LIGHTING THE WAY TO GREENER RETAIL

A research paper on digital lighting

www.nualight.com

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CONTENTS

ABSTRACT 5
1 – THE RETAIL ENVIRONMENT 6
2 – REFRIGERATION and RETAILERS 7
3 – LIGHTING and REFRIGERATION 9
4 – DIGITAL LIGHTING 10
4.1 – What is digital lighting? 10
5 – Key lighting parameters 11
5.1 – Energy & efficacy 11
5.2 – Illuminance 11
5.3 – Uniformity 11
5.4 – Lifetime 12
5.4.1 – Lifetime Definition 12
5.4.2 – LED Lifetime Measurement 12
5.4.3 – Fixture/Fixture Lifetime vs. LED Lifetime 14
5.5 – Reliability 14
5.6 – Maintenance 14
5.7 – Colour 15
5.7.1 – Colour Metrics for White Light Sources 15
5.7.2 – Colour Temperature 16
5.7.3 – Colour Rendering Index 17
5.8 – Stability 17
5.9 – Ease of installation 18
5.10 – Retrofit capability 18
5.11 – Consistency 18
5.12 – Certifications 18
6 – PAYBACK 20
7 – IMPLEMENTATION PROCESS 24
7.1 – Audit 24
7.2 – Specify 25
7.3 – Plan 26
7.4 – Validate 27
7.5 – Checklist 27
8 – SELECTING AN LED FIXTURE SUPPLIER 28
9 – THE OUTCOME 29
10 – APPENDIX 30

THE TRADING ENVIRONMENT FOR FOOD RETAILERS IS CURRENTLY POSING SERIOUS CHALLENGES, WITH SLOWER GROWTH AND INVESTMENT REQUIRED IN THE INTRODUCTION OF GREEN AGENDAS AND RISING ENERGY COSTS.

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ABSTRACT

The trading environment for retailers is currently posing serious challenges, with slower growth, rising energy costs and the need to fund green agendas.

A study of the energy usage of all common building users shows that retailers have the highest enduse intensity. More than 50% of energy usage in retailers is for refrigeration and this is mostly used in refrigerated retail display cases, such as freezers, coolers and beverage dispensers. The typical lighting fixtures in these displays are fluorescent and by virtue of their relative inefficiency, combined with the waste heat they produce within the chilled environment, the net effect is a 25% increase in the total power consumed by the illuminated cabinets.

In this paper we demonstrate that retailers can significantly reduce their energy spend by appropriate use of lighting, especially in refrigerated display environments. Digital lighting, based on light-emitting diodes (LEDs), offers multiple performance benefits compared with environmentally unfriendly fluorescents. Lighting ambience can be greatly improved and energy consumption can be greatly reduced since lighting inefficiency translates to higher loads on refrigeration and air conditioning requirements.

Digital lighting is not a commodity and its introduction into refrigeration display environments is not a matter of bulb replacement (i.e. purchasing and installing light bulbs from bulb manufacturers or component suppliers). Digital lighting, installed correctly, offers better merchandising, better photometrics, long lifetime, negligible maintenance, rapid payback and a strong return on investment. Each refrigerated retail display case presents a unique set of characteristics. The performance of digital lighting in a display case is a function of fixture design, case design and installation methodology. Inefficiently executed, the result will fall short of expectations and may end up costing rather than saving money.

In this paper we supply the retailer with information on the key parameters of digital lighting and then go through the implementation process, step by step, starting with technical audits, to specifying the lighting requirements, selecting an implementation partner and validating that the installation will meet performance and financial specifications.

Being green makes good business sense. Digital lighting is not only environmentally friendly but is also cost effective. In a fiercely competitive market, 2008 will be about tightening belts to deliver margins. Retailers will need to urgently deploy innovative solutions to be ahead of the game and going greener with digital light can provide the solution.

1 – THE RETAIL ENVIRONMENT

2008 will be a challenging year for retailers and recent trading statements indicate that many are struggling with slower growth, greater competition and a rapidly changing industry. Now more than ever global food retailers need to look at ways of selling more products and at the same time reducing costs. The rapidly rising price of oil, the concern over carbon footprint and the high energy usage in grocery multiples make it imperative for forward-thinking businesses to get green solutions on their strategic agendas.

The Holy Grail for retailers is to be more profitable, have better branding, be regulation compliant and find growth opportunities in difficult trading environments. But where should retailers place their efforts and what are the responsible strategies that will deliver enhanced brand value and increased profits?

The most effective approach is a holistic one encompassing superior operational efficiencies and providing differentiation and improved retail environments for the more discerning consumers in a changing world.

2 – REFRIGERATION AND RETAILERS

Retail energy usage has been recently surveyed by the California Energy Commission. Figure 1 below compares usage by this sector with the other common types of business use and grocery retailers come in at the top end of the scale with over 40 KWhr per square foot per annum.

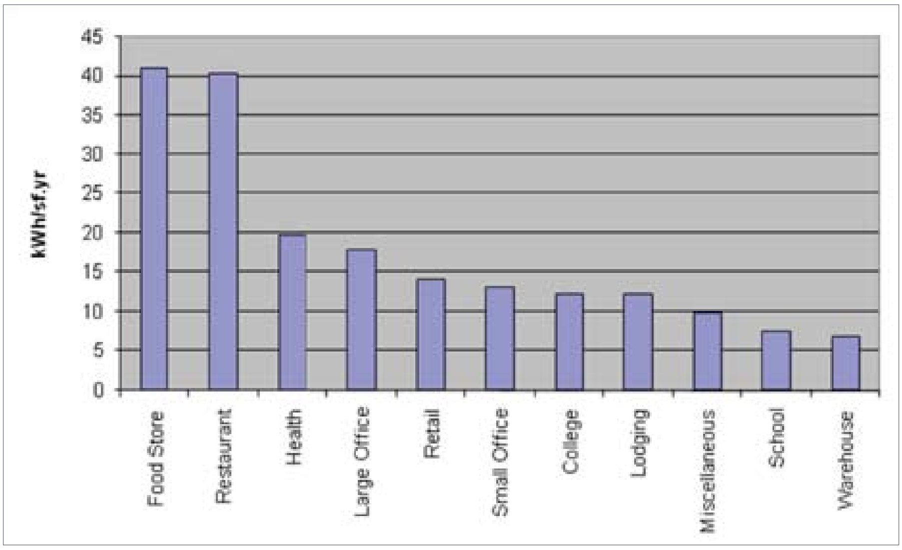

Figure 1: Energy use intensity for common building uses.
Source: California Energy Commission 2006.

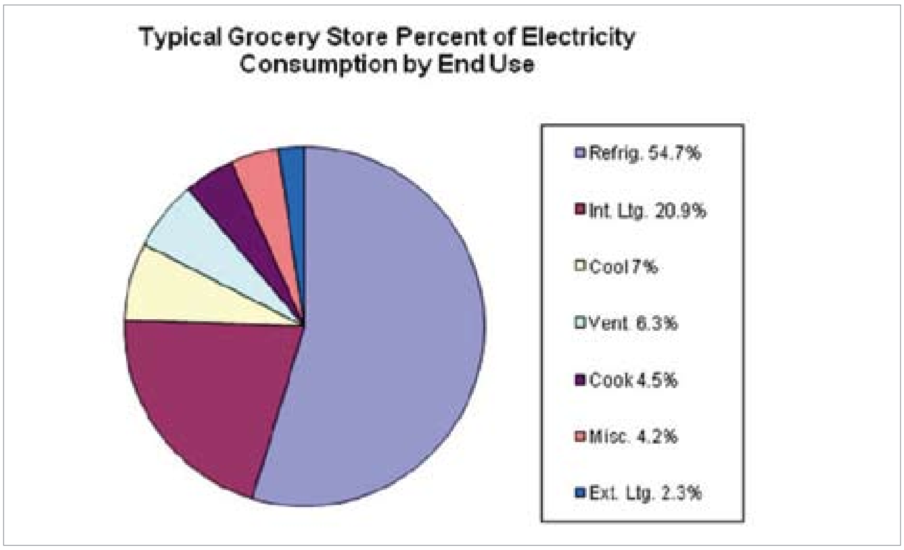

Figure 2: Survey of energy usage in grocery retailers.
Source: California Energy Commission 2006.

In the same survey, the end use within the grocery retailers was surveyed, and the single biggest category, coming in at 55%, was refrigeration (see figure 2). In badly designed or maintained retail environments this can rise to 70%. Clearly, improvements in refrigeration efficiency are crucial in energy saving initiatives.

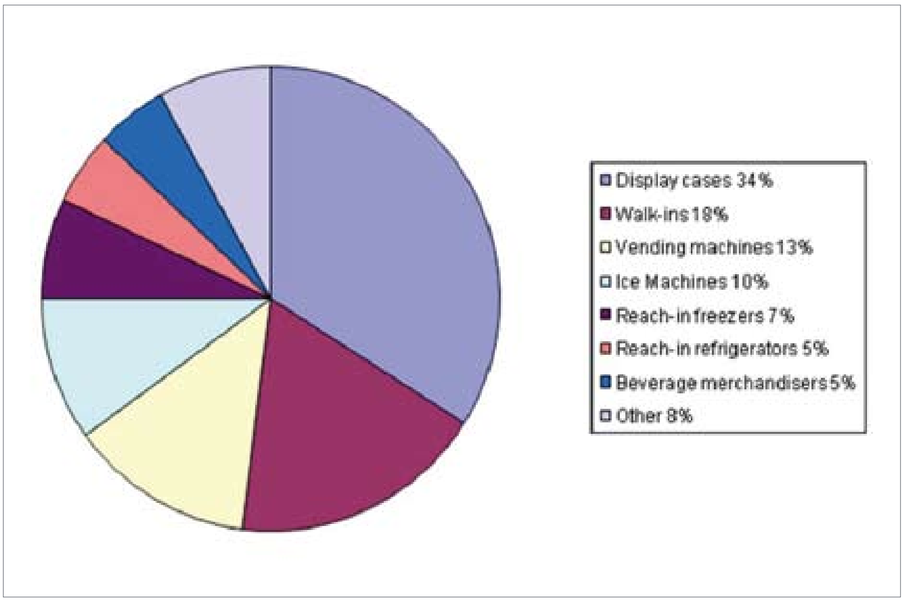

Figure 3: Types of refrigeration uses within grocery retailers.
Source: PG&E'99 commercial building survey report.

The use of energy within refrigeration has been also investigated, and it can be seen in figure 3 that more than 80% of it relates to usage in various types of illuminated displays.

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3 – LIGHTING AND REFRIGERATION

It has been recently reported[1] that 19% of the world's electricity bill comes from lighting. Lighting is embedded in almost all refrigerated retail display cases and inefficient lighting produces a waste heat, leading to increased energy consumption by the refrigeration system. Of course, there is a very wide variety of display cases and the percentage of energy wasted will vary with the type of case.

The data below is taken from a Nualight study on a typical single glass door vertical freezer case. The objective was to determine for this style of case the efficiency of the compressor in removing waste heat produced by the illumination. In this trial Nualight' s first generation Vantium® digital lighting product was found to be 41% more energy efficient than comparable fluorescent lighting in a single glass door freezer case. The test consisted of the comparison of a pair of new 36Watt 4ft fluorescent tubes and a pair of 25 Watt 4ft Vantium® fixtures. Both the fluorescent and the more directionally efficient Vantium® systems produced the same illuminance of 1,240 Lux at the centre of the back wall of the case. The same case was used to evaluate both sets of lighting.

Table 1 shows the data measured during the 168 hour trial. Because the freezer has to deal with waste heat from lighting, the difference in overall consumption in the case is greater than the difference in consumption in the lighting.

Consumption Comparison	2 x 36 Watt Fluorescent	2 x 25 Watt Vantium®	Units
Illuminance	1,240	1,240	Lux
Fixture Power Consumption	72	50	Watts
Case Power Consumption – No Lights	602	602	Watts
Incremental Case Consumption – With Lights	766	699	Watts
Incremental Case Consumption	164	97	Watts

Table 1: Comparison of total energy consumption in a freezer case for two different lighting systems.

There are important implications to be drawn from this data. The result of the test is a reduction of the incremental illuminated case consumption from 164 Watts to 97 Watts – a reduction of 41% – by using Vantium®. Equally striking is the fact that with the fluorescent tubes in use, the energy consumption of the case was increased by 27%, or in other words, **21% of the total energy consumption of the illuminated case was due to the lighting.** For a line of freezer doors with one fluorescent tube per mullion this number would be more like 15%, and can be halved by substituting with digital lighting fixtures based on LED technology.

1 Provost, CEO Philips, in Knowledge@Wharton, 20Feb2008

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4 – DIGITAL LIGHTING

4.1 – What is digital lighting?

Digital lighting is the term used by Nualight to describe energy efficient lighting for refrigerated display environments that is based on solid state technology [LED]. In this greener, more eco-friendly world, it is ideally considered as the natural successor to environmentally unfriendly and maintenance intensive fluorescent lighting. Digital lighting is increasingly being adopted by global food retailers who understand how to maximise lighting for retail gain. These retailers understand that the decision for adoption of LED into their stores is not as simple as a crude fluorescent bulb replacement scheme. Their success in maximising the return on investment [ROI] or the internal rate of return [IRR] from digital lighting has been to consider the additional peripheral benefits and to correctly include them into the investment appraisal.

The digital lighting concept cannot be achieved with bulb-based illumination sources such as incandescent, fluorescent, halogen, or metal halide bulbs. As well as being relatively energy inefficient, these are incompatible, without complicated electronics and drivers, with instant simple control of intensity and colour which is the basic requirement of digital lighting. In future, the Nualight digital lighting range will incorporate even newer technologies, which are currently in development worldwide.

The main benefits are:

- Reduced maintenance costs
- Reduced installation costs
- Reduced health and safety costs
- Enhanced merchandising opportunities leading to increase in sales (e.g. colour rendering, colour intensity and longer shelf life, improved product illumination)
- Value in exceeding retailer green initiatives (e.g. reducing carbon footprint)

At the time of writing, the requirements for digital lighting solutions are being supplied by light-emitting diodes. However, as other technologies such as organic LED (OLED) mature and become available, these will be incorporated into digital lighting fixtures.

5 – KEY LIGHTING PARAMETERS

5.1 – Energy & efficacy

One of the fundamental specifications to consider when evaluating any lighting system is the power consumption, as it forms a basis of its economic viability. Since there will generally be some form of power converter (sometimes known as a ballast) between the mains input and the lighting fixture, the end user must be clear in specifying that wattage will be measured at the wallplug and not at the fixture. Furthermore, there may be local regulations regarding the luminous efficacy of the installed system that stipulates a minimum lumens per watt value. In this case, the end user must be careful in specifying the lumen output of each fixture to confirm that the standard is met. Simply accepting the figure advertised by the lighting fixture manufacturer on a datasheet is not advisable and it has been shown that manufacturers commonly exaggerate the lumen output[2]. This misrepresentation is not always wilful but can arise through ignorance of the technology. Typically an errant manufacturer will simply take the LED manufacturer's data for a single LED and multiply it by the total number of LEDs to arrive at the lumen output figure, failing to take into account losses due to lenses, covers, reflectors, side walls, etc. These can easily cause a 30 to 40% loss in lumen output. Luminous efficacy is dependent on lumen maintenance, so as the output degrades over time so does the efficacy.

5.2 – Illuminance

The illuminance is the amount of light falling in the case. It is usually measured in lux, or lumens per square metre. It is important to measure the illuminance in an appropriate and consistent manner. This is dealt with in more detail below. The quickest way to measure the illuminance is to use a hand-held meter inside the display case in the location where the products will be on display. However, there can be serious inaccuracies in this way of measuring, depending upon the type of meter, the type of light fixture and the relative positions of the meter and the light source. Even small things such as proximity to a window or how reflective neighbouring surfaces are can make a surprising difference in the number of lumens shown by the meter. When performed correctly, using an appropriate meter and measurement methodology, the results can be used to determine the required digital lighting module to be used to replace the fluorescent. It is important to take appropriate account of the level of ambient lighting which is incorporated in the results.

5.3 – Uniformity

Illumination uniformity is important to optimally display product in, for example, freezer case lighting and undershelf lighting. One can determine the level of lighting uniformity required by performing a series of illuminance measurements at closely spaced intervals along the target plane. However, since it is the illumination pattern on the product on a whole that is viewed by the shopping customer, uniformity should be determined by recording an image of the illumination pattern on a plain white target screen positioned at the product face and importing the image into an appropriate imaging software package. This gives a true reflection of what the shopping customer actually sees in the store.

2 "DOE Solid-State Lighting CALiPER Program: Summary of Results Round 4 of Product Testing", U.S. Department of Energy, January 2008, http://www.netl.doe.gov/ssl/comm_testing.htm

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5.4 – Lifetime

5.4.1 – Lifetime Definition

One of the major advantages of LEDs over more traditional light sources is their superior lifetime characteristics. In addition, LEDs display a gradual degradation in light output over time under correct operating conditions. For this reason, the lighting industry's MTTF (Mean Time to Failure) approach to product lifetime must be abandoned in the case of LEDs, and new lifetime metrics for lumen maintenance used in its place.

The Lighting Research Centre at Rensselaer Polytechnic Institute[3], together with the major LED manufacturers has defined more suitable lifetime metrics for LEDs through the ASSIST (Alliance for Solid State Illumination Systems and Technologies) program.

L_{70} (hours): time to 70% lumen maintenance
L_{50} (hours): time to 50% lumen maintenance

The L_{70} figure represents the time taken for the LED to reach 70% of its original light output.

Research has shown that a 30% drop in light output over the lifetime of a light source is acceptable for most lighting applications. More demanding lighting applications may require greater than 70% lumen maintenance by the LED for a defined operating period.

Similarly, the L_{50} figure represents the time taken for the LED to reach 50% of its original light output. This 50% drop in light output is considered acceptable for decorative lighting applications.

5.4.2 – LED Lifetime Measurement

LED lifetime is dependent on a number of factors that must all be taken into account when producing a figure for LED lifetime:

- LED current
- LED junction temperature
- Ambient operating conditions (relative humidity, temperature stability)

Current estimates of LED lifetime can extend beyond 50,000 hours, which is impractical to measure in real time since this equates to almost six years. Instead, measured data points over a shorter period can be extrapolated to produce an expected lifetime figure.

Nualight has invested in in-house expertise and facilities in order to validate its product lifetimes. Reliability tests are run on all Nualight products under typical operating conditions, including freezer, cooler and room temperature environments. Ambient temperature and humidity are well controlled along with the LED current to reduce the number of variables associated with the measurement.

3 Source: http://www.lrc.rpi.edu/programs/solidstate/

The LED characteristics are monitored consistently using calibrated instrumentation and results are correlated to produce estimates of product lifetime. The first hours of operation of LEDs can vary quite a lot from one manufacturer to another, and it is possible for lumen output to initially increase rather than decrease. This is due to internal details in the packaging of the LED device – its topography, both internal and external, the materials used to make the electrical connection to the semiconductor, the materials used to encapsulate the device, and the phosphors used to generate the white output light.

5.4.3 – Fixture/Fixture Lifetime vs. LED Lifetime

Whereas LED manufacturers quote certain lifetime data for an isolated LED under controlled operating conditions, this cannot be translated to the lifetime of a fixture containing a plurality of these LEDs. One must consider the lifetime of the fixture as a whole, since this is dictated by the lifetime of all constituent elements and how these operate in unison (weakest link scenario). Essential for the lifetime of the fixture is:

- Efficient thermal design
- Choice of LED
- Choice of materials
- Robust mounting solution
- Choice of power supply
- Control circuitry and in-built electronic/electrical protection
- Operating environment (-40°C to +40°C)

Nualight carries out extensive lifetime and reliability testing on individual LEDs and assembled fixtures to ensure that digital light products meet with customer specifications.

Figure 4 shows the lumen output of a Vantium® lighting fixture at ambient temperatures of -30°C and at 2°C corresponding to typical environments in freezers and coolers respectively.

In order to avoid inaccurate estimation of lifetime, it is our practice at Nualight to measure lifetime of standard products over about 10,000 hours of continuous operation and then use the post 5000 hour data to perform a curve fit, from which the lifetime can be accurately predicted.

Figure 5 shows this process applied to the data from Figure 4, with an L_{70} lifetime prediction of 80,000 hours.

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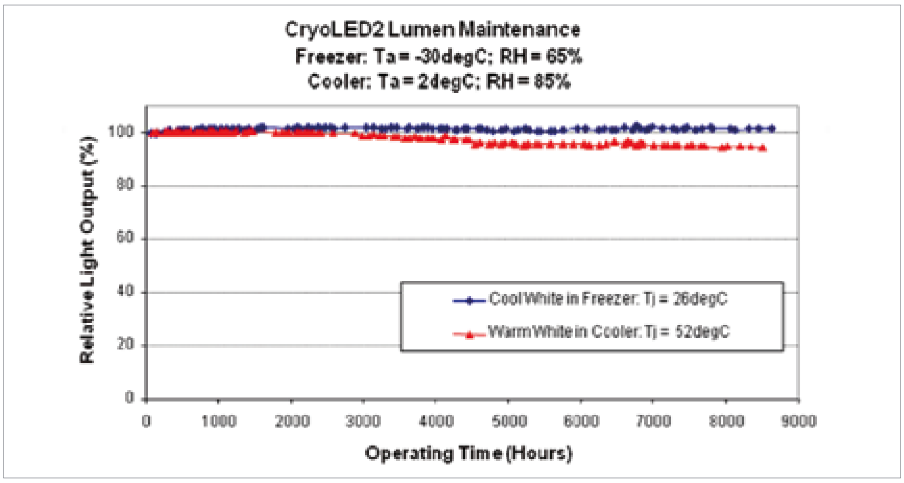

Figure 4: This graph shows the first 9,000 hrs of measured data for a Vantium fixture operated in two different environments: -30° C (typical freezer) and at 2° C (typical cooler).

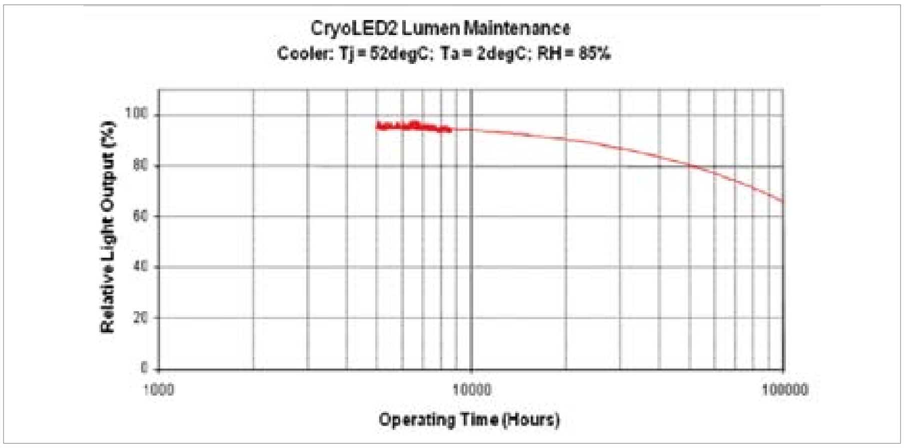

Figure 5: This graph shows the Arrhenius curve fit to the last 4,000 hours of data, showing a predicted L_{70} lifetime of 80,000 hrs for the Vantium in a typical cooler.

5.5 – Reliability

Reliability is defined as the probability that an item can perform its intended function for a specified time under stated conditions. People regularly specify reliability in terms of MTBF (mean time between failures) or MTTF (mean time to failure), however with LEDs lifetime is generally specified to 70% lumen output and they will continue to operate long after this time. In terms of LED reliability other factors need to be considered, such as colour temperature and CRI.

Only by carrying out independent lifetime testing on different LEDs under different conditions can any level of confidence be given on the overall reliability of the fixture. In order to guarantee lifetime the junction temperature of the LED has to be maintained below a specified level, therefore good thermal management of the heat generated within the device is critical. Use of fibre printed circuit boards and plastic housings should be avoided.

5.6 – Maintenance

There is a wide variation in the maintenance practises of retailers. In general, there will be a combination of planned maintenance and unplanned maintenance. Planned maintenance would for example consist, with a fluorescent installation, of an annual replacement of all fluorescent tubes, combined with more regular replacements of those tubes which have suffered early failure, are flickering, exhibiting a significantly reduced brightness or otherwise performing unsatisfactorily. In addition, there will be unplanned maintenance to correct failures which occur outside of the routine maintenance visits. With a digital lighting installation it will be possible to reduce the planned maintenance visits to zero for the first few years and then annually thereafter, mainly to perform spot checks on the lumen maintenance performance of the installation. The need for unplanned maintenance will also be greatly reduced due to the inherent reliability of digital lighting technology. This is summarised in the table 2 below.

Fluorescent	• Annual bulb change • Bulb failures • Ballast failures • Degradation of lumen output if exposed to chilled ambient • Large variation in door to door illuminance
LED Light Sources	• Lumen maintenance more important than mtbf • Can't assume same lifetime for the fixture as for the light source
Digital (LED) Fixtures	• IP54 typical for freezers/coolers • Hermetic sealing not required • Overall system reliability is that of the electronic components/drivers • Vantium® lifetimes of 70,000 hrs in freezers • Vantium® lifetimes of 50,000 hours in room temperature ambients

Table 2: Summary of the difference in maintenance requirements between traditional and digital lighting.

5.7 – Colour

5.7.1 – Colour Metrics for White Light Sources

White light can not always be described as simply "white light". For example, there is a clear distinction between the warm white light from an incandescent bulb in a domestic home and the cold stark white light from a fluorescent bulb in a hospital operating theatre. The CIE (Commision Internationale de l'Eclairage) has developed certain metrics to allow characterisation of white light and colour. Colour matching functions - approximating the sensitivity of the eye to red, green, and blue - produced the 1931 Chromaticity Diagram as shown in figure 6. This diagram gives white light an associated set of chromaticity co-ordinates (x, y) that reflect its perceived colour and colour temperature. This is the foundation of the colour binning structures used by white LED manufacturers. The outer boundary of the diagram, or spectrum locus, defines the region for monochromatic light at a particular wavelength.

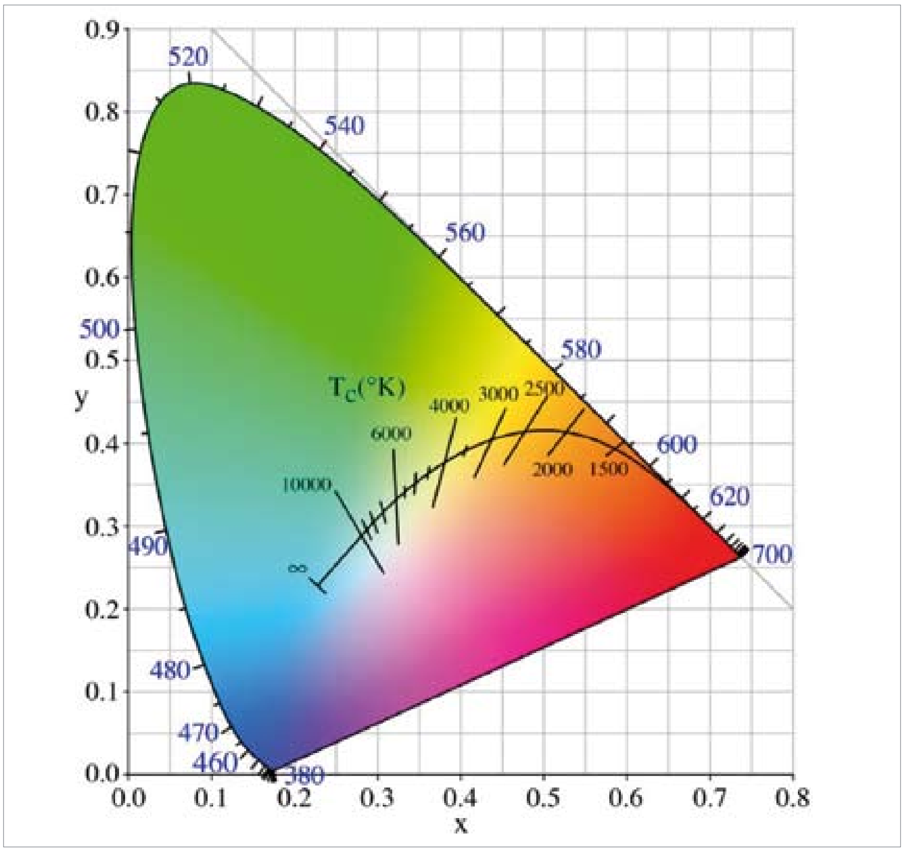

Figure 6: CIE 1931 Chromaticity Diagram with Planckian Locus (Source: http://en.wikipedia.org/wiki/Color_temperature).

5.7.2 – Colour Temperature

A white light source is often characterised in terms of its colour temperature, which is the temperature (units of Kelvin) of a Planckian black body source having the same chromaticity coordinates. The sun is the natural standard for how we perceive colour and it is also the most obvious example of a Planckian black body source. The chromaticity co-ordinates of a black body source fall on the Planckian locus as shown (black curve in centre) on the CIE 1931 Chromaticity Diagram (in figure 6). The Planckian locus is intersected by iso-lines, which are lines with a single colour temperature along their locus.

If the chromaticity co-ordinates of a white light source do not fall on the Planckian locus, it is characterised in terms of its correlated colour temperature (CCT), which is the closest colour to the colour of the white light source. This CCT value is applied to white LEDs since the colour bins extend above and below the Planckian locus.

Measurement of colour temperature for a white light source goes against convention in that a high colour temperature (e.g. 6000K to 10000K) is described as cool white, whereas a low colour temperature (e.g. 2500K to 3000K) is described as warm white.

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5.7.3 – Colour Rendering Index

For a white light source to be suitable for illumination applications, it must have a high colour rendering index. The CRI (colour rendering index) is a measure of how well a white light source renders a set of standardised colour tiles as compared with a reference source. The reference source is a Planckian black body source, which by definition has a CRI of 100. The reference source used has a direct impact on the CRI measurement, and should ideally have the same chromaticity coordinates and luminous flux as the white light source under test. Standard white LEDs containing a blue chip with yellow phosphor have limited CRI due to the relatively low power content at red wavelengths. CRI values can be improved at the cost of efficiency for white LEDs comprising of a blue/UV chip with a blend of several phosphors. The human element in CRI calculation makes it a subjective metric, and work is underway to develop a more quantitative measure of light quality. Typical CRI values are shown in table 3.

Light Source	CRI
Sunlight	100
Incandescent bulb	100
Fluorescent Bulb	60 – 85
White LED (blue chip with yellow phosphor)	55 – 85
RGB LED	60 – 85

Table 3: Source: "Light-Emitting Diodes", E.F. Schubert, Cambridge University Press.

5.8 – Stability

LED technology has inherent differences to more traditional lighting technologies, and these must be well understood by the digital lighting company in order to maximise fixture performance. Poor understanding of the core technological aspect of LEDs will likely lead to flawed designs that exhibit such problems as chromaticity drift and poor lumen maintenance. Chromaticity drift is the term given to an LED that undergoes a shift from warmer white tones (lower CCT) to cooler white tones (higher CCT), which can have a dramatic effect on the colour and quality of the light emitted. In retailing, the appearance or rendering of the illuminated product is of paramount importance. For this reason, stability of CCT and CRI is just as important as lumen maintenance.

Using accumulated expertise in LED technology, Nualight performs extensive testing on LEDs and carefully designs its digital lighting product series to meet application chromaticity specifications. Over the complete lifetime, Nualight's digital lighting products delivers chromaticity stability performance well within the tolerances as specified in the Energy Star Program Requirements for SSL Fixtures v1.0. The result is a lighting solution that not only enhances the appearance of the product following initial installation, but delivers high quality lighting over the lifetime of the fixture.

5.9 – Ease of installation

The ease with which digital lighting fixtures can be integrated into the display case designs of the OEMs is an important topic which has been carefully considered in designing the Vantium® product series. Full interface information is available for all major OEM case styles.

5.10 – Retrofit capability

Within the installed base of refrigerated display cases in the retail world, there is a wide variety of cases and many generations of obsolete older fluorescent tubing. A successful retrofit program has to ensure that it will be possible to include as much as possible of the installed base in the lighting upgrade, so as to retain a uniform look/feel in the stores. What counts here is the adaptability of the digital lighting fixtures to varying mechanical and electrical interfaces, so as to maximise the effectiveness of the retrofit project.

5.11 – Consistency

There is little merit in having a retailer dealing with one lighting supplier for freezers, another for multi-decks, another for serving counters etc. Unfortunately, some of the most prominent lighting companies that have introduced some LED lighting products for retailers have a rather limited range. Working with more than one supplier for a particular type of in-store technology presents unnecessary difficulty to the customer. Having recognised this problem, Nualight has identified the main display case requirements and has classified them as lighting fixtures for doors, shelves, islands, counters, combi, rooms and private label. It has products available which are tailored for the different needs of each of these applications. This is the most effective supply model from the retailer perspective and enables a phased approach to the introduction of digital lighting.

5.12 – Certifications

The electrical performance of the fixture will need to be specified in terms of parameters such as power factor and leakage current, often arising as a result of local regulations. Whereas certain certifications may be mandatory, such as RoHS compliance or CE compliance, others may be the industry norm, for example it may be usual for the product to have a UL listing. It is incumbent on the end user to be aware of all certifications that are relevant and to ensure at an early stage that the manufacturer is capable of delivering compliant products. A specialised fixture manufacturer will be able to work with the end user to ensure that the end product is properly certified.

Certifications are obtained as a result of product testing by relevant, independent and competent bodies. The purpose of formal certifications is to ensure that the product meets certain minimum agreed standards appropriate for the product and its working environment. These standards cover such things as safety, electrical interference and environmental impact.

It is vital that the fixture manufacturer is aware of what standards and directives must be met in order to achieve the regulatory compliance. For example, for CE certification the EU Electromagnetic Compatibility Directive would apply to digital lighting whereas, say, the EU Pressure Vessel Directive clearly would not. Furthermore, if a particular directive applies to a product, it must be further established what standards within that directive are appropriate and what specific tests must be carried out. The certifications required for a given product are subject to local laws and ultimately it is incumbent on the end user to be aware of all certifications that are relevant and to ensure at an early stage that the manufacturer is capable of delivering compliant products. A manufacturer experienced in the field such as Nualight will, in partnership with the retailer, be able to provide advice and expertise in this area, which can often be confusing to those unfamiliar with the regulations.

Other certifications are not legally required, but there may be an industry norm, for example it may be usual for the product to have a UL listing in a particular category. Again, the fixture manufacturer will be able to draw on its experience in the field to provide advice on this and be able to supply the correct product with best practice certifications.

6 – PAYBACK

Following the deployment of digital lighting, the retailer can expect to make substantial savings, which are summarised in table 4 below. In this table the factors are separated into hard and soft. Hard essentially means factors which can be unambiguously measured independently, such as a reduction in energy consumption and a reduction in expenditure on maintenance. It is also possible to factor in the rising price of energy and to make allowance for this. Embedded intelligence, such as adding sensors to the digital lighting fixtures so that they are dimmed when appropriate, can induce additional saving of up to 30%, which can be measured. In hot climates, there will also be some benefits to the HVAC budget. Soft factors are less easy to measure, but may in fact be worth much more to the retailer, for example sales increases from improved lighting. Regulatory factors, such as rebates, taxes or credits are easy to calculate but will vary from region to region.

Hard gains	Reduced energy consumption Reduced maintenance Reduced energy cost Embedded intelligence HVAC savings
Soft gains	Increased sales from improved lighting Improved produce shelf life Improved safety Better aesthetics Improved corporate branding Reduced carbon footprint and better sustainability
Regulatory gains	ESCo rebates Tax reliefs
Losses	Carbon taxes

Table 4: Some payback factors, categorised as described in the text.

Consider an example of a retail multiple that wants to replace fluorescents in its100 freezer doors, in each of 10 stores, with a digital lighting solution. We assume energy costs at 0.10/ kWhr and 16 hours per day opening. We only calculate the saving from the two "hardest" payback factors, which are energy and maintenance.

Annual energy savings	€55,330
Planned maintenance savings p.a.	€12,000
Unplanned maintenance savings p.a.	€ 5,400
Total annual cost saving	€ 72,730
Retrofit costs (materials & labour)	€220,000
Fixture lifetime	8.7 years
Payback period	3.0 years
Total savings over lifetime of light	€600,365
Annualised ROI / IRR	21.56% / 29.56%

Table 5: This table shows the benefits to this particular retailer in their retro-fit programme resulting in a 3yr payback period and a 20% ROI.

In fact, it might be more appropriate to include a 5% - 10% annual increase in energy, which will have the effect of shortening the payback even more. See figure 7 below.

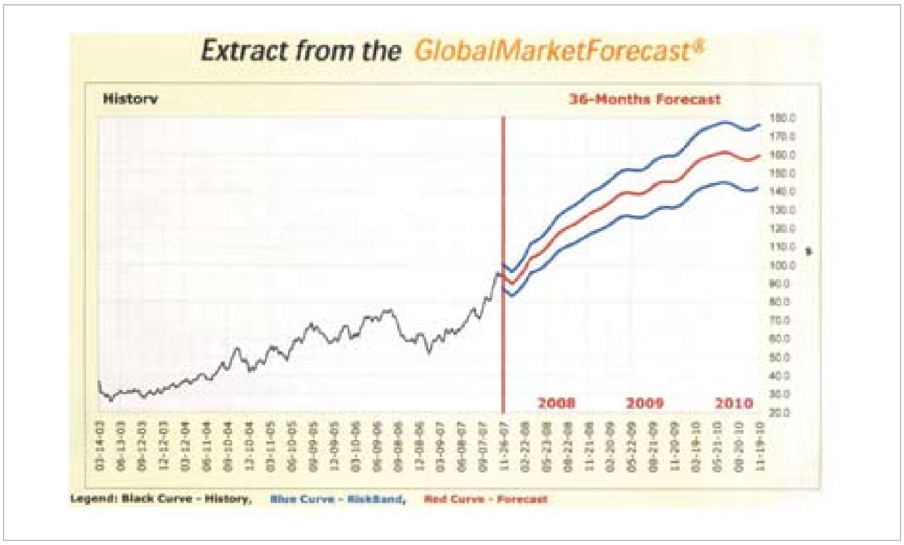

Figure 7: Oil price history over the previous five years, and one author's three year forecast, with low and high limits.

Figure 8: Vantium Porto, suitable for freezer door applications.

Merchandising considerations are more complicated to build into a cost model but are especially important. Digital lighting has an overall better quality of light than fluorescent. It is more controllable, it can be dimmed, switched (even at low temperatures), proximity switched, linked to wireless control - the variations are endless. Because LEDS are point-like sources of light they can be focused and redirected effectively with relatively small optics, making it easier to improve uniformity across extended displays and direct the light where it is most needed. Because the light source is compact and not fragile, the fixture designer has a lot more latitude and can produce look-good, feel-good light fixtures (as shown in figure 8). In short, digital lighting is more intelligent and appropriate for many applications.

The effect of increased sales due to better lighting in retail displays should not be surprising. Consider badly lit freezer doors, with flickering, dim or unlit fluorescents tubes. Apart from the difficulty in seeing the products on sale in the dark interior, there is a customer perception that if the lights are not working, neither is the refrigeration.

Figure 9: Installation used for before and after sales performance measurement.

We have measured this effect in a customer store where it was possible to replace all the fluorescents on one side of an aisle with digital lighting fixtures, while retaining the fluorescent lighting on the facing doors.

The customer was measuring sales per door, had full seasonal records and provided data on sales and margin performance. The results are shown in table 6:

	Vantium® LED	Fluorescent 36w
Annual sales per door	€33,588	€28,225
Sales improvement %	19%	–
Margin on goods %	16%	16%
Margin on goods	€5374	€4516
Annual improvement	€858 per door	–

Table 6: Comparative sales data for same-product sales from freezers before and after a digital lighting retrofit.

This case study is for a particular store with a particular range of product and should be generalised with caution - it resulted in a payback as short as five months for this retailer. However, it absolutely emphasises the potential for enhanced merchandising which can be achieved with digital lighting. In this case, sales increased by 19% in volume per door. Even an increase of 3% per door will reduce the payback period on a digital lighting retrofit to less than one year. Retailers will want to take note and measure for themselves, as part of the post-installation validation described below.

NUALIGHT

7 – IMPLEMENTATION PROCESS

7.1 – Audit

Following identification of a retail store lighting system suitable for retrofitting with Nualight digital lighting, the prospective implementation partner must be aware of the performance of the already installed lighting. This information is gathered in the form of an on-site audit of the store lighting carried out by the partner in order to select the best solution for the application from the Nualight digital lighting product range. In the event that no current product matches the application, these performance data are essential in providing the structure for a design specification to develop a digital lighting solution. To obtain this data on installed lighting systems, the partner must be instructed on how to perform illuminance measurements and light uniformity measurements at the product and the customer "point of decision".

Retailers are specifically interested in the level of illumination and the quality of the light on the product - not necessarily lumen output, colour temperature, colour rendering index, etc. The straightforward method to achieve this is for the partner to measure the illuminance in lux (amount of light falling on a surface, lumens per square metre) at specific points of interest in the application using an appropriate calibrated portable light meter. Photos and accurate sketches with dimensional data, along with illuminance measurements combine to formulate a clear picture of what is required for a successful retrofit. The uniformity of the illumination in the case should be appropriate to the application. In the technical section on digital lighting above, we explain in more detail how to measure uniformity.

From a physical design standpoint, the partner must take note of the mechanical envelope available, the installed mounting fixtures used and their positions, and any other constraints that exist in the application (cable exit, existing wiring, etc.). This information is key to providing a digital lighting solution with an installation process that is trouble-free and efficient, which in turn, minimises loss of sales.

Based on technical knowledge and discussions with the retailer, the partner must assess the installed lighting in terms of lifetime, reliability, and realistic operating costs - key areas where Nualight digital lighting has a distinct advantage. Considering fluorescent-based lighting installations in retail stores, the lifetime of the product display case far outweighs the lifetime of the fluorescent bulb, leading to multiple bulb replacements on the same case. The inefficiency of fluorescent bulbs increases considerably when operating in temperature controlled cases as opposed to ambient room temperature, with the result that the light output may drop below an acceptable level before bulb replacement.

To determine the real costs associated with a fluorescent lighting installation for a vertical freezer case as an example, the vendor must consider at least the various items outlined in table 7:

	Task	**Complete**	**Notes**
Audit	Cost of installed lighting system		
	Energy cost of lighting		
	Energy cost of thermal load on freezer compressor		
	Cost of product spoilage (due to glass breakage, mercury, UV, IR)		
	Cost of bulb replacements, regular and intermittent		
	Cost or replacing ballast and other components		
	Loss of sales during maintenance		
	Loss of sales due to poor lighting		

Table 7: Checklist for assisting with the technical audit.

7.2 – Specify

The most important parameters to specify are the total (not the nominal) consumption of the new lighting fixtures, the rated lifetime, and the compatibility with the installed display cases in the event of a retrofit.

Lifetime specification: the end user will perform ROI calculations based on the expected fixture lifetime. It is important that this lifetime be included in the product specification, and that the supplier is willing to guarantee the specification. LED lifetime is normally what defines the fixture lifetime and is detailed above. However it is important to be aware that the lifetime of a product is dependent on the lifetime of its constituent parts, not just the LEDs. For example, high powered fixtures sometimes employ forced air cooling to achieve the rated LED lifetime of (say) 50,000 hours, but the lifetime of the fan itself could be substantially less than this. The specification process will be aided by the use of table 8 overleaf.

	Task	Complete	Notes
Audit	Power usage		
	Regulatory compliance		
	Industry standards compliance		
	Fixture lifetime		
	Lighting output		
	Controls (e.g. dimming, PIR sensing)		
	Acceptance criteria		

Table 8: Checklist for assisting with the specification process.

7.3 – Plan

New installation or retrofit installations can each present different challenges. One of the main factors for both is the ease in which the lighting fixtures can be fitted. Being able to choose between different mounting solutions can speed up installations significantly.

With new installations it may be preferred to permanently fit the fixtures using integral brackets. Due to the diversity of cases on the market, the ability to offer a range of brackets is necessary to allow for different channel depths as required. The ability to specify cables of different lengths and colours to suit the frame dimensions and wiring conventions is also important.

With retrofit installations having flexibility where the mounting hardware is located is a great benefit as the accuracy in placement of the mounting holes becomes insignificant. It might be preferred to use clips to hold the fixture in place rather then locating and fixing integral brackets, or possibly use a combination of both. In general 30 minutes should be allowed to remove the two existing fluorescents and retrofit the digital lighting fixtures into a freezer.

A checklist is provided (table 9), to assist in the process of planning the installation. This is generic, as the actual planning process which is required will be retailer-dependant and will be familiar to the project leader.

	Task	Complete	Notes
Audit	System delivery		
	Installation		
	Timescale		
	Validation		
	Announcements (press releases etc)		

Table 9: Planning checklist.

7.4 – Validate

Having carried out all due diligence in regards to the lighting requirements, expectations, and specification, the final installation should go through a formal validation process to ensure that it is indeed performing as it should. Energy consumption and light output (level, CCT, CRI uniformity) in all modes of operation are of course critical, but another less obvious facet of the installation is the effect of digital lighting on the customer. Specifically, how do customers react to the change, are they purchasing more products and if so what products? Positive results from this type of validation, carried out in partnership with the customer, can lead to further adoption of the technology and have a tangible positive effect on the initial investment. A validation audit of all technical aspects after a period of 12 months should also be considered. This will promote confidence in the longevity of the technology and demonstrate the fixture supplier's willingness to work with customers rather than adopt a "fix and forget" approach. The key points are summarised in table 10.

	Task	Complete	Notes
Audit	Functionality		
	Power usage		
	Light output (levels, uniformity, CRI, CCT)		
	Sales data gathering and analysis		

Table 10: Validation checklist.

7.5 – Checklist

The checklist shown above is necessarily in summary form only – as an appropriately qualified installation partner will have detailed templates available to suit the various implementation scenarios to share with the retailer.

8 – SELECTING AN LED FIXTURE SUPPLIER

It is important to select a supplier who can provide all of the retailer's short-term needs for all of their display case configurations. Table 11, for example, shows the Nualight vision with respect to products for refrigerated display illumination. In addition to having standard products available for the six most common case types, Nualight also offers retailers the opportunity to custom design their own product by offering a choice of configurations in terms of design, illumination, styling and colour temperature, as outlined in table 12:

Vantium Porto	DOORS	Any freezer door case configuration.	Full Door / Half Door Options
Vantium Largo	SHELVES	Any multi-deck case configuration.	Frontshelf / Undershelf / Canopy Options
Vantium Centro	ISLANDS	Any deep well and coffin case configuration.	Handrail / Integrated Glass Cover Options
Vantium Fresco	COUNTERS	Any meat serveover, salad bar or deli counter.	Canopy / Peripheral Options
Vantium Duo	COMBI	Any type of door / island combination case.	Any combination of the Vantium product series.
Vantium Alto	ROOMS	Any walk-in cooler or freezer room.	Ceiling Light Options
Vantium Uno	PRIVATE LABEL	Technology licensing for own brand applications.	Available for licensing across all retail and commercial applications.

Table 11: The Nualight Vantium product series.

Colour temp	Length	Brightness	Case type	Extrusion colour	Power supply	Cable	Bracket	Retro-fit or New Cases

Table 12: Configuration options for the Nualight Vantium product series.

As digital lighting will ultimately be pervasive, it is important for the retailer to partner with a supplier who can not alone provide an end-to-end solution with respect to the initial rollout, but understands where the underlying solid state lighting technology is going in the future, and is ready to make the decision to incorporate new elements of this at the appropriate time.

9 – THE OUTCOME

In this paper we have described the technical, financial and merchandising issues faced by retailers considering making the transition from fluorescent to digital lighting. There are complexities involved which can make it difficult for the non-expert to find the optimum path through the choices which are available. We describe a process which will enable them to undertake this in a more systematic way, to determine by an audit of their existing facilities what operational improvements and financial benefits might be available, how to specify the digital lighting, select a vendor and validate that the promised results accrue. Although this can be done by in-house personnel, it is unlikely that many retail multiples will have the expertise available, and it will usually be necessary to work closely with an external partner on this process. This is a service which Nualight offers, as well as having the broadest available product range, Nualight takes a consultative approach to the implementation of digital lighting. Retailers can avail of Nualight technical workshops which provide an understanding of the fundamentals of digital lighting in food retail applications.

Nualight is a pioneering digital lighting company and an authoritative industry expert in this market – it is the only company in the industry exclusively focused on refrigerated display merchandising equipment. A one-stop-shop, Nualight understands the applications and the requirements from a retailer's perspective, it has a 5th generation product portfolio and has strong relationships with case manufacturers, energy consulting organisations and installation companies. The company offers installation, retrofitting and maintenance services. Concerned by the urgency of green compliance, Nualight will shortly make available to the industry a web based toolkit, dealing with the selection, evaluation, installation and operation of digital lighting solutions. This will enable retailers to confidently forecast their return on investment and shorten their implementation deadlines.

www.nualight.com

10 – APPENDIX

Glossary

A

Ambient Temperature
The surrounding temperature within an environment.

Amperes
("Amps.") A measure of electrical current. Power (Watts) = Voltage (Volts) x Current (Amps).

American National Standards Institute (ANSI)
A consensus-based organisation which coordinates voluntary standards for the physical, electrical and performance characteristics of lamps, ballasts, fixtures and other lighting and electrical equipment.

Anode
The "positive" terminal of a diode.

Application
Also called "lighting application," it refers to the particular use the lamp is being put to (e.g. retail lighting application). The term can also refer in a general way to "application engineering" which deals with specific parameters and usage of light sources (e.g. how to do a lighting layout, where to place fixtures and so on).

B

Ballast
An auxiliary piece of equipment required to start and to properly control the flow of current to gas discharge light sources such as fluorescent and high intensity discharge (HID) lamps.

Ballast Factor (BF)
This is the percentage of a lamp's rated lumen output that can be expected when operated on specific, commercially available ballast. For example, ballast with a ballast factor of 0.93 will result in the lamp's emitting 93% of its rated lumen output. A ballast with a lower BF results in less light output and also generally consumes less power.

Beam Angle (Viewing Angle)
The angular dimension of the cone of light from a source encompassing the central part of the beam to the angle where the light intensity is 50% of maximum. The beam angle sometimes called "beam spread" is often part of the ordering code for the reflector lamps. It can also be referred to as the viewing angle when applied to LEDs.

Beam Lumens
The total lumens present within the portion of the beam contained in the given beam angle.

Beam Spread
For reflector type lamps. The total angle of the directed beam (in degrees horizontal or vertical) to where the intensity of the beam falls to 50% or 10% of the maximum candlepower value as indicated.

Blackbody
An ideal material that absorbs all incident radiation and re-emits the maximum possible radiation for a given temperature. The sun is the closest example of a blackbody. Incandescent lamps also closely resemble a blackbody.

Bulb
A loose way of referring to a lamp. "Bulb" refers to the outer glass bulb containing the light source.

Brightness
Brightness is the visual perception of the amount of light emission based on the luminance of a source.

C

Canadian Standards Association (CSA)
An organisation that writes standards and tests lighting equipment for performance as well as electrical and fire safety. Canadian provincial laws generally require that all products sold for consumer use in Canada must have CSA or equivalent approval.

Candela (cd)
The measure of luminous intensity of a source in a given direction. The term has been retained from the early days of lighting when a standard candle of a fixed size and composition was defined as producing one candela in every direction. A plot of intensity versus direction is called a candela distribution curve and is often provided for reflector lamps and for fixtures with a lamp operating in them.

Candlepower
An obsolete term for luminous intensity; current practice is to refer to this simply as candelas.

Candlepower (Mean Spherical)
Initial mean spherical candlepower at the design voltage. Mean spherical candlepower is the generally accepted method of rating the total light output of miniature lamps. To convert this rating to lumens, multiply it by 12.57 (4 pi).

Cathode
The "negative" terminal of a diode.

CE
CE marking is a declaration from a manufacturer that the product conforms to the requirements of the appropriate European Directive, allowing quicker access to the European market.

Chip
A very small area of semi-conducting material. Also known as a "die," it is the "active" light-emitting component of a LED.

Chromaticity
Measure to identify the colour of a source, typically expressed as (x, y) coordinates on the CIE 1931 Chromaticity Diagram.

Chromaticity Coordinates
A system for measuring the colour of the light emitted from a source - either a primary source like a lamp or a secondary source like an illuminated object. The x, y, and z chromaticity coordinates relate to the response of the human eye to the primary colours of light of red, green and blue. Usually only two numbers, x and y coordinates ranging from 0 to 1 specify the chromaticity.

Coefficient of Utilisation (CU)

In general lighting calculations, the fraction of initial source lumens that reach the work plane. CU is a function of fixture efficiency, room surface reflectances and room shape.

Colour (Dominant Wavelength)
LEDs are designed to emit light at specific wavelengths or colours. The dominant wavelength is a quantitative measure of a LED colour as perceived by the human eye and is usually measured in nanometres. In order to specify a LED, you must specify the colour or dominant wavelength range required for your application. Some applications may have colour constraints in order to meet specific government specifications or regulatory guidelines.

Colour Bin
LEDs are sorted according to their wavelength or chromaticity coordinates into different groupings or "bins."

Colour Rendering Index (CRI)
An international system used to rate a source's ability to render object colours. The higher the CRI (based upon a 0 –100 scale) the richer colours generally appear. CRI ratings of various sources may be compared, but a numerical comparison is only valid if the sources are close in colour temperature and luminous flux. CRI differences among sources are not usually significant (visible to the eye) unless the difference is more than 3 to 5 points.

Colour Rendering Indicator
Draws attention to the fact that this is a source with high colour rendering, which helps objects and persons illuminated to appear more true to life.

Compact Fluorescent Lamp (CFL)
The general term applied to fluorescent lamps that are single-ended and that have smaller diameter tubes that are bent to form a compact shape. Some CFLs have integral ballasts and medium or candelabra screw bases for easy replacement of incandescent lamps.

Colour Temperature (Correlated Colour Temperature - CCT)
A number indicating the degree of "yellowness" or "blueness" of a white light source. Measured in Kelvins, CCT represents the temperature a blackbody must reach to mimic the colour of the source. Yellowish-white ("warm") sources, like incandescent lamps , have lower colour temperatures in the 2700K – 3000K range; white and bluish-white ("cool") sources, such as cool white (4100K) and natural daylight (6000K), have higher colour temperatures. The higher the colour temperature the whiter, or bluer, the light will be.

Cool White
A term loosely used to denote a colour temperature of around 4100 K. The Cool White (CW) designation is used specifically for T12 and other fluorescent lamps using halophosphors and having a CRI of 62.

Cosine-Corrected
An illuminance meter that measures the light level correctly irrespective of the angle the light is coming from.

D

Daylight Lamp
A lamp resembling the colour of daylight, typically with a colour temperature of 5500 K to 6500K

Dichroic Reflector (or Filter)
A reflector (or filter) that reflects one region of the spectrum while allowing the other region(s) to pass through. A reflector lamp with a dichroic reflector will have a "cool beam" i.e. most of the heat has been removed from the beam by allowing it to pass through the reflector while the light has been reflected.

Dimmable
Whether or not the source luminous flux can be varied while maintaining reliability.

Dimmer, Dimming Control
A device used to lower the light output of a source, usually by reducing the wattage it is being operated at. Dimming controls are increasing in popularity as energy conserving devices.

Dominant Wavelength
A quantitative measure of the colour of a LED as perceived by the human eye. It is usually measured in nanometres.

E

Efficacy (Luminous Efficiency)
In lighting terms, efficacy or luminous efficiency is a measurement of how effective a light source is in converting electrical input power to LUMENS of visible light, expressed in LUMENS-PER-WATT (LPW). In scientific terms, efficacy is a measurement of the conversion between optical power (Watts) and luminous flux (lumens), based on the eye sensitivity function.

Efficiency (Wallplug)
The efficiency of a light source is simply the fraction of electrical energy converted to light, i.e. watts of visible light produced for each watt of electrical power with no concern about the wavelength where the energy is being radiated. For example, a 100 watt incandescent lamp converts 7% of the electrical energy into light; discharge lamps convert 25% to 40% into light. The efficiency of a fixture is the percentage of the lamp lumens that actually comes out of the fixture.

Electromagnetic Inference (EMI)
High frequency electronic ballasts and other electronic devices can produce a small amount of radio waves which can interfere with radio and TV. International standards and requirements must be met for EMI levels before an electronic device is considered compliant.

Electromagnetic Spectrum
A continuum of electric and magnetic radiation that can be characterised by wavelength or frequency. Visible light encompasses a small part of the electromagnetic spectrum in the region from about 380 nanometres (violet) to 770 nanometres (red) by wavelength.

Energy Star
A program to promote energy efficient consumer products set up by the Environmental Protection Agency in the United States in 1992.

Energy Policy Act (EPACT)
Comprehensive energy legislation passed by the U. S. Congress in 1992. The lighting portion includes lamp labelling and minimum energy efficacy (lumens/watt) requirements for many commonly used incandescent and fluorescent lamp types. Federal Canadian legislation sets similar minimum energy efficacy requirements for incandescent reflector lamps and common linear fluorescent lamps.

Energy Policy Act (EPACT) Indicator
Means this lamp is federally regulated for Energy Efficiency.

Eye Sensitivity
A curve depicting the sensitivity of the human eye as a function of wavelength. The peak of human eye sensitivity is in the yellow-green region of the spectrum. The normal curve refers to photopic vision or the response of the cones of the eye. (See Photopic, Scotopic, Fovea, Foveal vision)

F

Flammability Rating
Plastic materials used in electronics design should be certified to a suitable flammability rating to ensure the safety and reliability of the product. Flammability ratings are awarded by UL in North America, and IEC in Europe.

Flicker
The periodic variation in light level caused by AC operation that can lead to strobe effects.

Fluorescence
A physical phenomenon whereby an atom of a material absorbs a photon of light and immediately emits a photon of longer wavelength. If there is a significant delay the phenomenon is called phosphorescence rather than fluorescence. It is interesting that "phosphors" used in lamps exhibit "fluorescence," not "phosphorescence."

Fluorescent Lamp
A high efficiency lamp utilising an electric discharge through low pressure mercury vapour to produce ultraviolet (UV) energy. The UV excites phosphor materials applied as a thin layer on the inside of a glass tube which makes up the structure of the lamp. The phosphors transform the UV to visible light.

Footcandle (fc)
A unit of illuminance or light falling onto a surface. It stands for the light level on a surface one foot from a standard candle. One footcandle is equal to one lumen per square foot. See also Lux.

Forward Current
Current through a diode in the direction of its greatest conduction.

Forward Voltage (Vf)
The voltage across a diode for a given forward current.

Fovea, Foveal Vision
A small region of the retina corresponding to what an observer is looking straight at. This region is populated almost entirely with cones, while the peripheral region has increasing numbers of rods. Cones have a sensitivity peaking in the yellow-green corresponding to the eye response curve.

Full Spectrum Lighting
A marketing term, typically associated with light sources that are similar to some forms of natural daylight (5000K and above, 90+ CRI), but sometimes more broadly used for lamps that have a smooth and continuous colour spectrum.

G

Glare
Visual discomfort caused by excessive brightness is called discomfort glare. If task performance is affected it is called disability glare. Glare can be direct glare or indirect (reflected) glare.

H

Halogen Lamp
A halogen lamp is an incandescent lamp with a filament that is surrounded by halogen gases, such as iodine or bromine. Halogen gases allow the filaments to be operated at higher temperatures and higher efficacies. The halogen participates in a tungsten transport cycle, returning tungsten to the filament and prolonging lamp life.

High Intensity Discharge (HID) Lamp
A general term for mercury, metal halide and high-pressure sodium lamps. HID lamps contain compact arc tubes which enclose various gases and metal salts operating at relatively high pressures and temperatures.

I

Illuminance
The "density" of light (lumens/area) incident on a surface; i.e. the light level on a surface. Illuminance is measured in footcandles or lux.

Illuminance Meter
A device that measures the illuminance at a location calibrated either in footcandles or in lux. (Also known as a light meter)

Incandescent Lamp
A light source that generates light utilising a thin filament wire (usually of tungsten) heated to white heat by an electric current passing through it.

Infrared Radiation
Electromagnetic energy radiated in the wavelength range of about 770 to 1,000,000 nanometres. Energy in this range cannot be seen by the human eye, but can be sensed as heat by the skin.

Intensity Bin
LEDs are sorted according to their intensity values into different groupings or "bins."

International Electrotechnical Commission (IEC)
A private organisation that defines standards for all electrical, electronic and related technology, with a view to safety, performance, and energy efficiency.

Inverse Square Law
Formula stating that if you double the distance from the light source, the light level goes down by a factor of 4, if you triple the distance, it goes down by a factor of 9, and so on.

Isocandela Plot
A plot with lines connecting points of equal luminous intensity around a source. Isolux Plot (or Isofootcandle Plot) A line plotted to show points of equal illuminance (lux or footcandles) on a surface illuminated by a source or sources.

K

Kelvin
A unit of temperature starting from absolute zero, parallel to the Celsius scale. 0C is 273K.

Kilowatt (kW)
The measure of electrical power equal to 1000 watts.

Kilowatt Hour (kWh)
The standard measure of electrical energy and the typical billing unit used by electrical utilities for electricity

use. A 100-watt lamp operated for 10 hours consumes 1000 watt-hours (100 x 10) or one kilowatt-hour. If the utility charges -0.14/kWh, then the electricity cost for the 10 hours of operation would be 14 cents (1 x -0.14).

L

Lamp
The term used to refer to the complete light source package, including the inner parts as well as the outer bulb or tube. "Lamp", of course, is also commonly used to refer to a type of small light fixture such as a table lamp.

Lamp Types
Filament lamps: Incandescent, Halogen, Halogen-IR.
Discharge Lamps: Fluorescent, HID (High Intensity Discharge)
HID Lamps: Mercury, HPS (High Pressure Sodium), MH (Metal Halide) and CMH (Ceramic Metal Halide)

Leadframe
A metallic frame used for mounting and connecting LED chips. The leadframe functions as the electrical leads of the device.

Lens
An optical element which controls the distribution of light by redirecting individual rays. Fixtures often have lenses in addition to reflectors.

Lifetime
LED reliability is described in terms of lifetime, which is the variation of light output with time, or lumen maintenance, for a LED operating in well controlled ambient conditions at a set current. LED Lifetime is critically dependent on LED junction temperature, forward current and environmental conditions. For most lighting applications, lumen maintenance of 70% is necessary over the required operating period. Lumen maintenance of 50% is acceptable for decorative lighting applications.

Light
Radiant energy that can be sensed or seen by the human eye. Visible light is measured in lumens.

Light Emitting Diode (LED)
A semiconductor that directly converts electrical impulses into light. Some LEDs today incorporate fluorescent materials to change the colour characteristics of the emitted light.

Lumens
A measure of the luminous flux or quantity of light emitted by a source. For example, a dinner candle provides about 12 lumens. A 60-watt Soft White incandescent lamp provides about 840 lumens.

Lumen Maintenance
A measure of how well a lamp maintains its light output over time. It may be expressed numerically or as a graph of light output vs. time.

Luminaire
A complete lighting unit consisting of a lamp (or lamps), ballast (or ballasts) as required together with the parts designed to distribute the light, position and protect the lamps and connect them to the power supply. A luminaire is often referred to as a fixture.

Luminaire Efficiency
The ratio of total lumens emitted by a luminaire to those emitted by the lamp or lamps used in that luminaire.

Luminance
A measure of "surface brightness" when an observer is looking in the direction of the surface. It is measured in candelas per square meter (or per square foot) and was formerly referred to as "photometric brightness."

Luminous Efficacy
(See EFFICACY)

Luminous Intensity
A measure of the visibility of a light source generally expressed in candelas. It is defined as luminous flux per unit solid angle (steradian) in a given direction.

Lux (lx)
A unit of illuminance or light falling onto a surface. One lux is equal to one lumen per square meter. Ten lux approximately equals one footcandle.

M

Mean Lumens
The average light output of a lamp over its rated life. Based on the shape of the lumen depreciation curve, for fluorescent and metal halide lamps, mean lumens are measured at 40% of rated lamp life. For mercury, highpressure sodium and incandescent lamps, mean lumen ratings refer to lumens at 50% of rated lamp life (See Lumen Maintenance).

Metal Halide Lamp
A high intensity discharge light source in which the light is produced by the radiation from mercury, plus halides of metals such as sodium, scandium, indium and dysprosium. Some lamp types may also utilise phosphor coatings.

Mesopic
Typically referring to nighttime outdoor lighting conditions, the region between PHOTOPIC and SCOTOPIC vision.

Monochromatic Light
Light with only one wavelength (i.e. colour) present.

N

Nanometre
A unit of wavelength equal to 1 x 10-9 m.

O

Operating Voltage
For electrical discharge lamps, this is the voltage measured across the discharge when the lamp is operating. It is governed by the contents of the chamber and is somewhat independent of the ballast and other external factors.

P

Package
LED's are available in either leaded-through-hole, or surface-mount packages. Through-hole LED's are ideal for wave solder circuit board applications. Most through-hole LED's are 2-leaded devices. Common through-hole package sizes include 3mm (T-1) and 5mm (T-1 *) diameter parts. Whereas, surface-mount packages are best used with reflow assembly. SMD devices are also useful when package size constraints are an issue.

Peak Wavelength
The wavelength at which peak optical power is emitted for a LED.

Phosphor
An inorganic chemical compound processed into a powder and deposited on the inner glass surface of fluorescent tubes and some mercury and metal-halide lamp bulbs. Phosphors are designed to absorb short wavelength ultraviolet radiation and to transform and emit it as visible light. In LEDs, a yellow phosphor is typically used in conjunction with a blue chip to produce white light.

Photometry
The measurement of light and related quantities.

Photopic
Vision for which the cones in the eye are responsible, typically at high brightness and in the foveal or central region.

Power Factor (PF)
A measure of the phase difference between voltage and current drawn by an electrical device, such as a ballast or motor. Power factors can range from 0 to 1.0, with 1.0 being ideal. Power factor is sometimes expressed as a percent. Incandescent lamps have power factors close to 1.0 because they are simple "resistive" loads. The power factor of a fluorescent and HID lamp system is determined by the ballast used. "High" power factor usually means a rating of 0.9 or greater. Power companies may penalise users for using low power factor devices.

Q

Quartz
A name for fused silica or melted sand from which many high-temperature containers are fashioned in the lighting industry. Quartz looks like glass but can withstand the high temperatures needed to contain high intensity arc discharges.

R

Radiation
A general term for the release of energy in a "wave" or "ray" form. All light is radiant energy or radiation, as is heat, UV, microwaves, radio waves, etc.

Rated Lamp Life
For most lamp types (LEDs not included), rated lamp life is the length of time of a statistically large sample between first use and the point when 50% of the lamps have died. It is possible to define "useful life" of a lamp based on practical considerations involving lumen depreciation and colour shift.

Reflectance
The ratio of light reflected from a surface to that incident upon it.

Reflector Lamp (R)
A light source with a built-in reflecting surface. Sometimes, the term is used to refer specifically to blown bulbs like the R and ER lamps; at other times, it includes all reflector lamps like PAR and MR.

Reverse Voltage (VR)
Voltage across the diode for a given reverse current.

S

Scotopic
Vision where the rods of the retina are exclusively responsible for seeing, typically like the light levels in the countryside on a moonless, starlit night.

Scotopic/Photopic (S/P) Ratio
This measurement accounts for the fact that of the two light sensors in the retina, rods are more sensitive to blue light (scotopic vision) and cones to yellow light (photopic vision). The scotopic/photopic (S/P) ratio is an attempt to capture the relative strengths of these two responses. S/P is calculated as the ratio of scotopic lumens to photopic lumens for a light source on an ANSI reference ballast. Cooler sources (higher colour temperatures lamps) tend to have higher values of the S/P ratio compared to warm sources.

Spectral Power Distribution (SPD)
A graph of the radiant power emitted by a light source as a function of wavelength. SPDs provide a visual profile or "finger print" of the colour characteristics of the source throughout the visible part of the spectrum.

Specular Reflection
Reflection from a smooth, shiny surface, as opposed to diffuse reflection.

Spot
A colloquial term referring to a reflector lamp with a tight beam of light, typically around 10 degrees or less. It comes from the fact that such a lamp produces a narrow spot of light as opposed to a wide flood of light.

T

Task Lighting
Supplemental lighting provided to assist in performing a localised task, e.g. a table lamp for reading or an inspection lamp for fabric inspection.

U

Underwriters Laboratories (UL)

A private organisation which tests and lists electrical (and other) equipment for electrical and fire safety according to recognised UL and other standards. A UL listing is not an indication of overall performance. Lamps are not UL listed except for compact fluorescent lamp assemblies - those with screw bases and built-in ballasts.

Ultraviolet (UV) Radiation

Radiant energy in the range of about 100–380 nanometres (nm). For practical applications, the UV band is broken down further as follows:

- Ozone-producing - 180–220 nm
- Bactericidal (germicidal) - 220–300
- Erythemal (skin reddening) - 280–320
- "Black" light - 320-400

The International Commission on Illumination (CIE) defines the UV band as UV-A (315–400 nm); UV-B (280–315 nm) and UV-C (100–280 mm).

V

Viewing Angle

The off-axis angle where the display may be satisfactorily viewed (defined by lenses, obstructions, or intensity decrease). The viewing angle referred to as the 2-half theta angle (2Q*) indicates how focused the light is when emitted from the LED. This angle is determined by measuring the angle from direct on-axis to the angle where intensity falls to* of the on-axis intensity, and then multiplying this difference by 2. The shape of the encapsulant dome lens controls the viewing angle of the LED. Flat LEDs without domes generally have a very wide viewing angle. The choice of viewing angle also affects the LED intensity. As the viewing angle is increased, more area is covered by light, however the on-axis intensity is reduced.

For applications where the LED will project light onto a small area or on an object far from the emitter, a narrow viewing angle is ideal. For applications where the LED will project light onto a large area, or on an object very close to the emitter, a wide viewing angle is ideal. For instance, backlighting an indicator or switch in a cavity of less than 18mm would typically call for a surface mount LED with a 120° viewing angle.

Illuminating an object of 100mm x 100mm size that is 600mm away would require a 5mm LED with a 20° or smaller viewing angle. Oval-viewing angle LEDs are available for applications requiring illumination of areas that are not square or circular. These LEDs have a wider viewing angle in either the horizontal or vertical direction.

Volt

A measure of "electrical pressure" between two points. The higher the voltage, the more current will be pushed through a resistor connected across the points. The volt specification of an incandescent lamp is the electrical "pressure" required to drive it at its designed point. The "voltage" of a ballast, (e.g. 277 V) refers to the line voltage it must be connected to.

Voltage

A measurement of the electromotive force in an electrical circuit or device expressed in volts. Voltage can be thought of as being analogous to the pressure in a waterline.

W

Warm White

Refers to a colour temperature around 3000K, providing a yellowish-white light.

Watt

A unit of electrical power. Lamps are rated in watts to indicate the rate at which they consume energy.

Wavelength

The distance between two neighbouring crests of a travelling wave. The wavelength of visible light is between 400 and 700 nanometres.

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