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SOLID-STATE LIGHTING FOR REFRIGERATED DISPLAY CASES

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Abstract

The intent of this paper is to initiate a discussion within the community interested in commercial refrigerators, on the possible use of LED lighting in commercial refrigerated and freezer display cases. The fluorescent lighting presently used in commercial refrigerators is inefficient in the application and also it provides poor lighting for merchandising. LED is a solid-state light source that is rapidly evolving as an energy efficient long life light source. A laboratory human factors experiment was conducted to assess the preference for the different lighting systems. Two refrigerated display cases, one with the traditional 4-ft T8 fluorescent lighting system and the other with a prototype LED lighting system, were placed side-by-side in a laboratory setting. Compared to the lighting produced by a single large source such as a linear florescent lamp, the lighting produced by a distributed LED lighting system was more uniform. Sixteen human subjects participated in this study and rated their preference for the two lighting systems. The results show that human subjects strongly preferred the display case with the LED lighting even though the LED system produced less than half the flux of a fluorescent system. At the present time a properly constructed LED lighting system for refrigerators would have similar energy consumption as a fluorescent system. Since the LEDs are still in their development phase, at the present time they are much more expensive than fluorescent systems. With the proposed advancements in the efficacy of LED systems, one can expect future commercial refrigerators to be equipped with LEDs that can provide better lighting. In addition these new LED based lighting systems would consume less than half the energy as compared to the fluorescent lighting systems.

Introduction

Commercial refrigerators consume over 50% of the total electric energy used by supermarkets [1, 2]. It has been shown that in commercial refrigerators lighting can consume up to 15% of the total energy [1, 2]. Although this document will re fer to refrigerators, this term includes both refrigerated and freezer display cases. The most widely used light source in commercial refrigerators is the linear fluorescent lamp. There are many drawbacks to using linear fluorescent lamps in refrigerated display case lighting applications and they are described in the following paragraphs.

In general fluorescent lighting is considered energy efficient because as a light source the fluorescent lamp has very high luminous efficacy: almost 90 lumens per watt (LPW) when operated at room temperature. In comparison, the efficacy of a standard incandescent light bulb is 15 LPW. The light output of a fluorescent lamp is very sensitive to ambient temperature. As seen in Figure 1, the light output of a linear fluorescent lamp peaks around 30 °C ambient temperature, and it drops off very rapidly on either side as the temperature varies [3]. Light output of some of the newer fluorescent lamps such as the T8F32 4-foot linear fluorescent lamp, with electronic ballasts drops about 20 % in a refrigerated display case operating at 7°C, and would drop further in freezer cases. Since the overall light output drops and the input watt remains almost the same the efficacy of the fluorescent lamp reduces. Additionally, the way the fluorescent lamps are configured into the commercial refrigerators, only about 60% of the light is used within the display case to light the merchandise. The rest escapes out of the display case. As a result of these factors only about half the original light is utilized in lighting the display case. Therefore, in this application the system efficacy of the fluorescent lighting system is about 45 LPW.

Fluorescent lamps contribute to the heat gain inside the refrigerated unit and decrease the system efficiency of the cooling system. Less than 25% of the total energy consumed by a fluorescent lamp is converted to light energy, the rest is converted to heat [3]. More than half the heat is in the form of radiant heat that is absorbed by the items placed inside the refrigerator. The heat generated by the lighting systems also contributes to uneven distribution of temperatures within the display case itself.

Lamp manufacturers rate linear fluorescent lamp life as 20,000 hours. The lamp life is determined by subjecting a large number of fluorescent lamps to 3 hours on and 20 minutes off cycle testing at 25°C. The time at which 50% of the lamps cease to operate is considered the lamp life. It is important to understand that the lamp life test is performed with a particular ballast and if the ballast is changed then the lamp life also could change. If the lamp and

the ballast are not properly matched lamp life may be very short. Furthermore, cold temperatures may shorten the lamp life of fluorescent lamps. This can increase maintenance cost.

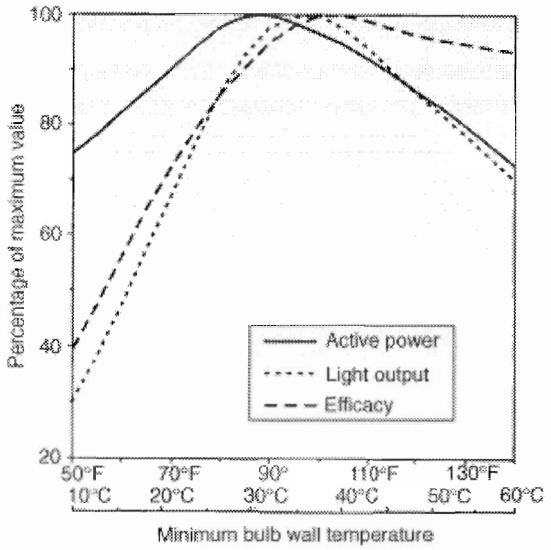

Figure 1: Typical fluorescent lamp light output variation as a function of temperature [3].

Fluorescent lighting systems provide diffuse general lighting within a refrigerated display case with little flexibility for altering the light distribution to create a more visually appealing merchandise display. The lighting within the display area is very uneven. In most supermarket display cases it is difficult to see the products that are set behind because the products in the front obstruct the light and cast heavy shadows.

The fluorescent lighting presently used in commercial refrigerators is inefficient in the application and also it provides poor lighting for merchandising. Therefore the goal of this paper is to initiate a discussion within the community interested in commercial refrigerators regarding the possible of use of an alternate lighting technology that is energy efficient in this application and can provide better lighting for merchandising.

Lighting requirements for refrigerated display cases

The lighting in refrigerators plays an important role. It attracts the attention of customers, provides visual appeal to the display area and the products displayed, and conveys a message regarding the store, the display case and the merchandise sold. To achieve all of these attributes, the light source must be carefully selected and the lighting must be properly designed and applied.

Good lighting within the refrigerated display case means meeting functional, aesthetic, and energy requirements. Functional lighting requirements call for more uniform light throughout the display case independent of the product arrangement within the case. The vertical illuminance at any point within the display area must be at least 500 lux [5]. There should not be any veiling reflections off the displayed objects. These requirements ensure that the customer is able to clearly see and read the writing on the displayed products. Aesthetic lighting requires the light source to have good color rendering properties, so the displayed products look colorful and appealing. In addition the light source color appearance must be similar between adjacent refrigerated display cases to maintain aesthetics [4].

In most other architectural dis play lighting applications additional accent lighting is applied to the displayed objects, along with the general ambient lighting so the objects are highlighted. Lighting practice recommends high light levels and high contrast (up to 30:1) between the objects on display and the background [5, 6]. Using efficacious lighting systems, including the light source, ballast, and the lighting fixture/reflector, and minimizing the amount of wasted light provides energy efficiency. Usually fluorescent lamps are used for general lighting applications, and halogen PAR or MR lamps are used for accent lighting.

Alternative lighting solution

As mentioned earlier the goal is to identify an alternate lighting solution for commercial refrigerated display cases that can provide the necessary visual appeal for merchandising and consume less energy. Light emitting diode

(LED) is a potential lighting technology that can provide the solutions to many of the problems stated earlier for the target application.

LEDs are the first sign of a rapidly evolving solid-state light source technology. Although LEDs were invented during the later part of the 1960's it is only after the mid 1990's, when white light LEDs were developed it became a potential light source for general lighting applications [7,8]. Just within the past two years, the luminous efficacy of commercial white LEDs has reached 30 LPW [9]. Industry experts are predicting white LED efficacy to reach 50 LPW by 2005 and 100 LPW by 2010 [10]. Some of the key features of LEDs include potential for energy savings, low maintenance, dynamic control of intensity and color, the fixture can be conformed to almost any shape, and they are rugged and durable because there is no filament or glass to break.

Experiment

Recently the authors of this manuscript conducted a laboratory experiment to compare the traditional fluorescent lighting system with a distributed LED lighting system in a refrigerated display case application [11]. Two stand-alone type refrigerated display cases were placed side-by-side in a laboratory setting. Both refrigerators came with a 32-watt T8, 6500 K fluorescent lamp. As shown in Figure 2, the fluorescent lamp was mounted vertically near the door hinge. One of the refrigerators was retrofitted with a prototype LED lighting system that had two types of LEDs. The first was a linear array of 5mm white LEDs that provided a more directional lighting on the displayed products; the second used high flux LED illuminators that provided diffuse general lighting within the display case [11]. The length of the LED fixtures was similar to the width of each shelf. As shown in Figure 2, two LED fixtures were mounted horizontally on each shelf to provide the necessary light level on the displayed objects. The number of LEDs selected to light the display case was based on the required light level on the displayed objects. Illuminance measurements made within the display cases showed more uniform light levels within the case with LED lighting system as compared to the fluorescent lighting system [11]. The flux from the fluorescent lamp was about 2200 lumens and the average illuminance level on the vertical surfaces of the displayed products was 686 lux with a standard deviation of 653 lux. The flux from the LED lighting system was about 900 lumens and the average vertical illuminance was 629 lux with a standard deviation of 146 lux. Both lighting systems achieved the minimum recommended light level for display applications, which is 500 lux on the vertical surface [5].

The ambient lighting in the area was kept similar to what it would be in a typical supermarket. Sixteen human subjects participated in this study [11]. All subjects were screened for deficiencies in color vision prior to starting the experiment. Each subject viewed the two display cases simultaneously and rated their preference on a 1 to 3 scale. Preference was rated for the overall appearance of the display cases and for the individual products within the case. Zero indicated no preference, 1 indicated little preference, and 3 indicated high preference. One of the lighting conditions observed and rated by human subjects was the null test, in which both cases were lit by the fluorescent lighting system and had identical product arrangement and light levels. Figure 3 illustrates the results of the null test. Statistical analysis of this data showed no significant preference for either display case, thus the null condition was verified. In the final experiment subjects rated their preference for the display cases lit by the fluorescent and LED lighting systems; the results are illustrated in Figure 4. Statistical analysis of this data showed significant preference for the display with the LED lighting system. This indicated that human subjects strongly preferred the display case with the LED lighting.

Table 1 summarizes the light output characteristics and energy use of linear fluorescent and LED lighting systems. The table also shows projected energy use in 2005 and 2010 for LED lighting systems. It appears even at the present time a properly constructed LED lighting system for refrigerators would have similar energy consumption as a fluorescent system. However, the LEDs are much more expensive than fluorescent systems. With the proposed advancements in the efficacy of LED systems one can expect future LED equipped commercial refrigerators to have better lighting with less than half the energy consumption.

Table 1: System efficacy and energy use projections.

Lighting system	Light output (lumens at 7°C)	System Efficacy (Lumens/watt)	Energy use (KWhr)	Energy Savings
32 Watt Fluorescent	2200	69	0.76	
LED in 2002[9]	900	30	0.72	5 %
LED in 2005	900	50	0.43	43 %
LED in 2010[10]	900	100	0.22	71 %

Summary

The intent of this paper is to initiate a discussion within the community interested in commercial refrigerators, on the possible use of LED lighting in commercial refrigerated and freezer display cases. A laboratory human factors experiment was conducted to assess the preference for the different lighting systems in refrigerator lighting applications. Two refrigerated display cases, one with the traditional 4-ft T8 fluorescent lighting system and the other with a prototype LED lighting system, were placed side-by-side in a laboratory setting. Compared to the lighting produced by a single large source such as the linear florescent lamp, the lighting produced by a distributed LED lighting system was more uniform. Sixteen human subjects participated in this study and rated their preferences for the two lighting systems. The results show that human subjects strongly preferred the display case with the LED lighting even though the LED system produced less than half the flux produced by the fluorescent system. With the proposed advancements in the efficacy of LED systems, one can expect future commercial refrigerators to be equipped with LEDs that can provide better lighting. In addition these new LED based lighting systems would consume less than half the energy as compared to the fluorescent lighting systems.

Acknowledgments

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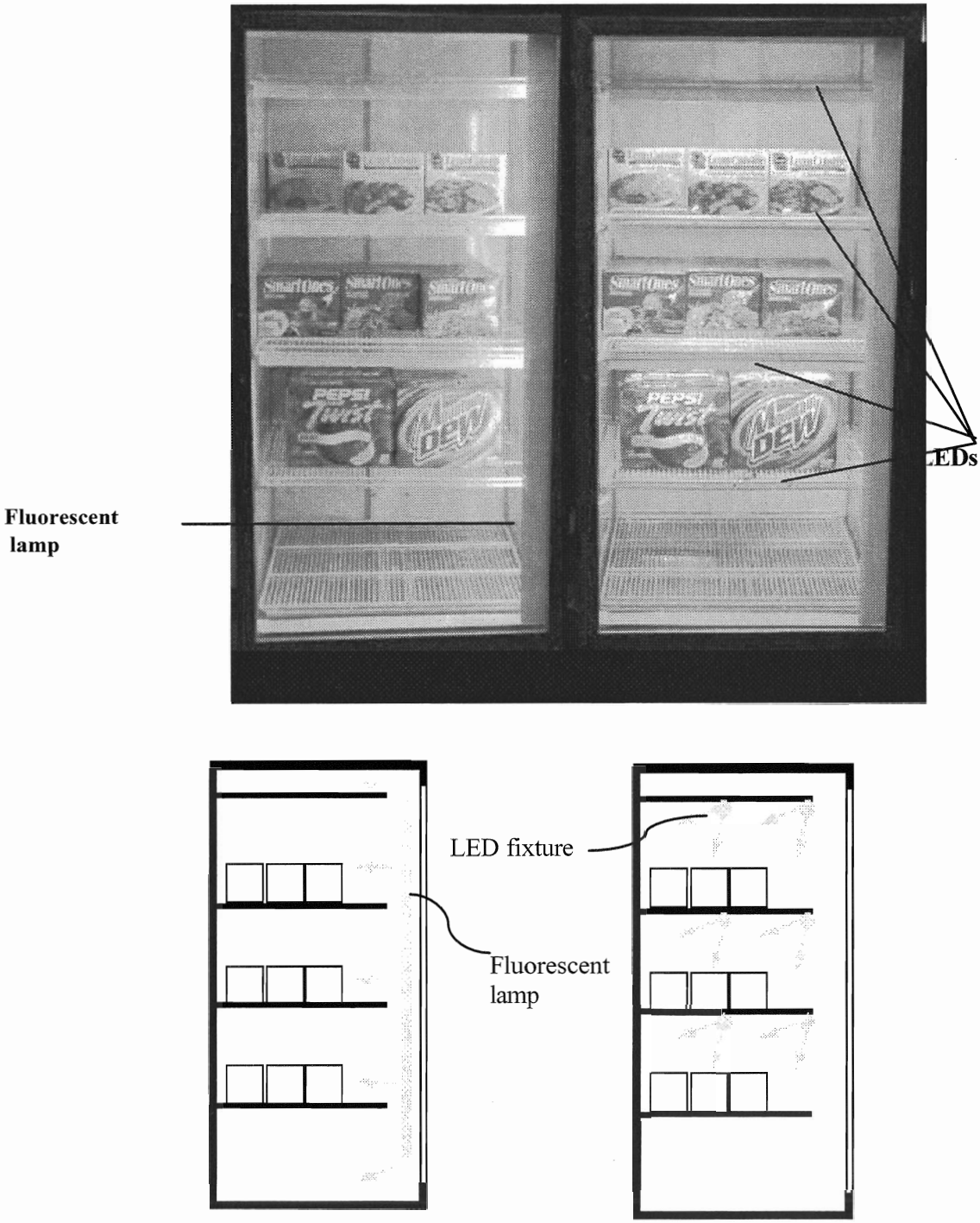

Figure 2: Refrigerated display cases with florescent lighting on the left and LED lighting on the right.

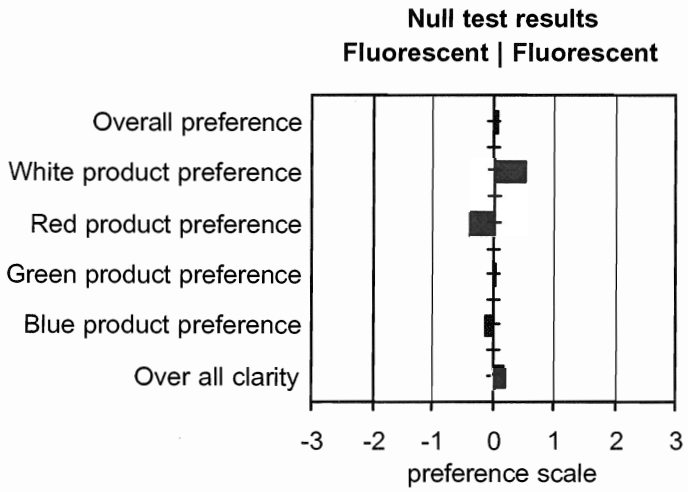

Figure 3: Null test results: Preference rating results when the two cases were lit identically with fluorescent lamps. Numbers indicate preference in a scale of 0 to 3. Negative values are for the display case on the left (fluorescent system); and the positive values are for the display case on the right (fluorescent system).

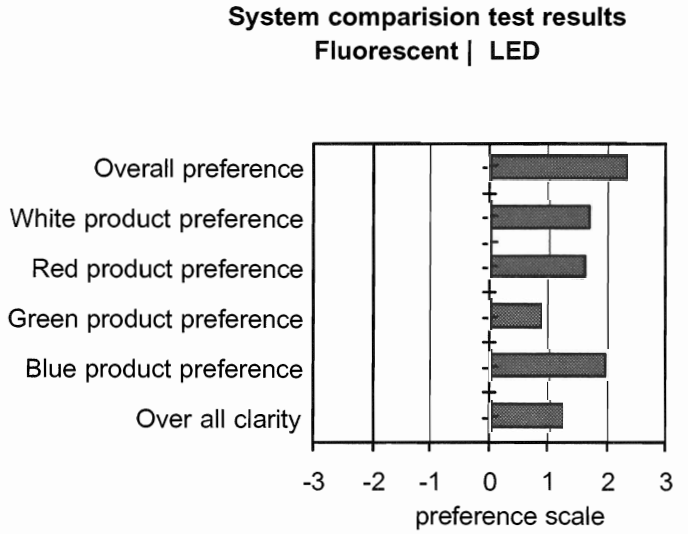

Figure 4: Preference rating results: when the two display cases, fluorescent and LED lighting, were compared side-by-side. Numbers indicate preference in a scale of 0 to 3. Negative values are for the display case on the left (fluorescent system); and the positive values are for the display case on the right (LED).