FIRE EFFECTS ON HIGH EFFICIENCY COMPACT FLUORESCENT LIGHTING

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ABSTRACT

The Energy Independence and Security Act of 2007 has mandated that most of the incandescent lights currently in use will be phased out by 2014 and replaced with more efficient means of producing light. Many manufacturers have begun producing compact fluorescent and LED lighting to replace the incandescent bulb. While this is a boon for energy conservation, what will it mean for the fire investigator? For years investigators have used heat distorted light bulbs to help determine the origin and intensity of fires. The purpose of this study is to establish a base of information on the effects of fire on new styles of lighting, and how the effects of fire can aid the investigator in his or her work.

HISTORY

The use of electric incandescent lights dates back to Thomas Edison's development of the first technically and commercially successful light in 1878[1]. Incandescent lights have been the most popular source of light for over a century because they are available in a variety of sizes; voltages (both AC and DC); and are easy to produce, install and use. Because of their popularity, and their tendency to distort during a fire event, the ubiquitous light bulb has been used for decades as a method of determining the direction and intensity of fire movement, and hence point to a fire's origin. The distortion of light bulbs is such a reliable indicator that it has been incorporated into many fire investigation texts.

> **NFPA 921-2011**
> ***6.2.15 Distorted Light Bulbs.*** *Incandescent light bulbs can sometimes show the direction of heat impingement. As the side of the bulb facing the source of heating is heated and softened, the gases inside a bulb of greater than 25 W can begin to expand and bubble out the softened glass. This has been traditionally, albeit misleadingly, called a pulled lightbulb, though the action is really a response to internal pressure rather than a pulling. The bulged or pulled portion of the bulb will be in the direction of the source of the heating, as shown in Figure 6.2.15.*
>
> ***6.2.15.1*** *Because they contain a vacuum, bulbs of 25 watts or less can be pulled inward on the side in the direction of the source of heating.*
>
> ***6.2.15.2*** *Often these light bulbs will survive fire extinguishment efforts and can be used by the investigator to show the direction of fire travel. In evaluating a distorted light bulb, the investigator should be careful to ascertain that the bulb has not been turned in its socket or that the socket itself has not turned as a result of coming loose during or after the fire.*[2]

A competing technology to the incandescent light is the fluorescent light, with the first practical lamp being invented in 1938. Although more energy efficient, fluorescent lamps were larger; more expensive; required more expensive; and complex fixtures and only operated on a limited range of AC voltages.

The helical (three-dimensional spiral) compact fluorescent lamp (CFL) was invented in 1976 by Edward Hammer, an engineer with General Electric in response to the 1973 oil crisis. Due to production expenses, the invention was shelved. The design eventually was copied by others, and in 1995 helical lamps became commercially available. Since that time production has steadily grown and improved designs have come to market.[3]

The Energy Independence and Security Act of 2007 was passed with the intention of reducing energy consumption and dependency of foreign energy sources. Title III of the act mandated improved energy efficiency for appliances and lighting. The target of the lighting provision is the incandescent bulb with bans on the manufacturing and importation of popular sizes beginning in 2012 and ending in 2014. The United States is not alone in this effort as such countries as Argentina, Australia, Brazil, Canada, China, Israel, Malaysia, Philippines, Russia, Switzerland, Venezuela and the European Union began similar programs as early as 2005.[4]

DEFINING THE PROBLEM

With bans on incandescent lighting taking place around the world, a reliable tool of the fire investigation industry is quickly disappearing. The question is this—can compact fluorescent lighting be used in a similar manner as incandescent light to track a fire's movement and help determine the area of origin?

INTENT OF STUDY

This research project was designed to determine, a) if compact fluorescent lights can survive similar conditions as their incandescent counterpoints, and b) if compact fluorescent lights can be used to as indicators of fire movement, intensity and origin.

TESTING

The test was designed to simulate conditions similar to what might be found in a typical compartment fire. The intention was to create a small scale compartment with a vertical fire plume, a horizontal ceiling jet, and an upper layer hot enough as to be capable of softening glass.

The interior chamber dimensions were 1.46 m (57.5 in.) long x 0.85 m (33.5 in.) wide x 1.22 m (48 in.) high. Top and bottom panels were constructed from 12.7 mm (½ in.) reinforced cement board, and side walls were constructed from two layers of 12.7 mm (½ in.) gypsum board. Porcelain fixtures were placed at various locations on the ceiling and walls to provide different orientations and exposures to the fire plume and ceiling jet. *(See Fig. 1.)*

For the first round of tests fixtures were positioned relative to the front wall where the fire plume was was located. Positions of the fixtures were as follows:

Ceiling 1 (C1) – 204 mm (8 in.) from front wall, centered
Ceiling 2 (C2) – 610 mm (24 in.) from front wall, offset 102 mm (4 in.) to the right
Ceiling 3 (C3) – 940 mm (37 in.) from front wall, offset 102 mm (4 in.) to the left
Left Wall (L1) – 760 mm (30 in.) from front wall, offset 102 mm (4 in.) from the ceiling
Right Wall (R1) – 760 mm (30 in.) from front wall, offset 152 mm (6 in.) from the ceiling

The fire plume was created using two propane torch burners aimed up and parallel to the front wall of the chamber. Control of the fire was achieved by the use of flow control valves. Ventilation holes were placed near the bottom of the front wall and the top of the rear wall to ensure adequate ventilation for the fire. A view port was positioned to allow observation of the flame. Thermocouples were placed midway along a side wall at various heights to monitor the fire conditions and allow feedback for controlling the fire.

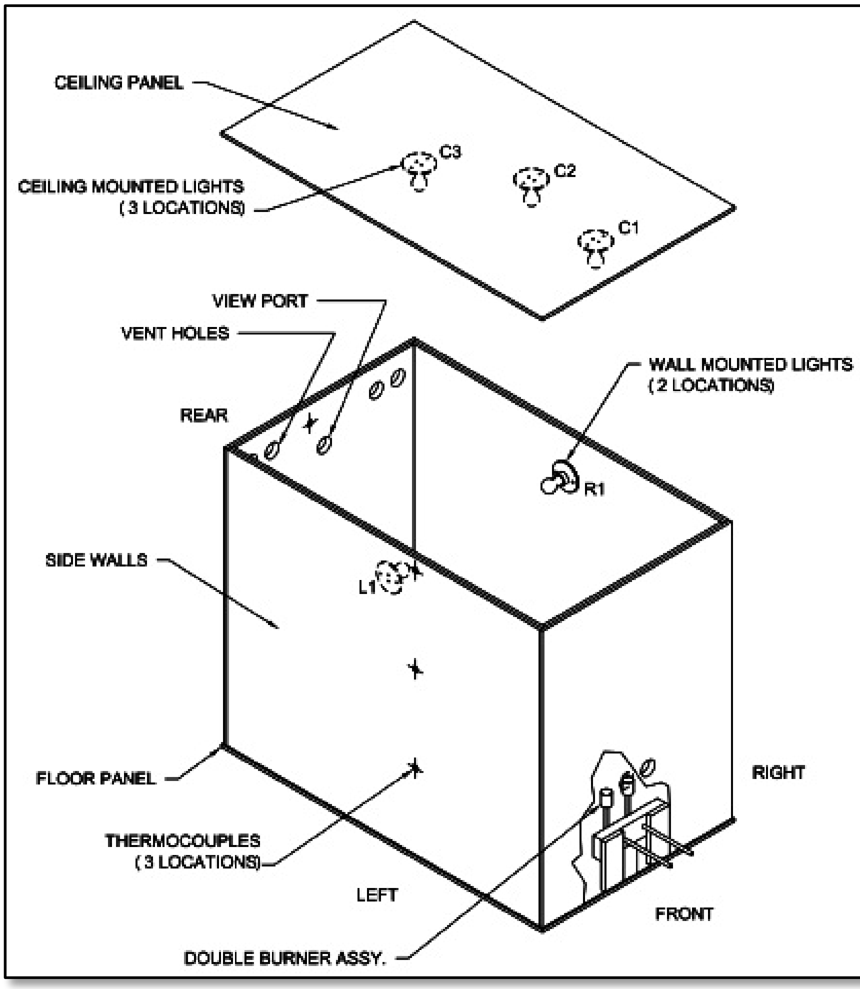


Figure 1.
Test Chamber Design

Figure 2.
Test Chamber Exterior, pre test.

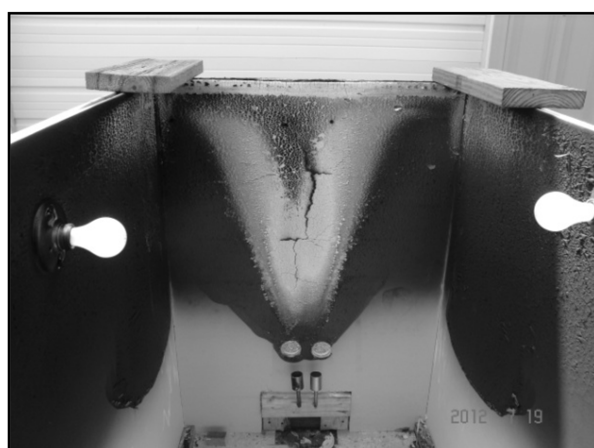


Figure 3.
Test chamber interior, post test.

Experimentation showed that a minimum temperature of 650°C (1200°F) (measured at the uppermost thermocouple) for at least 5 minutes would distort some, though not all, of the glass light bulbs used as a control and baseline for the testing.

After test perimeters were established using tradition glass incandescent light bulbs, tests were conducted under similar conditions using compact fluorescent light bulbs. Two types of compact lights were used. The first was the helical integrated CFL (*Fig. 5*), currently the most popular design in North America.[2] The second type was a helical integrated CFL enclosed in a glass bulb—designed to mimic the size and shape of traditional incandescent bulb—known as an "A-Line" or "Type A" CFL[5] *(Fig. 6)*. While other types of CFL's exist in the market place, these are the most common drop-in replacements for incandescent lights.

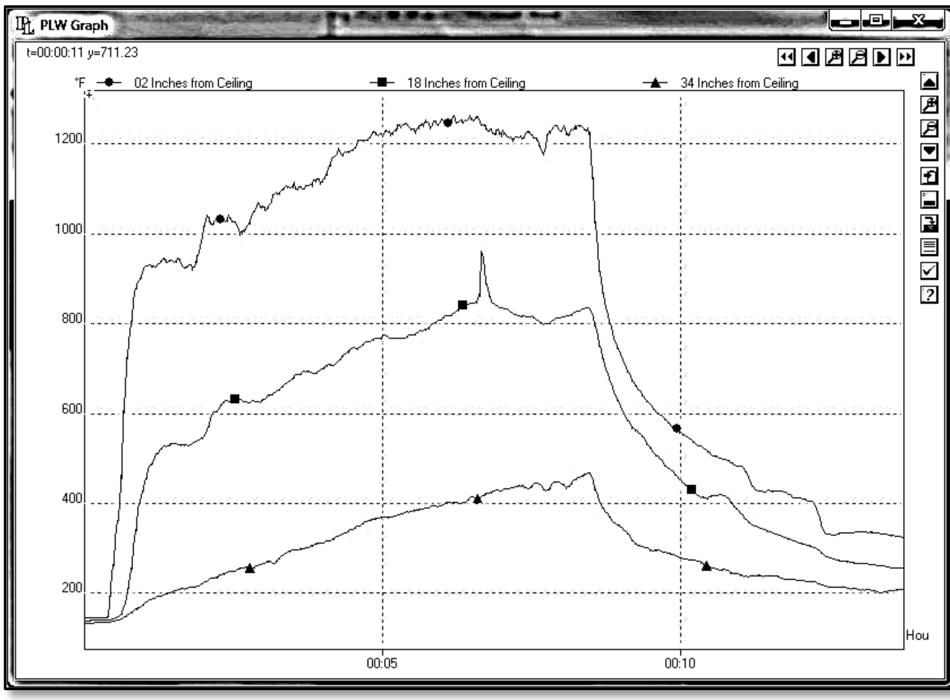


Figure 4.
Typical Heat Profile of 1ST Round of Tests.

Figure 5.
Helical Integrated CFL.

Figure 6.
Type A CFL.

After the initial tests were completed, a second set of tests were conducted with the various types of lights "in parallel", so results could be compared of all the lights exposed to exactly the same conditions. Five fixtures were placed on the ceiling 610 mm (24 in.) from front wall (except the center fixture which was slightly closer due to spacing issues). Two fixtures placed on opposite sides 760 mm (30 in.) from front wall and offset 102 mm (4 in.) from the ceiling.

During the parallel tests, three helical CFL's, three Type A CFL's and a single incandescent light (in the center fixture) were placed into the test chamber. The fire was lit and the chamber heated in stages so that the effects of the heat could be observed on each type of light at different points in temperature profile. After allowing the chamber to cool only long enough to be safely opened, photographs were taken and the chamber reheated to a higher temperature. The process was repeated until all of the CFL's were destroyed.

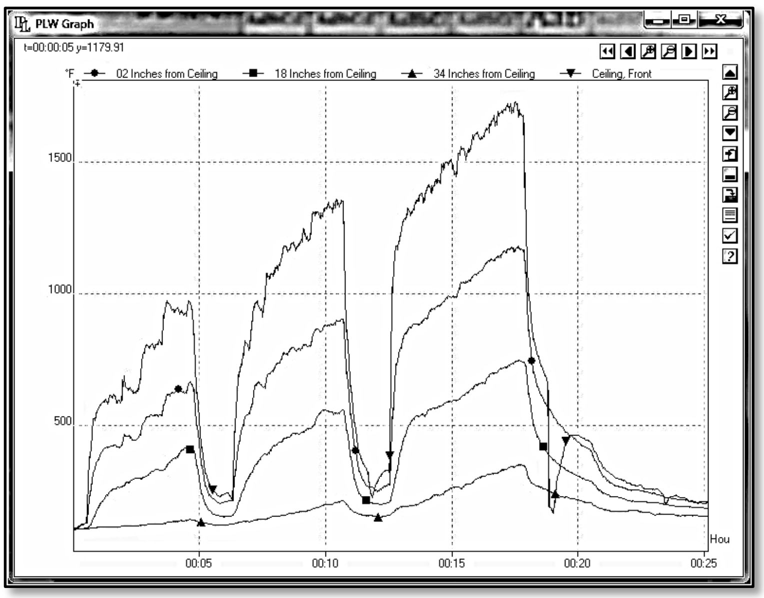
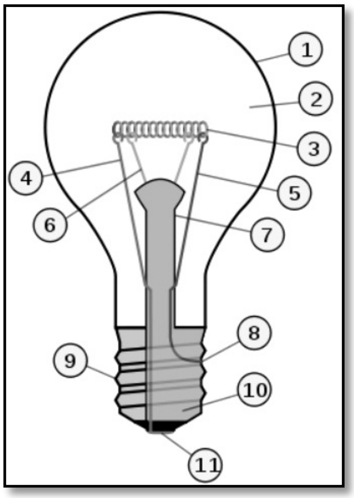


Figure 7.
Heat Profile from a Parallel Test.
Note a 4th thermocouple was added in the ceiling jet.

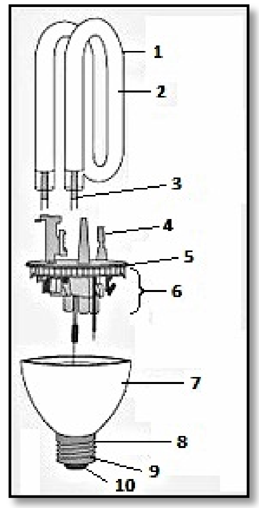
ANATOMY OF A LIGHT BULB

Incandescent and compact fluorescent lights differ greatly in their construction and operation, but most important to this study, in their materials. While incandescent lights are made entirely of heat resistant glass and metals, fluorescent light incorporate more light weight and less heat resistant materials such as plastics, paper circuit boards and small electronic components. They are able to do so because they generate less heat, typically consuming only 25 - 33% of the energy consumed by incandescent lighting[3] while producing the same amount of light. Figures 8a and 8b show typical construction for both types of lights.



1. Glass bulb
2. Vacuum or inert gas
3. Filament wire (tungsten)
4. Contact wire (metal)
5. Contact wire (metal)
6. Support wires (metal)
7. Stem (glass)
8. Soldered connection
9. Cap (aluminum, typ.)
10. Insulation (glass, typ.)
11. Contact (metal)

Figure 8a.
Incandescent light.[1]



1. Glass tube
2. Inert gas
3. Electrode (metal)
4. Tube retainer clip (metal)
5. Mounting plate (polycarbonate)
6. Electronic ballast (circuit board & components)
7. Housing (polycarbonate)
8. Cap (stainless steel, typ.)
9. Insulation (plastic, typ.)
10. Contact (metal)

Figure 8b.
Compact Fluorescent light.[3]

OBSERVATIONS

Incandescent Lights

Damage only occurred to the incandescent lights located on the ceiling panel in or directly adjacent to the fire plume. *(Positions C1 and C2.)* No discernible damage occurred to the lights located on the side walls of the chamber, or at the rearmost ceiling fixture. As the thermocouples were also located on a side wall of the chamber, it can be surmised that the gases in the plume and ceiling jet was at a higher temperature in the center of the ceiling than at the side walls. This is confirmed by published softening temperatures for glass in the range of 760–870^{o}C (1400–1600^{o}F),[6] and by later tests with a thermocouple mounted mid-ceiling.

(In the following illustrations, a BLACK ARROW denotes the direction of flame travel, and a WHITE ARROW denotes significant details.)

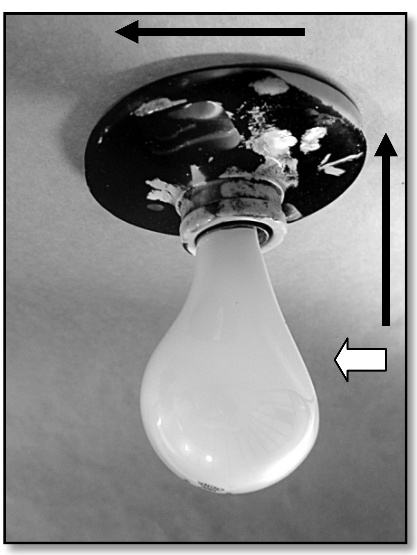


Figure 9.
"Pulled" bulb.
Position C1, in fire plume.

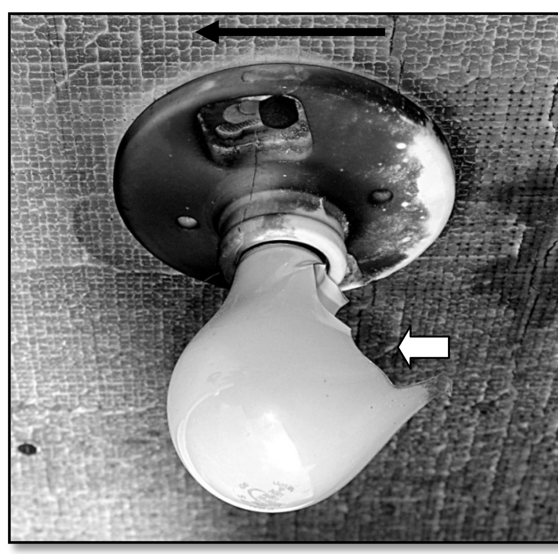


Figure 10.
"Popped" bulb.
Position C2, in ceiling jet.

Helical Integrated CFL'S

The helical compact fluorescent lights were tested under conditions similar to those used for the incandescent light studies. Unlike the incandescent lights, all of the helical CFL's regardless of position, were damaged during this study. The thermoplastic polycarbonate material of the housing melted and burned, compromising the structural integrity of the light. Typically, very little of the helical lights remained in the porcelain fixture. Also typical, much of the helical CFL's (i.e. the helical tube and ballast) could be found on the floor of the test compartment almost intact, save the damage incurred from the impact with the floor.

Although little of the helical CFL's was left in the porcelain outlets used in the test, remnants remained in some of the fixtures which could aid in determining the direction of the ceiling jet. Due to uneven heating, the cooler side of the light would typically leave a "tail" hanging down indicating it took longer to soften and had the opportunity to stretch. Depending on the fixtures proximity to the fire plume the tail could burn away or remain intact after the fire.

(In the following illustrations, a BLACK ARROW denotes the direction of flame travel, and a WHITE ARROW denotes significant details.)

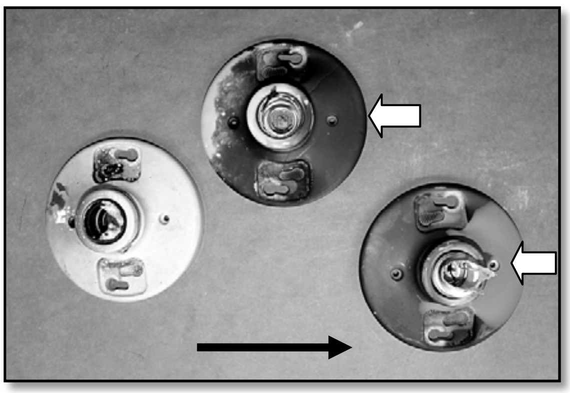


Figure 11.
Ceiling mounted helical CFL's post fire. (Removed from test chamber.) Note increasing residue "shadow".

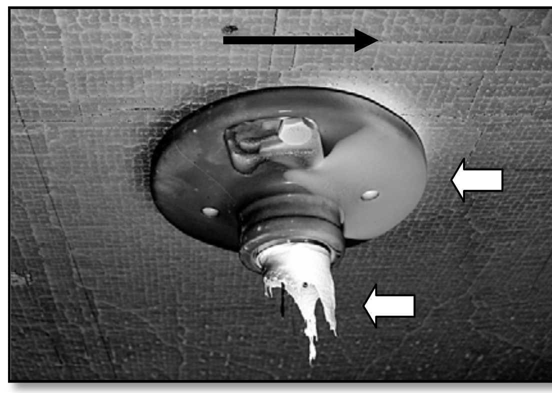


Figure 12.
Ceiling mounted helical CFL.
"Tail" and residue "shadow" are present.

Figure 13.
Remains of helical CFL on floor.
Glass tube and electronic components are mostly intact.

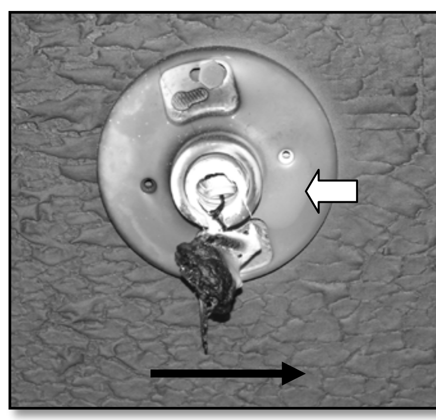


Figure 14a.
Wall mounted helical CFL, position L1.
There is a visible residue "shadow".

Figure 14b.
Same wall mounted helical CFL post fire.
Note un-charred side of housing away from ceiling jet.

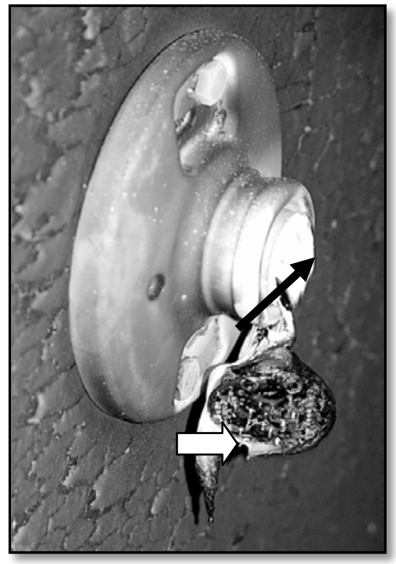


Figure 14c.
Same wall mounted helical CFL post fire.
Note charred circuit board towards ceiling jet.

Another interesting phenomenon seen on several fixtures was a "shadow" on the side of the fixture away from the ceiling jet. The shadow was in the form of a residue and is probably a result of the pyrolysing polycarbonate material being deposited on the fixture. The residue was a tan-gray color, and was easily removed by touching. In general, the greater the distance from the fire plume, the more pronounced the shadow.

It was later discovered that the shadow was more permanent than originally thought. During the second round of testing the porcelain fixtures were being wiped clean between tests. It was found that below the tan-gray dust a dark residue stain had attached itself to the fixtures and was not easily removed *(Fig. 15)*. This effect was consistent for both the helical and Type A CFL's tested. It is most likely that if the fire was of a higher temperature and/or a longer duration that the residue would also burn away.

(In the following illustrations, a BLACK ARROW denotes the direction of flame travel, and a WHITE ARROW denotes significant details.)

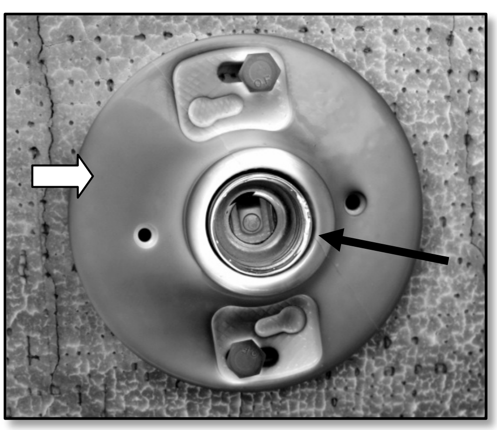


Figure 15a.
Fixture showing shadow after fire.

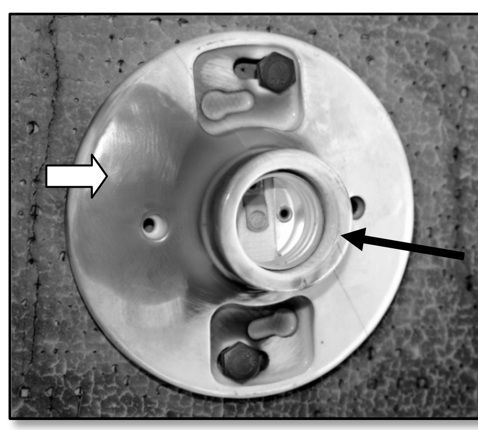


Figure 15b.
Same fixture after wiping with a cloth.
Note stain matches shadow in previous photo.

Type A CFL'S

The Type A compact fluorescent lights were tested under the similar conditions as those used for both the incandescent and helical compact fluorescent light studies. Similar to the helical CFL's, all of the Type A CFL's were damaged during this study.

The Type A lights displayed a wider range of damage than the helical CFL's. This may be due to the higher mass of the light and its ability to absorb more heat. On one extreme, absolutely nothing was left of a ceiling mounted Type A CFL except the stainless steel cap screwed into the porcelain fixture *(Fig. 16)*. The softening of plastic combined with the weight of the entire construction pulled the light completely free of the cap *(Fig. 17, positions C1 and C2)*. The remains of the light lay on the floor, mostly intact, with some melting and charring present *(Fig. 18)*. At the other extreme a ceiling mounted Type A CFL remained fairly intact, and had distinct damage on the side facing the ceiling jet *(Fig. 19, position C3)*. Damage to the Type A CFL's on the side walls was similar to that found on helical CFL's *(Fig. 20 and 21, positions L1 and R1)*.

(In the following illustrations, a BLACK ARROW denotes the direction of flame travel, and a WHITE ARROW denotes significant details.)

Figure 16.
Ceiling mounted Type A CFL, position C1.
Only the cap remains in the fixture.

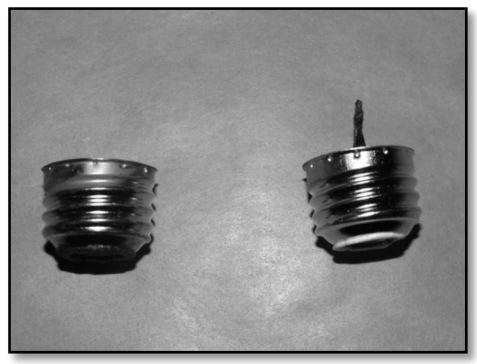


Figure 17.
Caps from ceiling mounted Type A CFL's.
From ceiling fixtures in positions C1 and C2.

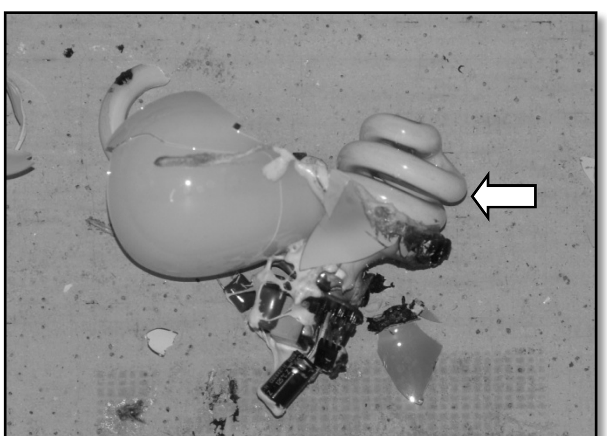


Figure 18.
Remains of Type A CFL on floor.
Many components survived, including an intact glass tube.

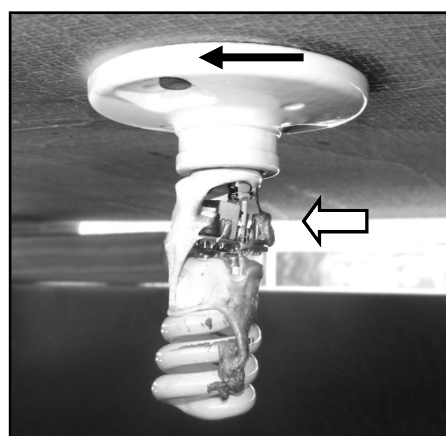


Figure 19.
Ceiling mounted Type A CFL position C3.
Melting is heavier on side facing the ceiling jet.

No residue shadows were noted during the first Type A test, but this may be due to variations in heating conditions and not differences in light construction. The overall cleaner appearance after the burn is likely the result of a leaner fuel mixture during the test, although temperatures were similar to other tests. During later testing, both the helical CFL's and Type A CFL's left shadows and stains.

(In the following illustrations, a BLACK ARROW denotes the direction of flame travel, and a WHITE ARROW denotes significant details.)

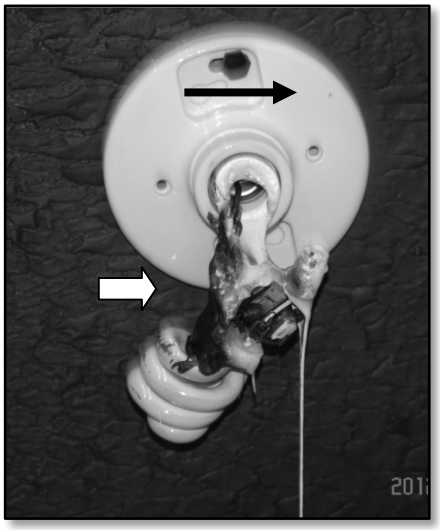


Figure 20.
Wall mounted Type A CFL position L1.
Charring is heavier on side facing the ceiling jet.

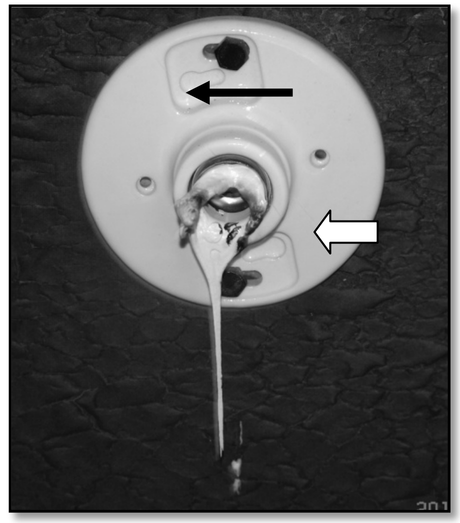


Figure 21.
Wall mounted Type A CFL position R1.
Although the light is almost completely missing, charring still occurred on the side facing the ceiling jet still occurred.

Parallel Test Results

In the first round of tests only one type of light was used in each test, and although test conditions were similar, they were not identical. In the second round of tests, incandescent lights, helical CFL's, and Type A CFL's were tested side by side in the same tests under the same conditions. The results of the parallel testing confirmed what was observed and hypothesized in the previous tests. CFL's sustain fire damage sooner than incandescent lights due to their materials and construction. Type A CFL's, because of their greater mass, were at first more resistant to damage than helical CFL's, but once heated were quicker to fall apart due to their heavier weight. CFL's, although heavily damaged by fire, still left visible effects and patterns after the fire.

CONCLUSIONS

The incandescent light as we know it, while not completely becoming obsolete, will become much rarer than it is today. More efficient lighting has been mandated by many governments around the world and compact fluorescent lighting is leading the way as the most popular replacement. Fire investigators will have to adapt to the new technology and learn how to use it in their investigations.

Because of their construction and materials, compact fluorescent lights will be damaged more severely and at lower temperatures than traditional glass incandescent lights. The plastic housings will soften, melt and burn at temperatures that may not significantly affect traditional lighting. The integrated ballasts—made up of circuit boards, transformers, transistors, capacitors and other electronic components—are also less able to stand up to high temperatures. Far less of the CFL's will remain after a fire.

This does not mean, however, that compact fluorescent light should be completely discounted in fire investigations. Although they may be severely damaged during a fire, CFL's can still yield valuable information about the direction and intensity of fire travel. Fire effects can be left behind which are still able of indicating the proximity of the light to the fire, and from where the fire came. Melted tails, residue "shadows", charred and un-charred remnants can all be used in the place of the traditional melted glass light. A fire investigator, using proper care and caution, can use compact fluorescent lights to determine a fire's origin in much the same way we once used incandescent lights.

Further detailed testing and research is planned.

ABOUT THE AUTHOR

Richard J. Meier, CFEI, CFII, CVFI is currently a Staff Expert Fire and Explosion Analyst for John A. Kennedy and Associates in Sarasota, FL, USA. He holds a B.S. in Mechanical Engineering Technology from the University of Akron and the CFEI, CFII and CVFI certifications from the National Association of Fire Investigators. Prior to becoming a fire investigator, his work included more than 20 years in manufacturing and design engineering for a variety of products including plastics, metal products, fuel systems, hydraulic systems, control systems, air conditioning, and power generation equipment.

ENDNOTES

[1] Wikipedia.com, "Incandescent light bulbs", Retrieved 2012-08-09.

[2] National Fire Protection Association, NFPA 921, *Guide to Fire and Explosion Investigation*, 2011 Edition

[3] Wikipedia.com, "Compact Fluorescent Lamp", Retrieved 2012-08-07.

[4] Wikipedia.com, "Phase-out of incandescent light bulbs", Retrieved 2012-08-07.

[5] bulbs.com/learning/cfl.aspx, Retrieved 2012-08-09.

[6] National Fire Protection Association, Fire Protection Handbook, 20th Edition, 2008.