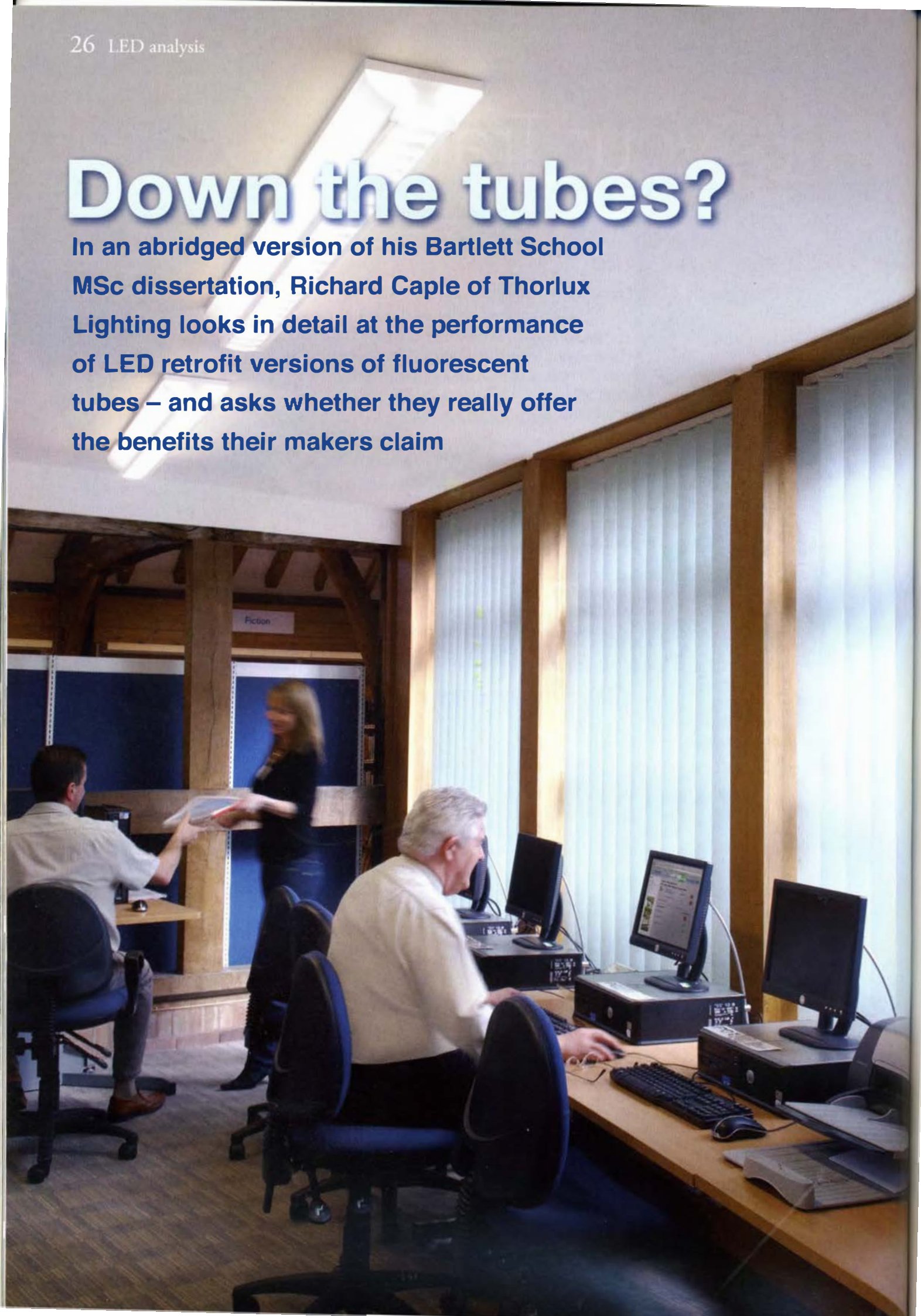
Down the tubes?

In an abridged version of his Bartlett School MSc dissertation, Richard Caple of Thorlux Lighting looks in detail at the performance of LED retrofit versions of fluorescent tubes – and asks whether they really offer the benefits their makers claim



The lighting industry is undergoing rapid change with the development of solid state lighting (SSL) technology. In particular LED sources are transforming the lighting scene by offering more energy-efficient lighting solutions compared with more conventional light sources. This fast development over the past 10 years has now reached a point where LED light sources, in some circumstances, outperform fluorescent lamps, generally regarded as one of the most efficient light sources for many commercial and industrial applications.

However, in taking up LEDs for all applications, are we rushing to adopt a technology that's not quite ready? And do we yet understand all the facts to make informed decisions? The focus of this study is an examination of one type of LED product that is becoming commonplace in the lighting market, the LED tube retrofit replacement for conventional fluorescent lamps. They are of a similar size and are intended as a simple one-for-one replacement – and manufacturers claim large energy savings can be made using these products.

Background

Linear fluorescent lamp technology has been around since the late 1930s and today is widely used in many applications. It is a very efficient, compact and relatively inexpensive source. Manufacturers have developed a number of different luminaire types to control and distribute the light from the lamp in a manner suitable for a range of applications. Linear fluorescent lamps are commonly used in the majority of commercial and industrial buildings, such as schools, hospitals, factories and offices.

Manufacturers have quickly taken the opportunity to incorporate LED technology in a linear package designed as a direct replacement for older linear fluorescent lamps, thus offering users energy savings without having to replace the entire luminaire. These LED tubes are being marketed as a far superior product to the fluorescent, offering users large energy savings, increased lamp life and reduced maintenance costs. But is this the true story?

The first issue we encountered in our study is that gaining technical information about LED tubes is quite difficult. Many of the manufacturers do not publish basic lamp performance criteria such as lumen output, colour rendering index (CRI) and correlated colour temperature (CCT). These are basic parameters needed when specifying lamps, not least to ensure that the relevant British Standards are complied with. Instead manufacturers/suppliers simply focus on the wattage of their products and make comparisons to the type of fluorescent lamps that they could replace.

Carbon Trust accreditation?
Many of the LED tube makers and distributors make reference to the Carbon Trust and include the Carbon Trust logo in their marketing, as evidence of their energy-saving credentials, even though Carbon Trust loan approval for small businesses is based on a demonstration of CO2 savings and is not therefore product specific.

The scheme does not stipulate whether or not a particular product is efficient, and does not indicate whether a product is suitable. The Carbon Trust name and logo are well known within the lighting industry, but using its name in marketing campaigns is clearly misleading.

There have been doubts for some time that LED tubes provide the same quantity and quality of light as fluorescent lamps. There are also concerns that the distribution of light from LED tubes is so different that it alters the photometric performance of the light fitting. For example, the US State Department of Energy (US DoE) has tested LED tubes since 2008 and has concluded that of all the LED tubes tested, not one matched the light output (luminous flux) of a comparable linear fluorescent lamp.

In US DoE light distribution tests, the overall performance of both lensed troffers and parabolic louvre light fittings deteriorated when fitted with LED tubes. The report also noted that the majority of LED tubes required the existing control gear for the fluorescent lamp to be removed from the circuit, which meant that mains supply voltage was then applied to the lampholders. This raised a number of safety related issues – and could invalidate safety certification, such as, in the case of European states, the CE mark. In addition, if the control gear is removed from the luminaire, emergency lighting provision will be compromised, unless such lighting is provided in another way – but this will further add to costs.

In summary, the US DoE report found that LED tubes were not a viable retrofit solution for fluorescent lamps. It established that the light output and colour performance were substandard when compared with fluorescent equivalents. The light distribution from the LED tubes significantly altered the intended distribution of the light fixture and if the shortcomings were addressed with extra light fixtures, there were virtually no energy savings.

Research method

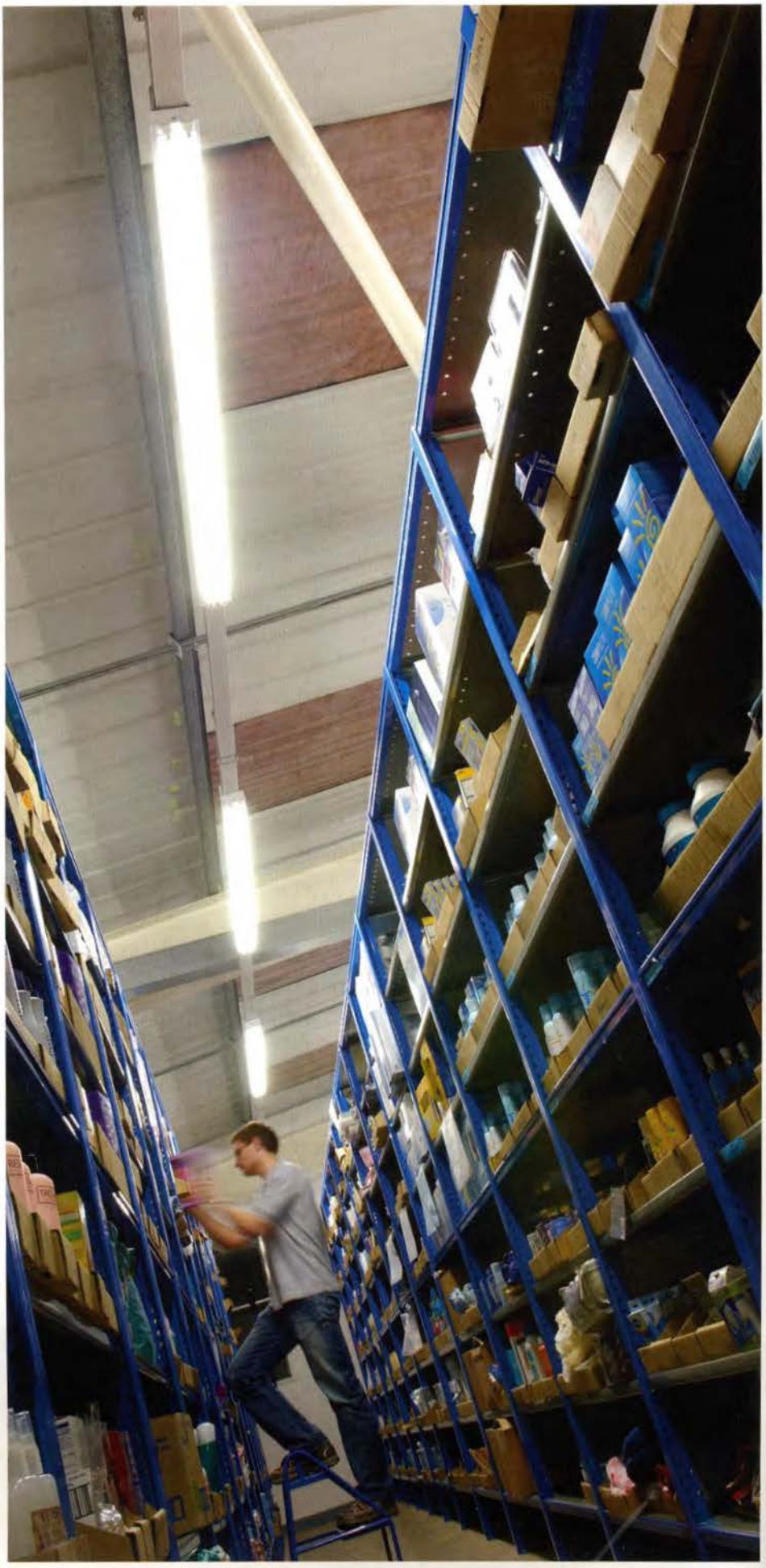
Within the UK context, the main aim of this research was to establish whether LED tubes are the simple retrofit solution that manufacturers claim. The study investigated and tested a number of LED tubes on the market for the following factors:

- Light performance
- Light distribution
- Lighting scheme performance
- Electromagnetic strength (radio-frequency interference and harmonics)
- Life-cycle costs

LED retrofits are available in both T8 (26mm diameter) and T5 (16mm diameter) formats. Because LEDs are mainly aimed at the retrofit market and T8s are still very common in UK commercial buildings, T8-format LED lamps were chosen for the trials. As T8 lamps are not as efficient as the modern T5, choosing T8 lamps as a comparison also gave the LED tubes the best chance of outperforming fluorescent sources. The benchmark linear fluorescent chosen for the tests was the common 36W 1200mm T8 840 lamp, made by GE.

Six corresponding LED tubes were sourced from four different manufacturers, including a well-known major lighting brand (Philips), a high street retailer (Maplin) and lesser-known internet lighting providers. The six LED tubes ranged in wattage from 18W to 22W, but all were marketed as suitable for replacing a 1200mm 36W T8 linear fluorescent lamp. The LED tubes were carefully selected so that the characteristics of each lamp were as similar as possible. Two LED lamps were available with frosted and clear tubes, and these were also compared in the tests. Table 1 (overleaf) gives an overview of the products to be tested. The values quoted are those claimed by the manufacturer.

The light performance, distribution and electromagnetic strength tests were all carried out using test equipment within a BSI-registered photometric



Lamp Ref	Manufacturer Type	Type	Cover Finish	Power (W)	Light Output (lm)	CRI	CCT (K)
Lamp A	Major Brand	36W T8 Fluorescent	N/A	36	3350	85	4000
LED Tube B	Major Brand	22W LED Tube	Frosted	22	1650	85	4000
LED Tube C	High Street	18W LED Tube	Frosted	18	N/D	84+	3000
LED Tube D1	Unknown Brand	18W LED Tube Clear	Clear	18	1870	75+	4000-5500
LED Tube D2	Unknown Brand	18W LED Tube Frosted	Frosted	18	1870	75+	4000-5500
LED Tube E1	Unknown Brand	20W LED Tube Clear	Clear	20	1600	N/D	4500-5500
LED Tube E2	Unknown Brand	20W LED Tube Frosted	Frosted	20	1600	N/D	4500-5500

Table 1: overview of LED retrofit tubes tested

Fluorescent luminaire with VDT louvre

laboratory at Thorlux Lighting in Redditch, and testing processes were in compliance with BSEN13032-1. Distribution tests were carried out on three different styles of luminaire – a bare batten luminaire, a batten with prismatic diffuser and a luminaire with visual display terminal (VDT) louvre – chosen to represent three of the most common styles of luminaire used.

Conclusions

For the majority of experiments within this study the LED tubes produced inferior results when compared to fluorescent lamps.

Reduction in lumen output

By far the largest pitfall of LED tubes was the significant reduction in lumen output compared to that of the fluorescent lamp. It was evident from the lighting scheme tests that the reduced lumen output resulted in a greatly reduced lighting level. The scale of the reduction in illuminance was so great it was clear that this would not be satisfactory in a real application.

The lower lighting level could have major implications for the users of the space, to the point where the scheme would not be suitable for the task being undertaken. This could directly affect safety and/or productivity. Under the Workplace (Health, Safety and Welfare) Regulations an employer is required to provide suitable and sufficient lighting allowing people to carry out their tasks.

The amount of light produced by one LED tube was down by more than 26 per cent on the manufacturer's claimed value, a significant reduction. This is on top of the already large decrease in output when compared with the fluorescent lamp. The total light output reduction therefore was 54 per cent which was confirmed by the results of the lighting scheme tests. The tests also highlighted that different covers affect the amount of light the LED tubes produce. In both cases the frosted tubes produced less light than the clear ones. Despite this, neither manufacturer advised of any differences in output.

Lamp A	Switch Start	36W T8 Fluorescent	2967	82	4149	42.2	70.3	0.916
Lamp A	High Frequency	36W T8 Fluorescent	2952	85	4038	33.3	88.5	0.974
LED Tube B	N/A	22W LED Tube	1434	90	4090	22.2	64.6	0.946
LED Tube C	N/A	18W LED Tube	1387	73	3169	18	77.1	0.498
LED Tube D1	N/A	18W LED Tube Clear	1390	71	5057	18.2	76.4	0.939
LED Tube D2	N/A	18W LED Tube Frosted	1360	72	5108	18.3	74.3	0.937
LED Tube E1	N/A	20W LED Tube Clear	1743	70	4327	21	83.0	0.612
LED Tube E2	N/A	20W LED Tube Frosted	1595	70	4335	21	76.0	0.644

Table 2: comparative lighting performance of the tested lamps

Poor light distribution

The other significant difference between a fluorescent lamp and an LED tube is light distribution. The tests clearly indicated that the light distribution from an LED tube is totally different to that of the fluorescent lamp. This had a sizeable effect on the way the luminaire distributed light into a space. Without photometrically testing the LED tube within a particular luminaire, it cannot be established whether the resulting distribution is satisfactory or not.

The original light fitting and lighting scheme are designed to meet the specifics of the application. Simply changing the fluorescent lamp to an LED tube, without understanding the possible effect on light distribution, could well have implications for the quality of the lighting scheme. Depending on the application, this could again affect the visual performance of those working under the changed lighting conditions. The lighting scheme tests indicated that uniformity decreased, and light levels on the upper walls and ceiling of the installation also decreased. For an office or factory application, for example, this can make the installation appear oppressive and 'cave like'. The wellbeing of workers might therefore be affected, which could also reduce productivity.

As highlighted in the distribution tests, in making real-life light level comparisons, measurements must be made at different distances from the light fitting. The high-intensity levels directly beneath the LED tube can be misleading. Light level comparisons

Bare batten fluorescent luminaire

Fitting	E.ave.WP	Difference	E.ave.Walls	Difference	E.ave.Ceiling	Difference
Batten with Lamp A	331	42.5%	237	54.0%	140	53.6%
Batten with LED Tube B	190		109		65	
Batten + Diffuser with Lamp A	292	45.9%	166	54.8%	109	54.1%
Batten + Diffuser with LED Tube B	158		75		50	
Louvred Luminaire + Lamp A	298	42.3%	84	27.4%	34	35.3%
Louvred Luminaire + LED Tube B	172		61		22	

Table 3: mean lighting levels on the working plane, walls and ceiling for the various light sources. The wall levels are an average of the four walls in the virtual test room

directly below the light fitting do not provide a reliable way of establishing whether a light fitting with an LED tube will illuminate a space to the same standard as the same luminaire with a fluorescent lamp. The light levels directly beneath the fittings may show little difference, depending on the style of light fitting. However, as measurements are made further away from the fitting, greater differences in light levels are likely to be experienced.

Mediocre colour rendering

There is also some concern over the colour rendering quality of LED tubes. BSEN12464-1 stipulates that for many applications such as offices, factories and teaching spaces, these types of space must use a light source that has colour rendering properties equal to or greater than Ra80. Apart from one single example, no LED tube achieved this level and in most cases they were well below the required value.

A lamp with a low CRI can affect the appearance of colours as well as the perceived health of human skin tones. The end result is environments that may be unpleasant to work in and, in extreme cases, this could affect the health and wellbeing of individuals working under those conditions.

It was also evident that some manufacturers considered it acceptable to provide their product with a wide colour temperature tolerance. Our survey identified one manufacturer advertising a product that had a colour temperature range of 1500K, which would be very noticeable to the human eye and very distracting in an application.

Low power factor

This was another major issue with LED tubes. When using LED tubes in a luminaire with more than one lamp way, in order for it to be recertified and gain a CE mark, it must use an LED tube with good power factor correction. Not all LED tubes achieve this – and poor power factor causes an electrical item to draw more current than needed. If this is ignored then any running-cost savings gained by using LEDs tubes can be lost in additional charges by the electricity supplier, which will increase its tariff or impose extra costs.

EMC variations

The results of the EMC tests clearly highlighted the technical variations that can be experienced with different types of LED tube. One tube made by a major lighting company did meet EMC requirements, but two other tubes made by other makers did not.

Need for recertification

This discrepancy pointed to the need for any converted luminaire using these tubes to be fully retested and CE certified. Replacing the fluorescent lamp with an LED tube can completely change the electrical characteristics of the luminaire, and further research and testing is needed to fully understand this process. For example, in hospital applications, where there are a number of very sensitive electrical devices, it is imperative that EMC testing is carried out to ensure that the converted luminaire does not have implications for life-dependency electrical systems.

Non-compliance with regulations

Our tests showed that LED tube performance was very variable; and in most cases the performance of the whole light fitting with LED tubes did not meet building regulation requirements. As the light fitting has been converted rather than replaced, within the current regulations there is no requirement for the conversion to comply.

However, the performance threshold set in the regulations is largely in line with best available technology (BAT), and of the luminaire styles tested with LED tubes only the batten met the threshold. Therefore, this is a good indicator that conversions with LED tubes are not actually that energy efficient when compared with other available technologies.

Whole life costs/lumen maintenance

While life-cycle cost calculations indicated that over 10 years there was a substantial energy saving with LED tubes, the same exercise also showed that the high cost of the LED tubes meant that there was virtually no financial gain. These tests also highlighted that the claimed life of LED tubes is based on lumen reduction, which was three times greater than the fluorescent lamps. So with LED

Fluorescent luminaire with prismatic diffuser

Fitting	Conducted		Radiated	Overall
	Live	Neutral		
Batten with Lamp A (High Frequency)	PASS	PASS	PASS	PASS
Batten with LED Tube B	PASS	PASS	PASS	PASS
Batten with LED Tube C	FAIL	FAIL	PASS	FAIL
Batten with LED Tube E1	FAIL	FAIL	PASS	FAIL

Table 4: pass/failures in the radio frequency interference (RFI) test

Fitting	E ave WP	Difference	E ave Walls	Difference	E ave Ceiling	Difference
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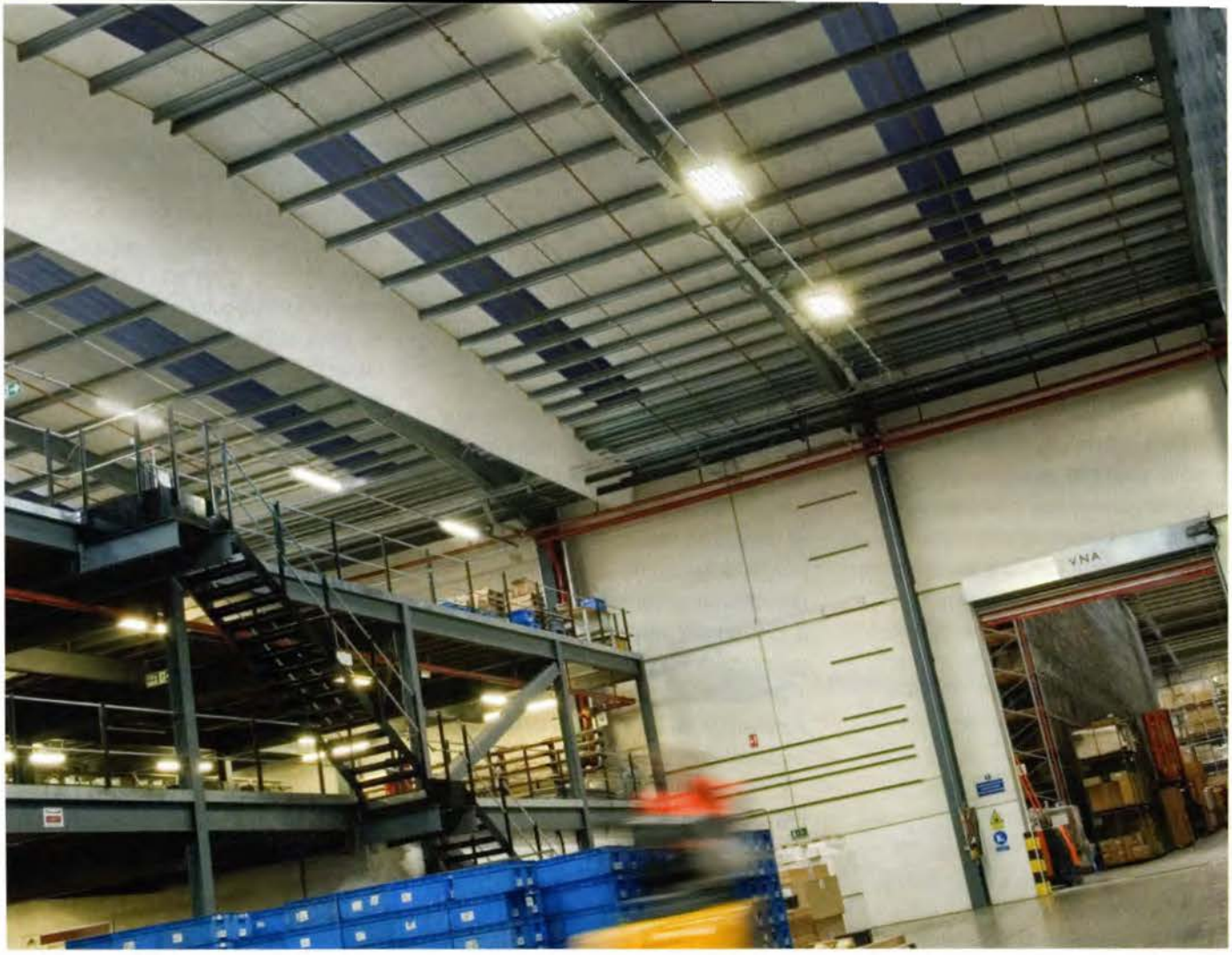

retrofits, not only would initial light levels be lower, through life they would deteriorate more than a fluorescent lamp. If they were replaced more often to avoid this issue, life costs would be up to 125 per cent more than if the fluorescent lamps had remained in place.

This test concluded that if the luminaires already had high-frequency control gear then there was no benefit in converting the luminaires to use LED tubes. It also highlighted that greater long-term savings can be made by converting switch-start luminaires to high frequency. Savings of 20 per cent over 10 years can be made, compared with just three per cent for the best LED tube – and by keeping fluorescent lamp technology, luminaire distribution, light levels and light quality will remain as per the existing installation.

No overall benefits

From this it can be concluded that LED tubes do not offer a simple and beneficial retrofit solution. In many cases they would not save the end-user money, and there is also a number of technical issues concerning their inferior performance. In order to guarantee that a satisfactory lighting solution is being achieved, a great deal of effort and time will be required in testing and recertifying the existing luminaire and proposed LED tube. Although LED tubes do indeed consume less energy, the resulting performance and quality of the lighting installation will be severely affected.

Finally, even if LED tubes increase in lumen output and reduce significantly in cost, there will still be a number of outstanding issues, such as satisfactory light distribution, emergency lighting provision and recertification to ensure compliance with EMC and safety aspects. All in all, LED retrofit tubes to replace fluorescent technology cannot yet be regarded as a good, cost-effective solution for commercial lighting applications. This could change in future, but it will require substantial price reductions and considerable improvements in the technology.

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Table 5: life-cycle cost comparisons for 2000 hours and 8760 hours burning