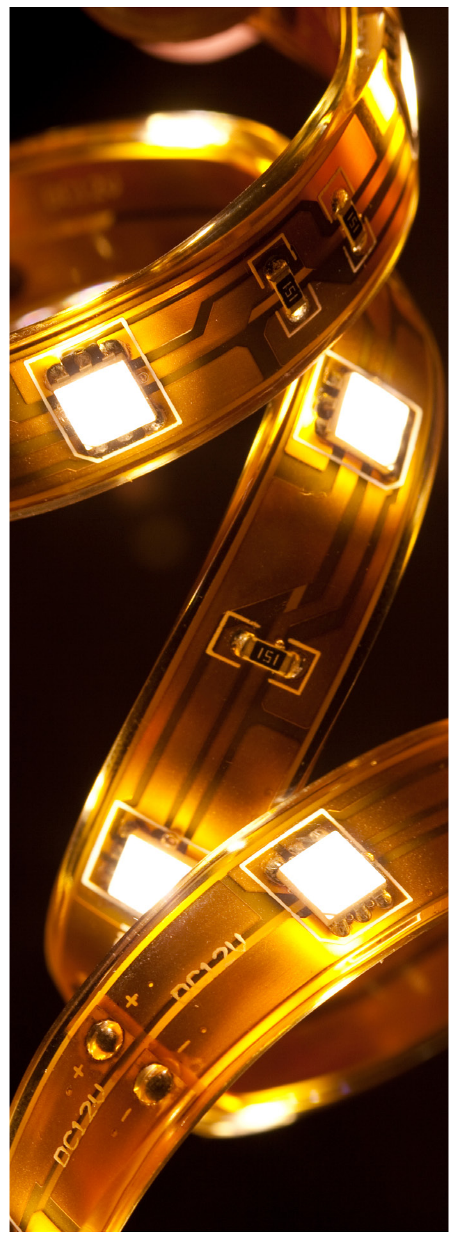
Several technologies are used to control lighting, and since these technologies were designed originally for incandescent loads, each has possible compatibility challenges when used with CFLs. They include:

Air-Gap Switches

The simplest controller is an air-gap switch, such as a traditional snap switch. The contacts of these switches have been designed and tested for the inrush characteristics of incandescent loads, but have not been designed or tested for the high inrush of electronic ballast loads.

Solid-State Controls

Solid-state controls do not use air-gap contacts but rather a semiconductor to open or close the circuit. As with air-gap switches, the semiconductor junctions of these switches have not been designed for the high inrush and Thermal Harmonization Distortion (THD) of electronic ballast loads.



Dimmers

Dimmers for lighting control most often use phase control to adjust the amount of power delivered to the lamp and thus changing the brightness. Special designs of CFLs are possible to allow dimming, but these are more complicated and expensive, and thus have not yet achieved widespread use.

Replacement Controls with No Neutral (Return) Connection

Some controllers, such as certain dimmers and motion detectors normally use a small amount of current (limited to 0.5 mA) even when “off,” using the switch-leg through the resistive lighting load as the return path. This small current is used to operate the con- trol electronics in the device. When the load on these controllers is changed to CFL lamps this small amount of current is enough to charge the capacitor in the CFL circuitry, and when enough charge has built up the CFL will flash briefly, even though the control is in the “Off” position.

Focus of UL Testing

1. Evaluation of compatibility of CFLs with lighting controls
2. Evaluation of controller contact damage due to high inrush currents
3. Substitution of CFLs into light fixtures intended for incandescent lamps

1. Evaluation of Compatibility of CFLs with Lighting Controls

UL sought to evaluate potential safety hazards due to incompatibility of CFLs and lighting controllers. Thirteen different controllers were connected one at a time to control a bank of CFL lamps mounted into recessed light fixtures in a suspended ceiling. The test arrangement is shown in figure[1].

The number of CFLs in the circuit was chosen based on the marked wattage rating of the controller and the marked wattage rating of the CFL lamps. For example a 600-Watt controller would be wired to control fourteen 42-Watt CFLs.

Three different manufacturers’ CFL lamps were installed, with approximately 1/3 of each type, in order to examine the effect of the incompatibility on various lamps. The lamps were designated “X”, “Y”, and “Z”. Each CFL was placed in the fixture with a double layer of cheesecloth surrounding the CFL electronics in order to act as a fire indicator. A layer of cheesecloth was also used as a fire indicator around each controller. Thermocouples were attached as shown below in figure 2 and 3.

The circuit was energized and run for 7 hours after temperatures stabilized. A typical time to temperature stabilization was approximately 1 hour. The appearance of the lighting from incompatible controller/lamp combinations typically showed an inconsistent flickering. Our subjective view of the flickering was that no person would be comfortable with the annoyance of this light output and if possible the user would either fix the problem or turn off the lamps.

Results

The sample controllers and lamps did not operate well together from the perspective of usable lighting, with an annoying flickering and some slight accompanying noise.

Hazard Evaluation

Test results were examined for any hazard due to the incompatible controller/CFL combinations. Attention was given to

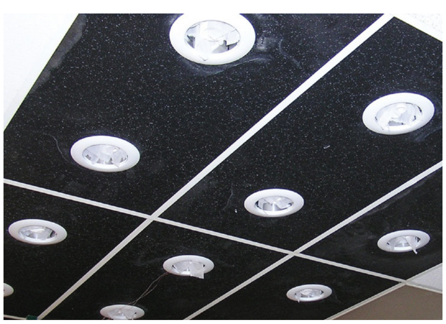


Figure 1: Test Arrangement

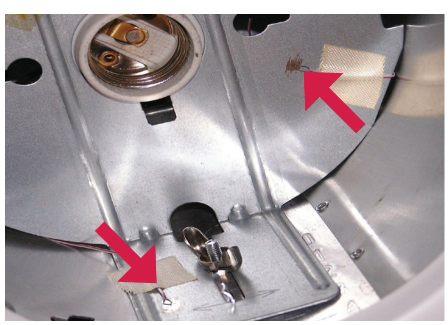


Figure 2: Fixture Thermocouple Locations

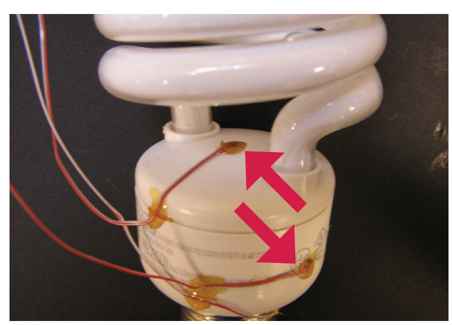


Figure 3: CFL Lamp Thermocouple Locations

both the lamp and the controller to note any indication of:

- **Fire Hazard:** Emission of flames, hot embers, glowing parts, burning or charring of the fire indicator
- **Shock Hazard:** Opening in an enclosure which would expose live parts
- **Other:** Damage to supply wiring, light fixtures, or wiring boxes

Temperature Results

All three lamps obtained predominantly lower temperatures when supplied by incompatible controllers compared to the no-control supply. Out of 39 controller/ lamp combinations, 7 lamps were higher in temperature while 32 were lower. Out of 39 controller/ fixture combinations, 5 fixtures were higher in temperature while 34 were lower.

For the results where higher temperatures were noted, the temperatures were up to 5°C above the no control condition, with the overall average temperature change being minus 3.6°C compared to the no control condition.

The overall thermal effect of incompatible controllers on the light fixtures and lamps is seen to be benign.

The poor-quality lighting output is such that users would be expected to fix the problem or turn off the power quickly, within an hour at the most, but more probably less than a minute. In that case, the incompatibility could be considered a reasonably-foreseeable misuse and the safety requirements for the outcome would be no evidence of fire, shock, and casualty hazards. In the unusual case where an incompatible controller is left on with a CFL load for a long time, the above tests show that temperatures will be comparable to operation with no controller.

While the sample controllers and lamps did not operate well together from the perspective of usable lighting, the result of the testing showed no indication of fire, shock, or casualty hazard from any CFL or controller. The lamps and controllers did not exhibit any obviously dangerous outcomes due to the incompatibility. However, temperatures on some lamps and light fixtures were elevated a few degrees compared to normal operation on direct 120Vac.

Controller	Max. Fixture Temperature °C	Max. Lamp Temperature °C	Lighting Effect	Fire or Shock Hazard	Other Hazard
A1	58	109	Random Flicker	None	None
A2	63	116	Random Flicker	None	None
A3	62	115	Random Flicker	None	None
B1	56	108	Random Flicker	None	None
B2	63	116	Random Flicker	None	None
B3	64	116	Random Flicker	None	None
C	57	109	Random Flicker	None	None
D	61	118	Random Flicker	None	None
E	60	116	Random Flicker	None	None
F	64	115	Random Flicker	None	None
G	66	120	Random Flicker	None	None
H	65	122	Random Flicker	None	None
I	60	116	Random Flicker	None	None

Recommendations

From a safety perspective, it appears that no changes are needed to safety standards or UL requirements.

However, the incompatibility of these lamps and controllers has negative consequences for customer perception, and customers will be frustrated with the products. Faster and more aggressive action is needed by a consortium of manufacturers, consumers, and UL to find a consensus path forward which addresses the customer's need for products which work well together, or are at least marked clearly to show their intended use.

2. Evaluation of Controller Contact Damage Due to High Inrush Currents

High inrush currents may cause large magnetic forces which lead to contact bounce and arcing in air-gap switches. This arcing may degrade contacts and lead to overheating or premature contact failure.

Methods

Four different methods were used to examine the effect on contacts due to the high inrush currents of self-ballasted lamps:

a. Examination of current immediately at contact closing

b. Physical examination of contacts to search for arcing and bounce at contact closure

c. Power integration to indicate arcing at contact closure

d. Comparison of contact damage during closing vs. opening the load

During each method, the circuit impedance was set at 275mΩ in order to consistently replicate the branch circuit impedance normally seen in residential installations. This results in a maximum short circuit current of approximately 435A.

A: Examination of Current Immediately at Contact Closing

The electronic circuit of a self-ballasted lamp presents a changing impedance, resulting in different inrush currents depending on the closing point on the alternating current voltage wave.

This may present an advantage to the switches and controllers which are used to switch the CFL load. Many of the circuit closings of the switch will be at a point when the self-ballasted lamp is going to draw a lower inrush current.

In order to examine this situation more closely, controlled-closing tests were performed on a full bank of CFLs, with the closing angle varied from 0° to 180° on the voltage wave.

- **Results**

  The figure 4 below shows results of the varying current inrush depending on closing angle. The greatest current inrush was obtained at 90° on the voltage wave

- **Analysis**

  The results show that while the maximum inrush current is high, the controller is not always exposed to the maximum. Many of the circuit closings will be when the inrush is considerable lower, and for those circuit closings during these reduced-inrush periods the outcome will be less stress on the contacts and current carrying parts of the switch

  As figure 4 above shows, the inrush current when the circuit is closed near 90° approached a peak of 220A. This is slightly higher than the 191A tungsten-load test inrush

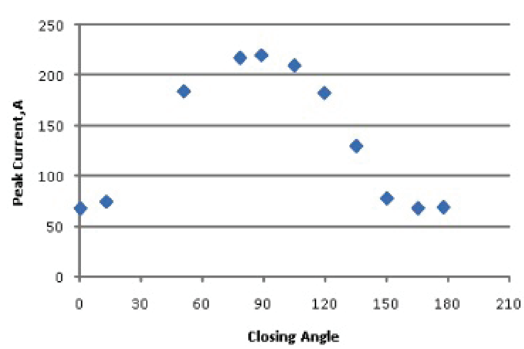


Figure 4: Current Inrush

for a 15A rated switch required by the Standard for Snap Switches UL 20. However, the inrush for the CFL load is of shorter duration than an incandescent lamp, as shown in this comparison (figure 5 and 6).

B: Physical Examination of Contacts to Search for Arcing and Bounce at Contact Closure

When contacts are closed they may "bounce" or "chatter" due to factors such as the springiness of their supports. In addition, if the inrush current at circuit closing is very high, the magnetic field created by the current may be sufficient to cause a magnetic repulsive force which will push apart the current-carrying parts, magnifying the possibility of bounce. Contact bounce is damaging to contacts because the contacts are separating during a high current, causing excessive arcing which vaporizes some of the contact material.

There is no specific current threshold, which can be used as a limit to eliminate this contact separation, because the design of the current-carrying parts, their spring force, and the current path will determine whether the current will be enough to force the contacts open.

Our interest in this portion of the test program is to assess whether the unique waveshape and inrush currents of self-ballasted lamps will cause additional damage to contacts in switches and controllers.

Switch contacts were subjected to 10,000 operations of 1 second ON and 59 seconds OFF with a 1400 Watt load of CFL lamps. This cycle count and rate was chosen to match UL 1472 (Standard for Solid-State Dimming Controls, Clause 5.4 Endurance Test) and to allow the switch and lamps to remain cool in order to avoid any change in the load characteristics.

The testing posed substantial difficulties because the CFL lamps do not survive long in a situation where they are switched 1s On and 59s Off. Hundreds of replacement lamps were needed through all the test cycles, and this led to load variability because lamps would burn out overnight and be replaced in the morning. However, this had the unanticipated side effect of providing many lamp end-of-life events to examine. During the testing, 247 lamps stopped working. Of these, 11 showed slight discoloration of their enclosure, while the remaining 236 showed no external signs.

After the cycling tests the contacts were examined visually to look for excessive wear. Our visual examination did not reveal any obvious problems or damage to the contacts. In fact the contacts, while showing clearly that they had seen arcing from the load, appeared to be in quite good condition with only surface effects. In our judgment the damage to the contacts was not at all substantial and the contacts had many thousand cycles of useful life remaining.

In order to take a much closer look at the contact damage, amples of both the tested contacts and untested contacts were examined by Scanning Electron Microscope (SEM) and Energy Dispersive X-Ray Spectroscopy (EDXS). These methods were not especially illuminating. Therefore, another investigation was required.

Overall, the tested contacts show relatively little damage.

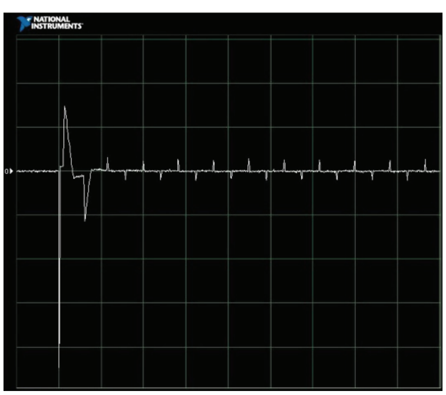


Figure 5: Current Inrush for CFL

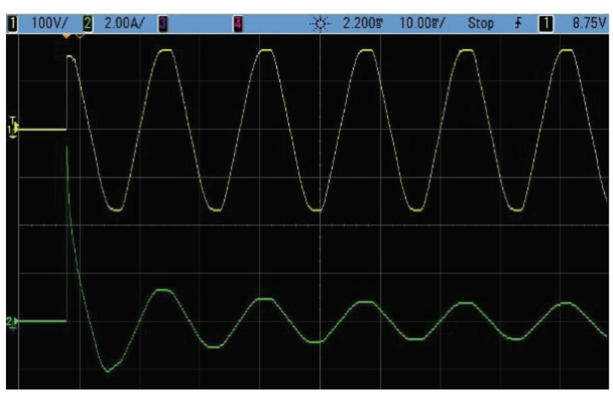


Figure 6: Current Inrush(lower trace) for 60 Watt Incandescent Lamp*

C: Power Integration to Indicate Arcing at Contact Closure

Instrumentation was arranged to measure the current through the contacts and the voltage across the contacts. If the contacts are closed completely there will be a very small voltage drop (almost zero), but if the contacts are arcing there will be a greater voltage drop, which will be observable on the waveform. Multiplying the voltage and current together and graphing the integral of the result shows a measure of the energy, which quantifies the arcing of the contacts during closing.

To begin, a snap switch was used. In order to see the effect of arcing, the contacts were purposely closed very slowly, "teasing" them into drawing an arc that was audible in the switch, and observable in the waveform, as shown in the figure below. The V*I integral over time (energy) during first inrush measured 1.9 Joules. Next, a dimmer switch was tested with firm closing and teased closing 10 times each, while supplying a 600W CFL load (16 lamps). The dimmer switch was chosen because it has a relatively light contact arm and so was seen as a likely candidate for contact bounce during high inrush current. The teased closing establishes the level of V*I that could occur during contact closing.

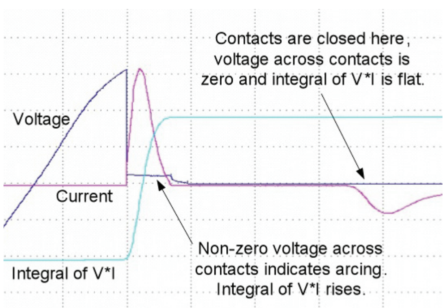


Figure 7: Current Inrush for CFL

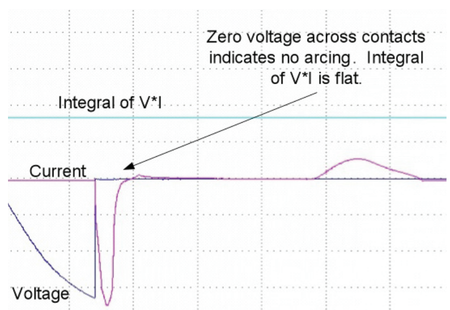


Figure 8: Current Inrush for CFL

- **Results**

	Controller	"Teased" contact closing	Normal contact closing
V*I integral during first inrush	Snap Switch	1.9 J	0.05 J
V*I integral during first inrush	Dimmer Switch Contacts	2.4 J (average of 10 operations)	0.09 J (average of 10 operations)

- **Analysis**

  From the snap switch test the difference between the arc energy measured during "teased" closing and during normal closing was a ratio on the order of 25:1. Thus, this power integration method shows promise as a means to discern arcing at contact closure and to measure the occurrence of bounce and/or arcing.

  The results of the dimmer switch testing also showed that arcing can be discerned by using the power integration method. Under normal closing conditions the V*I integral was extremely small, signifying that arcing at contact closing is very small, and thus the inrush does not appear to be causing any contact bounce.

D: Comparison of Contact Damage During Closing vs. Opening the Load

The load characteristic due to self-ballasted lamps is complex and unusual. The inrush current is very short in duration, but very high in amplitude. However, there will be many closing operations of the contact which are off-peak and do not see the largest possible inrush current. On the other hand, the opening action of the contacts happens when the current is much lower, often 1/20 or less the maximum inrush, and again there will be many operations which occur when there is less than maximum current. Thus it is not at all obvious which contact operation, closing or opening, causes the most damage to the contacts.

This test sought to evaluate and compare the two operations by arranging two identical snap switches controlling a full 1400 Watt CFL load, for 10,000 operations of 1 second ON and 59 seconds OFF. The switches were mechanically operated so that one switch always closed the circuit, and the other switch always opened the circuit. In this way, the contact damage due to closing could be compared with the contact damage due to opening.

- **Results**

  Following the 10,000 cycles a visual examination was performed. The photographs displayed below show a clear distinction with the opening contacts showing much more damage than the closing contacts. On the opening contacts, note the deposition of arcing byproducts on the brass arm, the greater size of the damaged area, and the appearance of a more violently arc-damaged surface.

- **Analysis**

  As a result of this examination it is evident that the contact opening operation draws a more substantial arc leading to more contact damage. This seems surprising given that the inrush current is 20 times or more the steady state current. The high inrush at the initiation of the load is relatively less important to the degradation of the contacts.

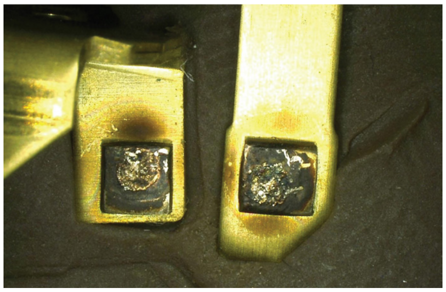


Figure 9: 10,000 Cycle Opening Contacts

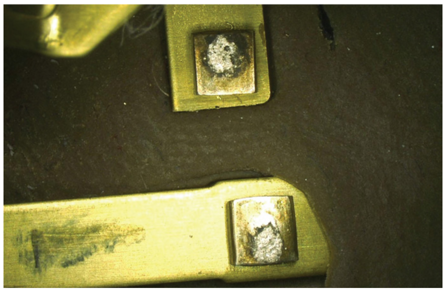


Figure 8: 10,000 Cycle Closing Contacts

Overall Analysis: Controller Contact Damage Due to High Inrush Currents

Based on the four methods and results, the high inrush currents of self-ballasted lamps are unlikely to cause any excessive damage to contacts. Most interesting is the Result in D, which shows that contact opening is the more severe operation for the specific load characteristics of the self-ballasted lamp.

3. Substitution of CFLs into Light Fixtures Intended for Incandescent Lamps

Background

A CFL which has the equivalent light output of a traditional incandescent lamp uses approximately one quarter the electrical power of the incandescent lamp. Thus it has been broadly assumed that substitution into recessed light fixtures can be done with no safety impact. Consumers tend to overlamp because the CFL may appear less bright when turned on,and they believe there is no problem with the substitution. From a current load standpoint alone this substitution should present no problems, but the effect of the waveshape and the unique size and shape of the CFL lamp were unknown.

Objective

This investigation sought to evaluate potential thermal hazards due to substitution of CFLs into previously installed light fixtures.

Methods

Three different methods were used to examine the thermal effects on installed fixtures:

a. Direct substitution of CFLs for incandescent lamps

b. Comparing Incandescent Lamps to CFLs with Incompatible Controllers

c. Comparing CFLs with No Controller to CFLs with Incompatible Controllers

A: Direct Substitution of CFLs for Incandescent Lamps

Three lighting fixtures were used for this test. Two of the fixtures (A and B) were recessed into a suspended ceiling, and one fixture (C) was a hanging pendant type. The fixtures chosen were residential-type, low-cost fixtures. Temperatures were monitored until stability with several ratings of incandescent and CFL lamps. For each fixture, two CFLs from different manufacturers were tested and the results compared to an incandescent lamp.

- **Results and Analysis**

  Results show that the maximum temperatures of fixtures with CFL lamps are much lower than incandescent lamps with equivalent light output. This was an expected outcome since CFL lamps are much more efficient in their production of lumens per Watt. However, the results also show that the highest temperature CFL lamp resulted in fixture temperatures lower than the coolest incandescent. This is an important finding which suggests that upsized CFLs may be substituted into existing fixtures with no reduction in safety.

- **Recommendations**

  Overlamping of incandescent fixtures with upsized incandescent lamps has long been a serious safety concern. With CFLs, substituting of the incandescent with an equivalent light output CFL lamp provides a lower-temperature outcome and thus provides a thermal benefit. Based on the analysis of the temperature tests in this investigation, an upsized CFL would be acceptable as a substitute, but this presents an application dilemma because oversizing of incandescent lamps has always been strongly discouraged.

B: Comparing Incandescent Lamps to CFLs with Incompatible Controllers

The next step in the evaluation of temperatures was to compare fixture temperatures when the self-ballasted lamps were controlled by dimmers and motion detectors. Controllers were specifically chosen for poor coordination with the CFL lamps, causing flickering and poor light output. The testing was intended tofind if the poor coordination between these controllers and the CFL lamps would result in increased temperatures in the fixtures.

For this comparison, a variety of commercially available dimmers and motion detectors were placed in the circuit.

Dimmers were set to 80% of their rated output by the use of an incandescent lamp load. (Example: For 80%, an incandescent lamp which drew 0.5A while on a dimmer set to 100% would be adjusted to allow 0.4A, and then a CFL was substituted into the fixture.)

The 80% point was chosen where it was found to be a setpoint which would cause incompatible operation of the controllers and lamps.

- **Results and Analysis**

  Results show that the maximum temperatures of fixtures with CFL lamps when supplied by incompatible controllers are much lower than incandescent lamps with equivalent light output. As in Investigation A, the results also show that the highest temperature CFL lamp resulted in fixture temperatures lower than the coolest incandescent. The results reinforce that even in an incompatible combination, any size CFL can be substituted into existing fixtures with no reduction in safety.

C: Comparing CFLs with No Controller to CFLs with Incompatible Controllers

The final step was to compare fixture temperatures for self-ballasted lamps with no controller to temperatures when the self-ballasted lamps were controlled by incompatible dimmers and motion detectors. Controllers were specifically chosen for poor coordination with the CFL lamps, causing flickering and poor light output. The testing was intended to find if there is a consistent way to compare or predict temperatures for CFLs with and without incompatible controllers.

Dimmers were set to 100% or 80% of their rated output by the use of an incandescent lamp load.

- **Results and Analysis**

  These results do not lead to a clear conclusion since there was no consistent scenario where one application was higher in temperature.

  Overall Analysis: Substitution of CFLs into light fixtures intended for incandescent lamps

  Based on the three methods tested and results achieved, the substitution of CFL lamps into incandescent fixtures results in considerably lower temperatures and no decrease in safety.

  When the CFL lamps are supplied by incompatible controllers the temperatures are consistently lower than with incandescent lamps.

  The temperatures between CFL lamps with no controllers vs. those with incompatible controllers are not consistently related, and no conclusive result was seen.

For additional information about the Transitioning from Incandescent to CFL and LED Lighting: As Simple as Changing Bulbs? white paper, please contact Fan He, PhD, Research Engineer, Electrical Hazards at Fan.He@us.ul.com.