Sustainable Airport Solutions

Aeronautical Ground Lighting

Evaluating the Business Case for LEDs

GSA

AERONAUTICAL GROUND LIGHTING
EVALUATING THE BUSINESS CASE FOR USE OF LEDs

London Southend Airport

GSA Green Sustainable Airports

NICOL TAYLOR CONSULTING

The North Sea Region Programme 2007–2013

Table of Contents

Executive summary

This is the report of a Study commissioned by London Southend Airport as part of the Sustainable Airport Solutions – Green Airports project ("Green Sustainable Airports)", part funded by the European Union.

LED lights have developed in use for Aeronautical Ground Lighting (AGL) over the last 10 years in Europe and worldwide. The report reviews the differences in performance between standard tungsten halogen AGL and the new LED technology. It focuses on the aviation regulation requirements to maintain AGL and examines how LED and tungsten halogen technologies compare in real world performance.

It is apparent that AGL manufacturers place emphasis on the reduction in maintenance and energy costs seen by adopting LED AGL fittings over previous tungsten halogen fittings. The Study has reviewed this closely and has developed a spreadsheet financial model which evaluates the investment performance of LEDs against tungsten halogen fittings using the measures of Net Present Value and Internal Rate of Return.

Case studies are introduced at three partner airports, Groningen Airport Eelde (GAE), London Southend and Billund. The case studies review the factors these airports considered when deciding whether use LED or tungsten halogen AGL and also their own experiences with maintaining both types of AGL. Within the GAE case study, the opportunity is taken to compare the results of the investment performance model used by a major AGL supplier with the financial model developed for this Study.

A review has also been undertaken to understand other applications for the use of LED lights at airports, this includes use of LED lights for aircraft parking apron floodlighting, and in car parks.

The Study concludes that LED AGL provides superior operational performance to tungsten halogen fittings, however, that real savings must be realised in maintenance costs for LEDs to make a real-terms financial saving over the life of an installation.

1. Introduction

1.1. Context at London Southend Airport – LED runway lighting

1.1.1. This Study was commissioned by London Southend Airport (LSA) as part of the Sustainable Airport Solutions – Green Airports project ("Green Sustainable Airports)", part funded by the European Union.

1.1.2. In the early stages of the GSA project, LSA was also in the planning stages for a £100m redevelopment programme comprising extension and resurfacing of its runway, provision of a new passenger terminal and railway station , new taxiway infrastructure, a new control tower and radar.

1.1.3. Within the scope of the runway and taxiway works was an upgraded Aeronautical Ground Lighting (AGL) system comprising runway and taxiway centreline lights, relocated runway edge lights, improved approach lighting, and supporting electrical infrastructure.

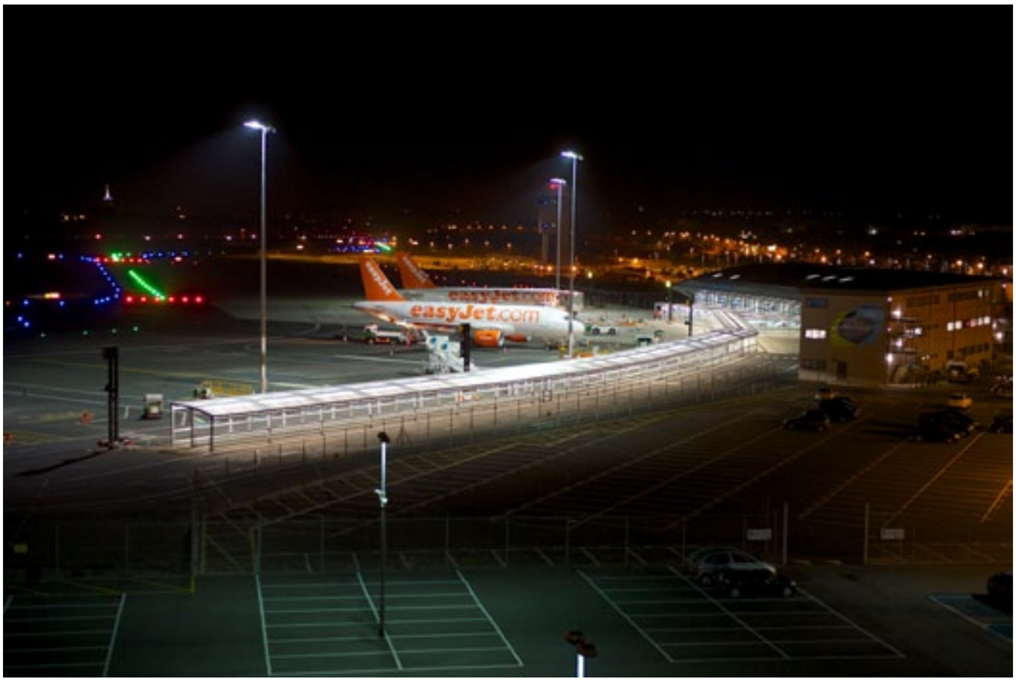


Figure 1.1 New Terminal and aprons at London Southend Airport; LED taxiway lighting visible centre left of picture.

1.1.4. Aeronautical Ground Lighting has used Tungsten Halogen (TH) light fittings since the 1960s. LED AGL has been used increasingly at airports on taxiways over the last 10 years. It was understood to be considerably more energy efficient and more reliable than equivalent TH AGL.

1.1.5. At the LSA project planning stage, it was intended that Light Emitting Diode (LED) AGL fittings should be used on the runway surface. As a participant in the GSA programme, LSA agreed to undertake a study of its implementation of LED runway lighting as its potential use was of great interest to other GSA airports.

1.1.6. As the airport redevelopment project progressed, however, it became apparent that UK Civil Aviation Authority (CAA) regulatory approval for LED AGL for use on runways would not be forthcoming within the time frame for the opening of the new runway[i]. Further that LED light fittings would be considerably more expensive than standard TH equivalents.

1.1.7. LSA was working to a firm opening date for its new facilities to accommodate the start of based operations by easyJet. The project was already extremely complex for the CAA, and could not be put at further risk by installing non-standard lighting which could delay overall CAA approval. Consequently a decision was taken to procure standard TH AGL for the runway and LED AGL for the taxiways.

1.1.8. It was decided to refocus the study on the developing use of LED lights for AGL and other airport applications across GSA partner airports, and in particular, to develop a better understanding of the business case for installing LED AGL.

Figure 1.2: Tungsten Halogen centreline and edge lights on London Southend Airport's runway. Note the warm yellow tones to the white light (see table 2.4).

1.2. Structure of this report

1.2.1. The remainder of this report is structured as follows:

1.2.2. Section 2 describes the development of LED AGL since 2002, the basic differences between TH and LED AGL, and the potential for the future development of airfield lighting systems which have been designed from the outset to accommodate LED fittings.

1.2.3. It became apparent at an early stage in the Study that AGL manufacturers were focusing their sales presentations to airports on the basis that although LED lights were more expensive, an LED installation would rapidly repay the outlay in maintenance cost and energy savings.

1.2.4. Section 3 therefore focuses in-depth on the maintenance requirements for AGL as required by ICAO and present UK standards and reviews how LED and TH lights compare. Section 4 reviews the financial case for moving to LEDs using a spreadsheet model based on one developed by a major UK Airport to understand their own business case to adopt LEDs.

1.2.5. Section 5 reviews partner airports' own decision making as to whether to adopt the new LED technologies, and also experiences with maintaining LED and TH AGL. Three case studies are discussed at Groningen Airport Eelde (Netherlands), Billund Airport (Denmark) and London Southend Airport (UK).

1.2.6. Section 6 discusses other potential applications of LEDs at airports including encapsulated LED strips for apron and holding markings, apron floodlighting and airport car parking.

1.2.7. Section 7 presents the conclusions of the Study.

2. Comparison of TH and LED technologies

2.1. Overview of the development of LED lights

2.1.1. The manufacturer ADB first started trials of LED centreline lights on taxiways at Brussels International Airport in September 2002.

2.1.2. Initially LEDs could only be used in low-intensity fittings. They were neither bright nor small enough to be used in high intensity runway AGL. In the 10 years since 2002, LED AGL design has progressed extremely rapidly. The power output of LEDs has increased and early reliability and performance issues have been addressed. In November 2013, only high intensity in-surface approach lights remain unavailable commercially[ii].

2.2. Regulatory standards and approvals

2.2.1. Manufacturers have provided LED AGL fittings which can directly replace TH fittings in standard airfield lighting circuits. They have further sought to evidence that the new LED AGL meets applicable ICAO or FAA standards for existing Tungsten Halogen AGL.

2.2.2. Within the UK, the CAA has responded cautiously and has worked with the UK Airport Operators Association to develop a structured approach for the evaluation and implementation of the new LED technology. In August 2012 , following successful trials at Manchester Airport, the CAA authorised use of in-surface high intensity LED AGL on runways. In its introduction, CAA Information Notice 2012/126[iii], states:

Since 2006, the development of LED technology in visual aids has advanced rapidly. Accordingly, the CAA, in conjunction with the Airport Operators Association, has recently conducted a trial of inset high intensity white and red runway centreline and touchdown zone lights within a CAT ll/lll system. The result of the trial has determined that, subject to their meeting the conditions specified below, the CAA will not object to the operational use of such LEDs. LED applications already permitted by NOTAL 2005/06, which include runway lead-off, runway guard bar, runway guard lights, taxiway centreline and edge, and obstacle lighting are unaffected by this change.

2.2.3. IN2012/126 also notes that

Elevated high intensity fittings, whether omni- or bi-directional are ***not*** *part of this policy change. Once any such fittings can be shown to meet an equivalent level of compliance, a further revision will be considered.*

2.2.4. It is understood that the reason elevated high intensity fittings have yet to be approved by the UK CAA is simply that it has not yet been asked by a UK Airport to consider them.

2.2.5. Over the year since its giving approval in August 2012, the UK CAA has been in the receipt of a very few reports under its MOR[iv] scheme in relation to LED AGL. These are understood to relate to the brightness of the lights. As at November 2013, the CAA has not yet completed its own analysis regarding these reports and identified underlying causes or other contributory factors which may be involved.

2.3. Direct comparison of LED and TH technologies

2.3.1. The following tables amplify and augment the overview above with additional detail and provide a side-by-side comparison of the principal differences between LED and Tungsten Halogen AGL over a range of attributes – namely

- technology/mode of operation
- unit life
- maintenance performance
- colour
- intensity
- power consumption
- winter operations/ EFVS
- future potential

2.3.2. Typical costs of LED fittings in comparison to TH fittings are discussed in Section 4.

ATTRIBUTE	TUNGSTEN HALOGEN (TH) unit	LED unit	Other commentary
2.1 Technology/mode of operation - overview	A halogen lamp consists of a tungsten filament sealed into a compact transparent envelope filled with an inert gas, plus a small amount of halogen such as iodine or bromine. The halogen cycle increases the lifetime of the bulb and prevents its darkening by re-depositing tungsten from the inside of the bulb back onto the filament.	A light emitting diode (LED) is an electronic light source. The LED is constructed from a semiconductor with specific properties such that when current passes through the device light is emitted[v]. Depending on the properties of the semiconductor the wavelength (color) of the light emitted will vary, although it will always be a discrete wavelength (monochromatic light). [vi] About 90% of the energy of an LED is converted into visible light, and no more than 10% into heat. The opposite is true for TH lamps, where most of the energy input is radiated as heat[vii].	LED luminaires are composed of multiple LEDs of the same colour which are arranged together, behind the fitting lens, to produce the required light intensity. LED product development by manufacturers has focused on developing increasingly brighter and smaller LEDs. The output and life of LEDs reduces with temperature. A major challenge for manufacturers has been to increase the power to the LED without increasing its temperature. At a critical temperature, the LED will actually start to dim with increasing current input. Groups of LEDs very close together on the same circuit board (as is required by inset pavement lighting) have the potential to generate a large amount of heat and hence have been more difficult to manufacture. To achieve compatibility between a standard 6.6A Aeronautical Ground Lighting circuit (see further below) and the new LED fitting, the circuit Constant Current Regulator (CCR) has to be "tricked" into thinking the LED fitting is a standard TH fitting by the use of interface electronics. This increases the power consumption, complexity and cost of the LED fitting. Future AGL circuits will be designed to accommodate LED lights from the outset, and this will potentially lead to improved reliability and lowered power consumption.

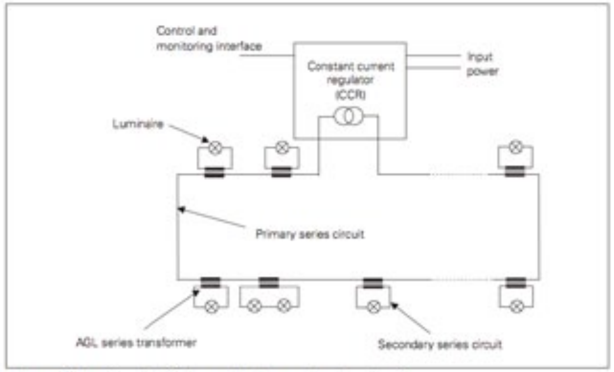
ATTRIBUTE	TUNGSTEN HALOGEN (TH) unit	LED unit	Other commentary
2.2 Unit life and reliability The UK CAA's licensing document, CAP168, and its relationship with ICAO Standards and Recommended Practices is described further in Section 3. UK CAA standards define lamp failure as the mean time before the light output is at or below 50% of the required standard[viii].	The life of a TH fitting is around 800 - 1000hrs if run at the highest power setting, and between 2000-4000hrs in standard use depending on what kind of fitting and where it is. Edge light fittings, for example, are larger and run at higher intensity. Their "maintenance planning life" at a busy airport may be only 2000hrs before scheduled replacement. Lamps start to degrade immediately on use (becoming dimmer). TH Lamps more prone to outright failure. At London Southend, increased failure of inset runway centreline lamps started to occur at 6 months following installation. When these were replaced, the new lamps were noticeably brighter than the older ones.	LED luminaires are expected to have lives ranging from 50,000 – 200,000 hours. ADB have reported 100,000hours life at high intensity settings, and 200,000hrs in settings equivalent to actual field use. The life of the LED fittings reduces with higher temperature, hence high intensity (high current) CCR step settings may reduce life as LED interface electronics dissipate the excess energy as heat. Manufacturers have progressively refined their designs to overcome this problem, with the excess heat being conducted into the light housing. Future AGL systems, designed to incorporate LED technology from the outset, have the potential to use lower than the standard 6.6A current setting. This has the potential to reduce temperature and increase life.	Field data is progressively being gathered to validate the actual life of LED lights in practice in high intensity /heavy aircraft aerodrome operations. The numbers in the opposite columns relate to claimed performance from various manufacturers. Some airports are basing maintenance planning on 120,000 hours for LED taxiway edge lights.[ix] In the past Heathrow Airport Ltd., for example, is understood to have used a replacement life of 50,000 hours for its own business case analysis regarding the relative costs of TH and LED fittings. To put in context, 50,000hrs is equivalent to a light being run for 14 hours per day for nearly 10 years. Early LEDs did exhibit particular failure modes (e.g. outright failure, flicker, or individual diodes "dying" and making the light appear dimmer). Reliability issues appear to have been fixed to the extent that failure rates of 1% or less are now exhibited. LEDs are still prone to outright failure owing to incorrect installation - e.g. "nipping" of power cables in the lights' seal. This can cause water to enter the unit and has been the main failure mode observed at LSA for taxiway LED AGL. Photometric testing (using proprietary equipment e.g. MALMS) shows that clean LED lights provide a constant light output following installation (equivalent TH lights exhibit a much more varied performance). <u>For LEDs, the failure modes move from the lamp to the physical casing supporting the LED lamp.</u>

ATTRIBUTE	TUNGSTEN HALOGEN (TH) unit	LED unit	Other commentary
2.3 Maintenance performance –(see sections 3 & 5 of this report)	Will require • periodic re-lamping. • require regular cleaning • inspection of seating ring bolts Expect replacement of lights which exhibit complete failure	Fittings do not require re-lamping, much less likely to suffer from complete failure. Will require • periodic cleaning • inspection of seating ring bolts	Failure modes for LED lights move to mechanical failures associated with the unit which encloses the light. A standard TH AGL circuit runs at high power and suffers from earthing faults. A lower powered circuit is potentially feasible with LED AGL, hence improving reliability.
2.4 Colour (see also "intensity" as the two are interlinked for TH lights). 	White runway lights appear yellow at low CCR current settings, and progressively become whiter as the lamp is run at higher intensity. Colours other than white are achieved by shining the light through a coloured lens. The lens reduces efficiency, hence coloured lights may have to be run at higher current intensity to achieve equivalent brightness (see section 3). Colour will change with intensity; particular green lights run at high intensity will have a yellowish tinge to them, and red lights will move towards being orange. Older TH lights cannot achieve the same intensity as newer fittings.	Colour appears much more "saturated" – white lights are white, yellow is yellow, green lights are devoid of yellow tinges. Red is true red.  	LED lights give a "truer" colour perception than TH lights. LED colour performance, is unchanging with intensity. There is the potential to use this reliability to enable changes in the present international colour standards. LED colour does not change with age, although there is some evidence that the lights may become dimmer. Use of LEDs will make for very clear distinction between white, yellow and red lights over all intensities. LED lights show the same colour from any angle (from some particularly acute angles the dichroic lens used on TH lights may cause the light to not display the correct colour – e.g. stop-bar red lights may appear yellow). Future AGL colour standards will focus increasingly on red being "the light that you never pass". Some regulators (e.g. the FAA) may not approve LED and TH fittings in the same circuit because of the different colour performance[x].

ATTRIBUTE	TUNGSTEN HALOGEN (TH) unit	LED unit	Other commentary
2.5 Intensity	The intensity (brightness) of TH lights is dependent on the current passed through them. This is one of the reasons why series circuits are used in AGL design, as the current in the circuit is constant, and hence the brightness of the lamps in the circuit is uniform (in so far as their normal variability allows). TH lights exhibit a non-linear response to input current, however. Put simply – progressively larger currents are required to achieve a noticeable change in brightness.	The brightness of an LED is determined by the frequency that the unit flashes on and off. The human eye interprets higher frequencies (ie a higher rate of on-off-on-off flashing of the diodes) as a brighter light. The brightness perception curve of LEDs varies linearly with frequency. Crudely, twice the frequency will be perceived by the human eye as twice the brightness. LEDs require a critical voltage to operate above – but this is fairly low. As the intensity is not dependent on current, there is the potential to use LEDs in parallel circuits. Low circuit power could allow for reduced cable sizes and should reduce earth leakage problems. LEDs have a shorter "rise and decay" cycle than TH lights – they're ideal for use in flashing lights -e.g. flashing runway guard bars.	The standards for AGL circuit design in the UK are defined in CAP168 Chapter 6, Table 6.6., with three permissible primary circuit currents of 6.6A, 12A and 20A[xi] For a standard TH circuit, the lamp intensity (brightness) is controlled by varying the output from the CCRs in a number of steps. CAP168 requires a minimum of five intensity settings to control the intensity of runway AGL: 1%, 3%, 10%, 30%, and 100%. Many airports use additional settings of 0.1%, 0.3% and 80% to increase flexibility and lamp life. The steps and current required to achieve the required brightness do not vary linearly with each other. For example, for a 6.6A circuit, at the 0.3% intensity setting the circuit current would be in the region of 2.9A; at the 100% intensity setting it would be 6.6A. LED lights are capable of being operated on much lower power to provide equivalent brightness. LEDs, particularly when used in a mixed installation with TH fittings, will require to be "tuned" to provide equivalent light output at the present CCR current "steps". Early LED installations may have been excessively bright for Pilot users, particularly at higher CCR settings. Some early LED installations also reported to have suffered from "flicker" effects when seen by a moving observer[xii].

ATTRIBUTE	TUNGSTEN HALOGEN (TH) unit	LED unit	Other commentary
2.6 Power consumption of overall AGL circuit			
Option 1 -Baseline: *Direct retrofitting of new LED units into an existing 6.6A AGL circuit.*	Baseline of 100% Standard 6.6A TH AGL circuit	Conservatively, the new installation will use only 70% of the baseline circuit's power consumption. Some sources indicate that the improvement may be as high as reducing consumption to 30-50% of the baseline circuit (e.g ref [xiii]).	There is a paucity of UK airport sourced independent data regarding the actual reduction in power consumption following the direct replacements of TH AGL with LEDs in a standard 6.6A circuit. Gatwick Airport is understood to be planning to monitor power consumption "before" and "after" LED installations on its runway. Power consumption of LED luminaires is 20-30% that of TH equivalents (ie 70-80% reduction in power consumption), however, the remainder of the infrastructure is not optimised for the LEDs (see below).
Option 2: Optimised standard circuit: *Fit LED units into existing 6.6A AGL circuit, but with reduced transformer and CCR sizes.*	Baseline of 100% Standard 6.6A TH AGL circuit	New installation will use 20-40% energy of baseline installation[xiv].	The reduced power consumption of the LED luminaire allows reduction in the size of the primary/secondary circuit transformers and CCRs in a standard 6.6A circuit.
Option 3: Circuit optimised for LEDs from the outset. *Future options:* • *LED units into a constant current low-power circuit (e.g. 2A circuit);* • *use of LEDs in constant voltage circuits.*	Baseline of 100% Standard 6.6A TH AGL circuit	With lower circuit current, 2% to 13% in power consumption of original TH baseline circuit[xv].	The next stages of optimisation would have to be endorsed by aviation regulators. These include a reduction in the maximum current in the circuit (ie from 6.6A to 2.9A or less) and perhaps even the use of parallel (ie constant voltage circuits). Use of lower power ratings might also allow AGL primary circuit cabling to be replaced with lower-rated cable, securing further capital cost savings. There may also be the potential to reduce the number of lights in the runway pattern (see section 3) which would further reduce energy consumption.

ATTRIBUTE	TUNGSTEN HALOGEN (TH) unit	LED unit	Other commentary
2.7 Winter operations and Enhanced Flight Vision Systems	Heat radiated through the lens assists with keeping the lights clear when the lights are on. In sub-zero temperatures, however, when the lights are switched off, the melted snow/ice can re-freeze to a hard rime, reducing light output when the light is next switched on.	LEDs do not radiate heat through the lens of the light fitting. However, the junction electronics at the base of the LED do generate substantial heat. For winter operations it had initially been assumed that LEDs would be more susceptible to icing owing to the heat not being radiated through the lens. Manufacturers have made "arctic kit" available which heats the lens. This has been found to be largely un-necessary as in practice the design of the LEDs requires use of a heatsink to disperse heat from the LED junction electronics to preserve the LED life. Some of this heat can be directed to the lens or the fitting annulus. In either case, the excess heat assists with melting snow/ice when the light is on[xvi].	One AGL expert spoken to in the course of the study, expressed the view that LED AGL may actually be easier to brush clean in snow than TH AGL. Further independent information is required. The lack of heat radiated through the lens has one other implication in respect of Enhanced Flight Vision Systems. CAA IN 2012/126 notes the following: *Aerodrome License Holders should be aware that the output of LEDs used to provide high intensity runway lighting and taxiway lighting is unlikely to be compatible with the Enhanced Flight Vision Systems (EFVS) that are fitted to a growing number of chiefly business aviation aircraft types. In order to detect and display aerodrome lighting patterns to a pilot, an EFVS relies on detecting the high infrared output that tungsten halogen lamps emit. The LEDs used in aerodrome lighting only emit energy in the visible spectrum. The operational benefit from EFVS in low visibility conditions is that they can permit aircraft which are so equipped to achieve, in lesser RVRs, lower decision heights provided that the aerodrome lighting emits high levels of infrared energy.*

ATTRIBUTE	TUNGSTEN HALOGEN (TH) unit	LED unit	Other commentary
2.8 Future potential	Manufacturers are concentrating efforts on developing LED lights. In the future, TH lamps will increasingly be seen as "legacy" technology.	In the rush to bring the technology to the market, and demonstrate its compatibility with existing airport systems and regulatory requirements, compromises have been made. Inset runway approach LEDs are the last major fitting to become available, as these are the brightest, and require a large number of LEDs to be located close together on the circuit board. These are expected to be available within the next year. Future LED fittings designed to fit into AGL circuits designed from the outset to support LEDs, may be cheaper (see further commentary in next column).	*Optimisation of AGL circuit design* Present AGL circuit design uses a series primary circuit to supply constant current via transformers to a secondary circuit (see figure below from CAP168 Chapter 6).  **Figure 6.14** Typical AGL constant current series circuit Future circuit design which is optimised for LED architecture from the outset may allow for lower currents (e.g. 2A) and the use of parallel (ie constant voltage) circuits. This in turn is likely to drive changes in LED fitting design, as present features (e.g. system interface electronics) which are used to enable operation in a 6.6A TH circuit become un-necessary. This in turn might lead to a reduction in cost of LEDs.

3. Regulatory requirements relating to maintenance of AGL

3.1. Introduction

3.1.1. International standards and recommended practices have been set by ICAO regarding the performance and serviceability of Aeronautical Ground Lighting. This section reviews these standards, and how they reflect the real-world performance of comparable TH and LED AGL installations. It then comments on how particular standards may change or be developed owing to the increasing use of LEDs by airports of LEDs.

3.2. ICAO Annex 14 requirements

3.2.1. The International Civil Aviation Organisation (ICAO) was established by the 1944 Convention on International Civil Aviation ("the Chicago Convention"). The European States in which the GSA Airports reside are all member states of ICAO.

3.2.2. Annex 14 to the Convention sets requirements for the design and operation of Aerodromes and Heliports in the form of Standards and Recommended Practices (SARPS) to be adopted by ICAO member states.

3.2.3. Annex 14, Volume 1 Aerodrome Design & Operations refers to requirements for AGL in the following sections:

Chapter 5	Visual aids for navigation
Chapter 8	Electrical systems
Chapter 10	Aerodrome Maintenance
Appendix 1	Colours for aeronautical ground lights, markings, signs and panels
Appendix 2	Aeronautical ground light characteristics

3.2.4. Other ICAO documents (notably Doc 9157 "The Aerodrome Design Manual"), provide additional detailed information to assist member states with the consistent implementation of the Annex 14 requirements.

3.3. Application of ICAO SARPS by member states.

3.3.1. Within the UK, the Civil Aviation Authority (CAA) presently licenses Aerodromes for public use in accordance with Civil Aviation Publication 168. "CAP168" is the national document which incorporates the Standards and Recommended Practices in Annex 14 in so far as they have been adopted by the UK. Chapter 6 of CAP168 - Aeronautical Ground Lighting - synthesises the information identified in the ICAO documents above into requirements for UK Aerodromes[xvii].

3.3.2. Other GSA member airports will have their own national documents or legislature for implementation of Annex 14 SARPS (e.g. the Luftverkehrs Verordnung in Germany).

3.3.3. The forthcoming EASA standards have the ICAO Annex 14 SARPS as their base. CAP168 (and other GSA states' national documents) will be superseded by EASA requirements when these are adopted by the UK. For the purposes of this report, however, CAP168 requirements are quoted as these are current and adhered to by London Southend Airport and other UK Airports consulted within the scope of the present study.

3.3.4. The following sections now reference both CAP168 and ICAO SARPS regarding

- the definition of serviceability
- maintenance strategies to achieve serviceability;

and

- the relative performance of LED and TH technology in meeting the requirements.

3.4. Serviceability of AGL as defined by ICAO

3.4.1. The term "Serviceability" is used in two senses as follows:

(i) the serviceability of an individual fitting; defined by ICAO Annex 14[xviii] (and thereafter in CAP168) as the time when the light is capable of providing only 50% of the required light output ("the 50% level").

and

(ii) the serviceability of the overall AGL system in respect of the percentage of fittings which are themselves serviceable. The criteria for this depend on how the runway is being used and specify that a particular number of fittings must be serviceable to a given maintenance performance level[xix].

3.4.2. Unserviceability of lights can degrade the pattern; outright failure of lights may incur operational penalties. For example CAP168 makes the following points in Chapter 6 §11.4.2:

Unserviceable light fittings should not be permitted to alter the basic pattern of the AGL system, which should always give adequate guidance. For AGL in use in RVR less than 400 m, no two adjacent light fittings should be unserviceable.

3.5. Real world performance of AGL

3.5.1. Later paragraphs in Chapter 6 of CAP168 make the following commentary regarding the variable performance of AGL installations and the potential for maintenance which does not result in compliance with serviceability requirements:

§12.1.5 The conventional AGL maintenance strategies of block change, or change on failure, have been shown to be inadequate with many of the lamps failing to meet the required standard either immediately or shortly after the maintenance activity (see paragraph 12.3.8). Lamps and associated equipment do not age at a uniform rate and consequently only limited benefit is achieved from a routine block change. On the other hand, if the performance of individual lights is allowed to decay until lamp failure occurs, then each light will be operating below the required standard for a substantial percentage of its life. Both strategies result in the possibility of entering LVPs with the installation operating below the required serviceability levels. Routine and regular targeted maintenance procedures are essential if this scenario is to be avoided.

§12.1.6 The performance of lights can change rapidly, especially at large aerodromes with high movement rates. Therefore, it is important to assess performance accurately on a regular basis and act upon the information collected. The frequency with which such assessments should be undertaken is dependent upon the type and age of the installation, maintenance policy adopted, movement rates and prevailing weather conditions. Typically, a weekly survey, with associated maintenance, has been found to be adequate for a major aerodrome.

3.5.2. The above paragraphs were all originally drafted with the performance of TH AGL in mind. They provide a description of the real-world performance of TH lights and the difficulties in maintaining them in accordance with regulatory requirements.

3.5.3. The point at which any individual AGL fitting may be expected to reach the 50% level will vary depending on a number of factors, however, <u>all other things being equal</u>, LED fittings are expected to take vastly longer to reach the 50% level than equivalent TH fittings and show less tendency to suffer outright failure.

3.5.4. TH lamps degrade in relation to the time that the lamps are run and the power which they are required to be run at. Overlaying this inherent and gradual decay in performance are environmental factors relating to the location of the light on the airfield (see further below).

3.5.5. The larger TH lights used at higher brightness settings for longer (e.g., runway edge lights) or being shone through coloured filters (hence requiring more power to achieve equivalent intensity – e.g. runway threshold) will require to be replaced more frequently[xx]. Lights in 24 hour use on runway stop-bars will require replacement at a higher rate than other taxiway fittings.

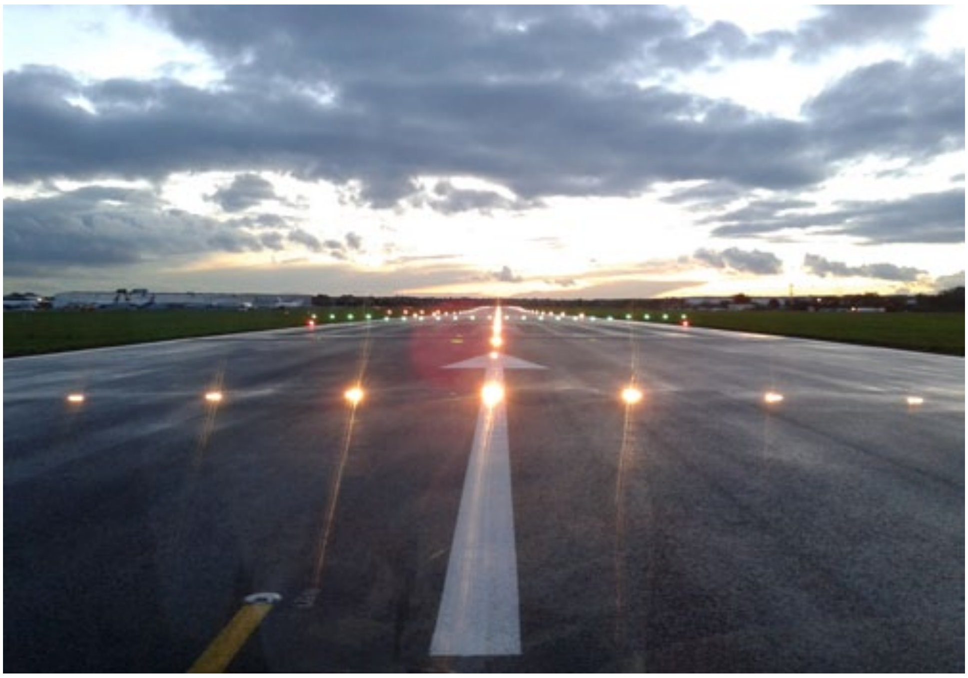


Figure 3.1 Pre-runway 24 threshold TH AGL at London Southend Airport, showing inset approach cross bar in foreground and green threshold lights in mid-picture.

3.5.6. LEDs also tend to reduce in life when run at higher intensity, but this effect evidently requires a much longer period of time to manifest (potentially in the tens of thousands of hours). The colour of LEDs is not derived from a filter in front of the lens, hence there is less requirement to increase power consumption to achieve equivalent intensity.

3.6. Comparison in life performance between new installations of TH and LED lights

3.6.1. Airport specific factors will make for potentially very large differences in AGL life-cycle/ performance between individual airports – for example:

- hours of operation of the airport
- frequency and weight of traffic using the runway
- modal split of runway utilisation
- weather conditions – extent of conditions requiring daytime use of AGL
- extent of winter operations (snow clearing operations may cause mechanical damage to fittings and lenses whether TH or LED, chemical usage in a number of different ways).
- operational practices at the Aerodrome (e.g. leaving runway stop-bars on permanently).

3.6.2. Some factors will be common to any installation whether TH or LED. Failures owing to water ingress into the light or mechanical damage to the lights (e.g. from snow clearing) are comparable between both fittings. Because the LED fitting need not be removed and replaced as often as a TH unit, the fitting is less likely to suffer failure owing to incorrect reassembly (see Figure 5.5 in this report). There is also less risk of FOD being left on the runway as a result of the re-lamping maintenance activity.

3.6.3. Centreline lights and other AGL in the touchdown zones are subject to greater mechanical stress than the AGL outside of these areas and will require cleaning more frequently owing to rubber deposits. Inset AGL on the runway will require regular inspection of seating rings and to check the torque settings on the nuts securing the fitting seating rings.

3.6.4. The importance of cleaning AGL should not be underestimated. CAP168 notes the following at §12.3.3:

The overall performance of AGL can be dramatically improved and maintained with the introduction of an adequate cleaning regime. The nature of their general location makes inset fittings particularly susceptible to the presence of dirt, dust, moisture and the effects of heavy loads. Staining of the glassware and rubber deposits can considerably reduce the light output of these lights and reductions of the order of 50% are not uncommon. The periodicity of AGL cleaning will depend upon environmental and operating conditions but typically AGL on runways that are subjected to a heavy traffic density should be cleaned at least once per week, and other AGL should be cleaned at least once every two weeks.

3.6.5. The evidence at present suggests that LED lights in high impact or highly trafficked areas require the same cleaning regime as TH lights, however, that they are less prone to outright mechanical failure.

3.6.6. TH AGL installations will be expected to exhibit a variable performance with time as the lamps age. At any point when TH lamps are replaced (and particularly when block replacement occurs) there is likely to be a difference in the visual appearance of the light pattern between the newly installed fittings and those remaining.

3.6.7. LED AGL thus far exhibits a more constant light output than comparable TH AGL (over the first few years of their lives at least). There is insufficient information available regarding actual ageing performance and failure modes for LEDs in the longer term (in the UK at least). Of particular interest will be their performance in high intensity runway operations when in-situ in excess of 5 years.

3.6.8. For both LED and TH installations, therefore, there will always need to be some level of intervention required comprising inspection, cleaning and fault replacement of the AGL.

3.7. The use of, and need to undertake photometric testing to evidence compliance

3.7.1. ICAO Annex 14 recommends that specialist testing to measure the photometric output of lights should be undertaken at least twice a year[xxi]. The ICAO Aerodrome Design Manual endorses vigorously the use of mobile photometric testing to allow the individual light output of AGL fittings to be tested. It relates this both to its use to demonstrate AGL compliance with the standards, and to it allowing a more efficient maintenance strategy to reduce costs to operators.

3.7.2. The equipment produces a bar graph which shows which fittings meet or exceed the correct output, and which require replacement.

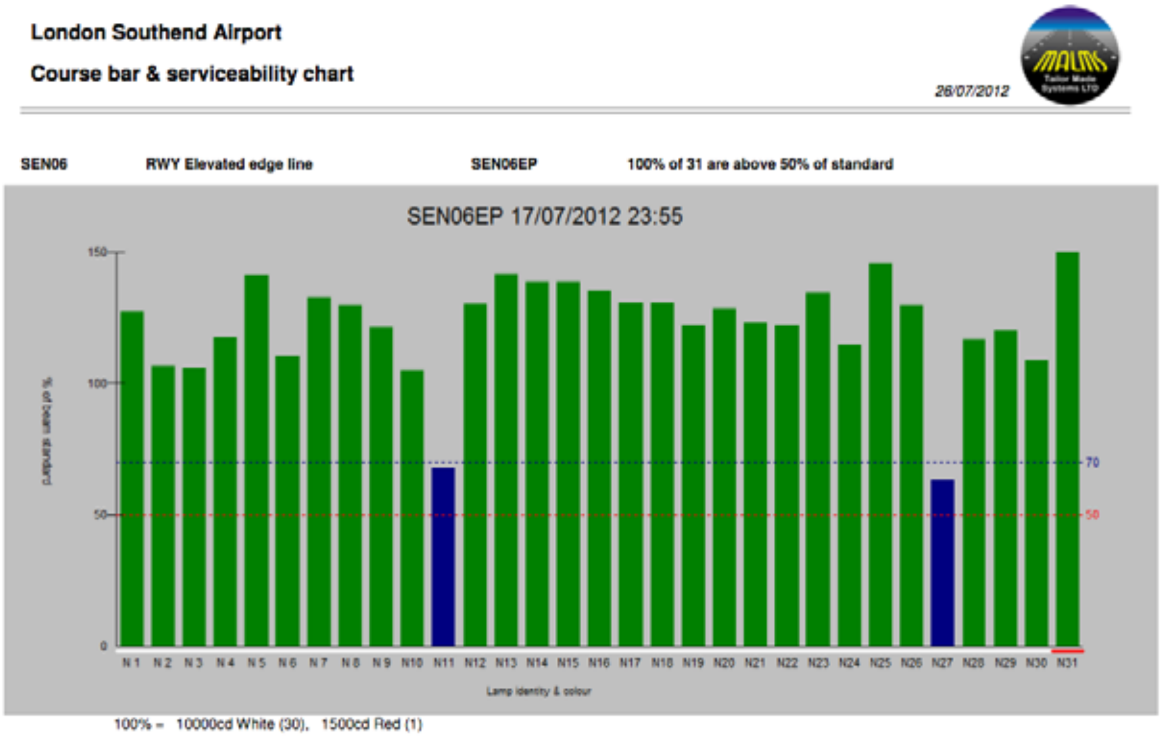


Figure 3.2 – example photometric test output for London Southend Airport TH AGL three months after the runway re-opened. Each column represents the light output and colour of an individual light - note the variability of this. If the same test were performed for clean LED runway AGL to bars would be expected to show equal light output over all the lights.

3.7.3. From the perspective of ICAO (and hence by extension national aviation regulators), regular photometric testing provides assurance regarding the known performance of the AGL installation at a point in time. A pattern of consistent test results, together with documentary evidence of the inspection, cleaning and maintenance regimes adopted, provide evidence that best endeavors are being made to reduce the risk of non-compliance to as low as reasonably practical. This principle applies equally whether the lights are TH or LED. At the busiest Aerodromes in the UK, with large numbers of lights, photometric testing is carried out at frequencies of once every two weeks or higher.

3.7.4. ICAO acknowledges that the test equipment is expensive, and suggests smaller Aerodromes hire the equipment as necessary. The ICAO Aerodrome Design Manual makes the following commentary, and particularly brings out the differences between large and smaller scales of airport operations:

(§17.5.3) High-density aerodromes, where all-weather operations with large jet transport aircraft are conducted, are less likely to meet the standards. Therefore, the use of mobile photometric measurement is encouraged to complement the routine lighting maintenance activities. There is evidence that significant benefits can be achieved for large aerodromes by using mobile photometric measuring equipment, including significant cost savings resulting from targeting maintenance activities. The frequency of photometric measurement required will depend on many factors, including traffic density, weather conditions, the season, etc.

and then….

(§17.5.5) Smaller aerodromes with relatively low movement rates and no traffic with large jet transport aircraft tend to have lesser aerodrome ground lighting facilities. In this case, the performance of the lights does not usually suffer the same level and rate of degradation, and a robust maintenance regime based on regular inspections and cleaning, and routine flight inspections should be adequate. However, photometric measurement may still enhance the efficiency of the maintenance activities at these aerodromes. Since photometric measurement to demonstrate conformance with the requirements need not be performed as often as for larger systems, a lease or contract arrangement may be more cost-effective than investment in mobile measurement equipment.

3.7.5. The ICAO guidance above is endorsed by the CAA, and CAP168 makes the following comment at Chapter 6 §12.4.4

With the use of photometric measurement within a robust maintenance programme, it should be possible to achieve and maintain a demonstrable performance level of at least 70% of the specified minimum. Where movement rates are high and aircraft types heavy, even if this level cannot be continuously achieved, AGL maintained in this way should display a significantly improved, balanced pattern of lights, which is of value to pilots.

3.8. Discussion

3.8.1. When maintenance personnel involved in AGL maintenance were consulted they were more equivocal regarding the practical benefit of photometric testing of TH installations. For example, some views expressed were as follows:

- the test shows only the performance at the time of the test and AGL light output can change very rapidly in a short period of time after it,
- that once photometric tests had established the relative performance of light fittings over time, a stable pattern of performance may emerge, which in itself may be sufficient to inform an ongoing maintenance strategy,
- block changes of TH lights were still employed for maintenance planning purposes, with a dedicated team replacing lights at larger aerodromes,
- a regular cleaning regime for the lights was the most important aspect of meeting required output levels on busy runways,
- concerns about the time on the runway taken to perform the tests,
- variance in results if equipment not correctly aligned
- bench photometric testing of TH light fittings before they leave the workshop following maintenance was possibly more cost-effective, as the test was quicker easier and more accurate to conduct, any re-assembly errors were corrected there and then, and the light's performance was assured prior to installation in the field.
- concerns were expressed regarding the costs of purchasing photometric sensing equipment (possibly in the region of Euro 100,000 for a mobile photometric testing unit),

and

- the results of photometric testing evidencing a much more uniform performance over time for LED fittings than for comparable TH lights.

Figure 3.3 LED AGL on runway centreline at Manchester Airport (green/yellow taxiway lead-off is also visible in middle distance) (Photo courtesy Paul Fraser-Bennison)

3.9. Lighting patterns and over-provision of lights to take into account variable performance

3.9.1. Experience reported of LED AGL on the runway centreline at Manchester Airport in the UK (relatively busy, with heavy movements) has shown that individual lamp failure rate over two years is as low as 0.5%[xxii]. The ICAO Aerodrome Design Manual (Part 4, Visual Aids – edition 2004) acknowledges that there is some over provision in lighting patterns and that these could be simplified without adversely affecting operational performance:

(§16.6.4) A radical redesign of aerodrome lighting systems is not practicable. What can be considered is to what extent the lighting specified can be reduced without adversely affecting the safety or regularity of operations. In the original design of lighting systems, considerable emphasis was placed on the reliability of the guidance. To ensure adequate levels of availability at all times, a high degree of redundancy was built into the lighting patterns so that a failure of complete lighting circuits hopefully would not hazard operations in any way. This over-provision of lighting to achieve reliability was compounded when additional patterns of lights were added to the basic designs as operations in low visibilities became more common- place. These trends have resulted in lighting systems that could potentially be simplified without any significant loss of guidance. Simulation trials have clearly demonstrated that the number of lights in the lighting patterns can be considerably reduced without adversely affecting operational performance[xxiii].

3.9.2. The text above has publication date 2004, which is at around the time that LED AGL had first started to be trialed. As discussed earlier, the advent of LEDs offers the potential to move away from traditional constant current circuits. Lower circuit power should lead to improved reliability through the reduction of earthing problems. Taken together with the improved performance and reliability of LED AGL over TH AGL and its superior colour performance, the possibility of reduction in the provision of lights in runway and approach patterns, or change in the colours of lighting used in those patterns cannot be discounted.

3.9.3. The ICAO Aerodrome Design Manual provides two figures to illustrate how improved reliability might enable a "reduced pattern" – these are reproduced below in Figure 3.3 below.

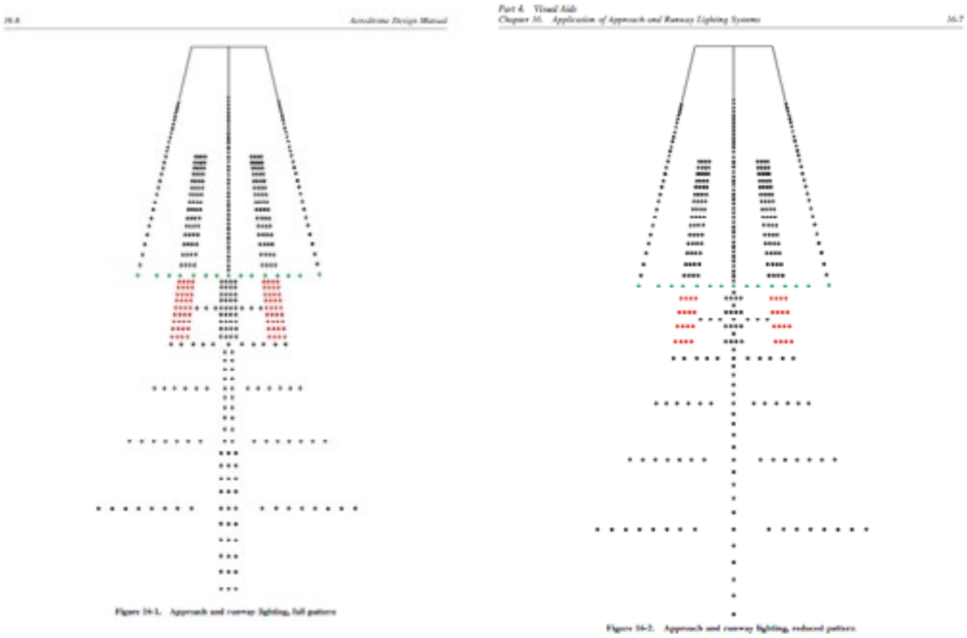


Figure 3.4: Figures 16-6 and 16-7 from Part 4 of the ICAO Aerodrome Design Manual showing a full and reduced lighting pattern.

3.9.4. For any such reduction in lighting pattern to be acceptable to aviation regulators, however, it is likely that a very substantial body of evidence of operational reliability would have to be provided.

4. Consideration of the investment performance of an LED installation versus a TH installation.

4.1. Use of spreadsheet calculation models

4.1.1. Section 3 has sought to understand the activities which give rise to maintenance and how TH and LED technologies differ in performance and maintenance requirements. It has identified that there are certain inspection and maintenance activities which will still have to occur in an LED AGL installation.

4.1.2. At present AGL manufacturers justify the increased cost of LED AGL by referring to the high savings in maintenance costs and energy consumption which can be made. They may provide simple models to demonstrate that the savings in maintenance and energy costs from adopting LED over TH lights allow the additional purchase costs to be recouped rapidly.

4.1.3. Models used by manufacturers appear to use undiscounted cash flows. They also tend to assume that all of the potential savings in maintenance costs can be realised. Using these models it is apparent that the extra-over cost for using LEDs can be recouped in as little as 2 years or less. It became apparent that development of an independent model for validation of these forecasts would be helpful.

4.1.4. This section describes how a spreadsheet model initially used by a major UK Airport for its own business case purposes has been modified to make input assumptions and calculations clearer. The model has been further developed to enable the relative merits of LED and TH installations to be evaluated in purely financial terms, separating out real and direct savings and taking into account the time value of money.

4.1.5. The model uses two measures, Net Present Value (NPV) and Internal Rate of Return (IRR). The extra-over cost of an LED installation is treated as a capital investment, and the savings made in maintenance and energy as income flows.

4.1.6. The section concludes with a review of how changes in input data affect the resulting NPV/IRR calculation.

4.2. Capital cost of new lights

4.2.1. LED AGL fittings are currently significantly more expensive than corresponding TH fittings as the table below shows.

Table 4.1: Comparison of the costs of TH and LED AGL

Type of light	Tungsten Halogen Unit cost	LED Unit cost	Factor
Runway edge (Inset)	£375.00[xxiv]	£825.00	2.2
Runway c/l	£170.00 to £220.00	£600.00	3.1
Taxiway c/l	£180.00	£330.00	1.8

4.2.2. At London Southend Airport, there are over 200 lights on the runway. A like-for-like installation of LED lights at Southend during the runway extension project would have added around £80,000 to the capital cost of the runway AGL over the equivalent cost of TH lights.

4.2.3. Discussions with the manufacturer ADB have indicated their strong support for system optimisation to take advantage of the lower power consumption of the LEDs. If this were possible it could reduce the sizes of transformers on the secondary circuit, and size or number of CCRs so as to offset the additional cost of the LED AGL fittings.

4.3. Cost of capital

4.3.1. Money costs money. Many organisations have to borrow at some rate of interest from a bank to finance their developments.

4.3.2. For a project to be worth doing financially, the return on the capital employed must be greater than the cost of that capital. There is also the opportunity cost of income foregone by investing money in a project (like LEDs) when another project could have provided a better rate of return.

4.4. Inflation and the time value of money

4.4.1. Inflation erodes the future value of money, thus at 5% per annum inflation, £100 in today's money might buy only £95 worth of goods and services the following year, and progressively less in following years. Conversely money invested in an account earning 5% interest would earn compound interest over the years invested.

4.4.2. For those organisations which have cash, inflation causes the real value of their money to reduce in value over time – so there is real pressure to invest to counteract this. At the very least, to avoid losses over time the return on the investment should not be less than the present inflation rate. For those organisations having to borrow money to finance their project, their cost of capital must include the borrowing cost, inflation, and some margin to achieve profit.

4.4.3. In the simplest of investment scenarios, investors may have to decide whether it's better to leave money in the bank than invest in a project, or to choose between alternative investments. Two tools exist to allow this kind of investment decision to be made *Net Present Value* and *Internal Rate of Return* (NPV & IRR).

4.5. NPV and IRR

4.5.1. NPV allows the total value of investment at some point in the future to be understood as a cash value in today's money. Owing to the time cost of money, the real value of future cash flows will be less – thus the future value of the cash income in the future must be discounted back to its present value. NPV uses a *discount rate* which can represent the equivalent return on capital the cash could earn if invested elsewhere.

4.5.2. If the NPV is greater than zero, then this is indicative that the project will add to the wealth of the investor over its life. If it's negative, then the project will cost the investor money. The discount rate used in the calculation in the spreadsheet is the cost of capital; at the very least, the discount rate should equal the rate of inflation.

4.5.3. The IRR is the discount rate, which if used in the NPV calculation above, will return NPV = zero. In pure financial terms, if the %IRR is greater than the % cost of capital, then the project is worth doing, if it's less than the cost of capital, it isn't. IRR rates may be set higher than the cost of capital to provide a *hurdle rate* – this allows the financial performance of competing revenue generating projects to be reviewed.

4.5.4. To perform an NPV/IRR calculation, the value of the initial investment must be known and then the subsequent cash flows (positive or negative) over the life of the investment.

4.6. Description of the "life costs" spreadsheet

4.6.1. This part of the model calculates the additional cost of LED AGL over an equivalent TH installation and then the potential energy and maintenance savings each year over 10 years. It separates out real direct savings (energy, spares) from potential savings in staff costs.

4.6.2. A sample output from the spreadsheet is contained in Appendix 2 to this report. The input variables and assumptions made in model are available for interrogation by the reader.

4.6.3. The input data required is as follows:

- Number of light fittings
- Energy per light fitting (LED/TH)
- Cost per light fitting (LED/TH)
- System optimisation: credit of capital and energy savings if installation optimised for LED
- Cost per kW/hr
- Average hours use per day
- Proportion of hours at different brightness settings
- Inflation rate for labour and spares cost
- Inflation rate for energy cost
- Labour employed to remove and replace lights on airfield
- Labour used to clean lights
- Labour used in workshop
- Hourly labour rates
- Costs of spares (TH/LED)
- Lamp life TH lights
- Outright failure rate LED lights

4.7. "Cost of capital" spreadsheet - NPV Cash flows

4.7.1. This part of the model takes the output data from the "life costs" model above and carries out a further NPV/IRR analysis using this as a cash flow. It allows the user to specify what proportion of the potential saving in maintenance cost is to be allocated as a yearly "income" over the life of the project. The user can also specify a cost of capital, which should not be less than the inflation rate.

4.7.2. A sample output from the spreadsheet is contained in Appendix 2 to this report. The model requires as input data

- the cost of capital
- the proportion of staff costs savings which are achievable ("factored staff costs").

4.7.3. In the first year, there is a large outflow of cash to fund the extra costs for the LED lights, and then the savings from maintenance, spares and energy are treated as income flows over the next 10 years.

4.7.4. Within the spreadsheet boxes marked with a red triangle in their upper right corner have further commentary regarding the assumptions being made and their implications.

4.8. Effects of varying input data

4.8.1. By changing the input parameters in the “life costs” model the following trends are observable in the financial performance of LED over TH lights:

- All other things being equal, as the number of hours the lights are on per day increases, it becomes better to use LEDs.
- All other things being equal, as the number of lights in use increases, it becomes better to use LEDs
- As the number of staff, staff costs, or length of time required to maintain the lights (in the field or in the workshop) increases, it becomes better to use LEDs. Airports which don't require to (or simply don't) maintain lights as frequently will not see as much benefit.
- Without some element of real staff cost saving, LEDs do not return financial savings (on the basis of present energy costs and forecast replacement parts cost).
- For large airport operations with large numbers of lights being run over 7 hours per day, and several staff employed a very small staff cost saving (in the order of 10%) will easily provide a positive NPV.
- For airport operations not running their AGL for as many hours per day, and not spending as much maintaining it, the maintenance savings may not be so significant to return positive NPV with IRR>cost of capital.
- A “running total” of NPV shows when the project starts to add value. This shows that, generally, payback occurs one or more years after the undiscounted cash flow.
- The staff cost saving required becomes greater the smaller the resource the airport devotes to maintaining its TH lights.
- The staff costs savings required become less if some level of system optimisation (e.g. capital savings due to smaller transformers or reduced numbers of CCRs) can be effected.
- For lights which are run at high intensity for longer, and have shorter lives, LEDs are much more cost effective (e.g. Manchester Airport may replace TH edge light lamps over 3 times per year).
- The number of staff cleaning the lights does not affect the business case as the same cleaning regime is assumed for both.

4.8.2. The results support the finding that for larger airports LEDs make financial sense within the narrow confines of NPV/IRR, provided some real savings in maintenance costs are made. For smaller airports, however, the case is not proven and will depend on input data.

4.9. Discussion

4.9.1. The "life costs" spreadsheet model may make assumptions which are arguable, however any alternative model would be expected to provide as its output an approximation of the positive and negative cash flows. <u>In this context, the NPV and IRR calculations could easily use input data sourced from any alternative model and would still be valid for that data.</u>

4.9.2. The intention of the work undertaken was to provide an independent model for objective use and interrogation by airports. The assumptions and arithmetic in the model are entirely visible and open to challenge.

4.9.3. Some of the assumptions made verge on being coarse and should be examined closely and understood by any user for contextual application at their own airport.

4.9.4. For example, by far the greater amount of potential savings from LEDs over TH lights relate to the reduction in staff hours required to undertake re-lamping. The re-lamping rate for TH lights is related to their hours in operation. The calculation of staff costs is based around there being a team of people devoted to re-lamping activities (which is the case at larger airports).

4.9.5. Particularly for smaller airports, there may be some further interpretative work and calculation required to come to a conclusion of the actual staff or in fact periodic "project cost" employed to maintain their existing TH AGL.

4.9.6. Smaller airports may only have a very small team of dedicated personnel who perform a very wide variety of tasks and spend a comparatively small amount of time maintaining AGL. There may be little practical scope for staff numbers to be reduced. For example, health and safety requirements and other practical considerations might always require at least two persons on the runway when maintaining AGL.

4.9.7. Where airports undertake regular periodic block replacement of lights rather than ongoing replacement (see below), the total annual cost of this maintenance activity can be used. The input data can be iterated to achieve the equivalent cost, or the calculated staff costs could be directly replaced with the block replacement costs. The resulting information, if fed to the NPV/IRR spreadsheet, will still provide a valid appraisal of financial performance.

4.10. Wider considerations and project context

4.10.1. In the case where an airport is considering upgrading or replacing its AGL as part of a wider runway rehabilitation programme (as is often the case), then the extra-over cost for adopting LED over TH technology could also be seen in that wider context.

4.10.2. For example, if the extra-over to adopt LEDs extended to £100,000, and the overall rehabilitation cost was £10 million, then the additional cost to install LEDs would account for 1% of the total project cost. This is not to say that this cost is in any way insignificant – merely that seen in a wider and perhaps more holistic context, the benefits of LEDs may make the additional investment worthwhile in its own right.

4.10.3. To understand the issues further, the scope for application of the spreadsheet model, and the likely take-up of LED AGL at GSA Airports over the next few years a questionnaire has been circulated to GSA partners. LSA, Billund and Groningen completed the questionnaire in time for the information provided to be incorporated into the case studies in the next section. A summary of the responses from these airports is contained in Appendix 3 to this report.

5. Case studies

5.1. Introduction

5.1.1. This section introduces case studies at Groningen Airport (GAE, Billund Airport and London Southend Airport. Each Airport has recently had to make business decisions regarding which type of AGL to install. At GAE and at LSA, decisions were taken (for different reasons) to install TH AGL on their newly extended runways. Billund has recently installed TH AGL on a short section of taxiway; at LSA a full installation of LED taxiway lighting was carried out as part of the airport redevelopment works.

5.1.2. These case studies give some indication of the complexities faced by Airports. The GAE and Billund case studies review the business cases considered by each Airport and their reasons to continue with TH technology. The LSA case study focuses on the experiences of maintaining the new LED and TH AGL following the completion of the airport redevelopment works in April 2012.

5.2. Groningen Airport Eelde (GAE, Netherlands) case study

5.2.1. GAE undertook a runway extension project in 2012/2013 to extend its runway from 1800m to 2500m length. The newly extended runway was opened on the 25 April 2013. An Aerodrome Chart and information regarding the AGL used on its runways and taxiways is provided at Appendix 3.

Figure 5.1 Groningen Airport Eelde, runway extension (Photo courtesy GAE).

5.2.2. The construction partnership responsible for the delivering the runway project, DuraVermeer-Imtech (PASE) - would also be responsible for the maintenance and upkeep of the installed AGL over a period of 10 years thereafter. The contract between the Airport and PASE provides for PASE to be paid at three month intervals over the 10 years on the basis of their maintenance performance. In the event that the lighting installation does not function correctly, there is provision for penalties to be charged to PASE.

5.2.3. PASE therefore had to decide what would be the most cost effective solution between TH and LED lights for the runway AGL, and came to the conclusion that TH lights should be used. Around 470 TH lights were installed along the length of the newly extended runway and in its approach lighting system.

5.2.4. The report which explains the decision process has been made available by GAE for review in this report. PASE relied on a standard cost model supplied by the manufacturer/supplier of their lights to calculate the time taken to return the extra-over cost of installing LED lights over TH lights. The analysis appears to have been carried out for the runway centreline, and the results extrapolated to other light services.

5.2.5. PASE's evaluation report states the following regarding uncertainties about the longer term reliability of LEDs.

In practise Imtech have some experience with LED lighting used in a situation comparable to that of the centre line and their findings are that a substantial percentage of the LED lights show faults on the short term. These problems can be attributed to incorrect electronic functioning and the seepage of water into the armature. The latter also applies for armatures that have been sealed by the suppliers before installation.

5.2.6. Imtech assumed an effective intervention rate of 10% for new LED units based on the lights being operated for 6 hours each day. A full overhaul of an LED unit was costed at €554 (about 66% of the cost of a brand new unit). Using the AGL manufacturer's investment performance model, Imtech calculated that the return on investment (expressed as the time taken for undiscounted cash flow to equal the difference in capital outlay) would take 10 years and 7 months. Sample outputs from the manufacturer's model are shown in Figure 5.2 below.

Calculation of yearly maintenance costs

Calculation of cost per light and per year (€)

	Halogen			AD-light		
	per operation	times per year	yearly cost per light	per operation	times per year	yearly cost per light
Purchase spare parts						
Prism replac.	48,00	2,0%	1,0	90,00	2,0%	1,8
Complete overhaul	125,00	1,0%	1,3	554,00	10,0%	55,4
Lamp replac.	52,10	75,0%	39,1	-	-	
Man-hours						
Prism replac.	22,00	2,0%	0,4	22,00	2,0%	0,4
Complete overhaul	28,00	1,0%	0,3	28,00	10,0%	2,8
Lamp replac.	16,00	75,0%	12,0	-	-	
On-site replacement						
Man hour	60,00	78,0%	46,8	60,00	12,0%	7,2
Van	1,00	78,0%	0,8	1,00	12,0%	0,1
Energy			16,4			4,3
		TOTAL:	118,10		TOTAL:	72,00

The yearly maintenance cost per light is:
118,1 € for halogen lights
72 € for AD-lights

Figure 5.2: Sample output from calculation performed by PASE for GAE

5.3. Use of LED AGL on taxiways by GAE

5.3.1. GAE have 70 LEDs installed on taxiways and the runway turnpad and about 40 TH AGL. GAE do not have plans to install further LEDs, however, in their response to the GSA questionnaire that indicated that they are currently performing a trial for the taxiway centreline where lights are connected to a data cable. Each light has its own IP address, and hence its status can be monitored remotely.

5.3.2. The LED lights are low voltage, and can be powered by induction from the power supply (ie no direct connection is required between the light and the power cable). The lights can be removed and replaced without isolating them from the power supply. This type of design optimisation to account for the characteristics of LEDs from the outset is of real interest.

5.4. GAE case study – discussion

5.4.1. At Groningen, the business case review is made more complex by the contractual arrangement adopted between the airport and its contractor. The energy savings which would have been made had LED AGL been installed would accrue to the airport. The risks of a relatively unproven technology becoming costly some years into the contract would be with PASE. Consideration of the additional capital costs if LEDs were to be used was material to both parties. Groningen had open and constructive discussions with the contractor, and agreed with PASE's eventual recommendation to use TH AGL.

5.4.2. The longevity of LED AGL is one of the key decision factors in many airports' considerations, particularly so when the lights are presently as much as three times more expensive than comparable TH units. As discussed earlier, Manchester Airport (AGL on 14hrs/day, circa 160,000 ATMs/20mppa over two runways) is currently experiencing about 0.5% failure rate of LED AGL on its runway centreline over three years since installation. Most of the lamp failures evidently occurred relatively soon after opening. It will remain to be seen whether this failure rate increases as the LED lights age.

5.4.3. The input data used by the Imtech was entered into the "Study model" developed for this report for comparative purposes. There were limitations to this as the data entry to each model is slightly different. In particular the manufacturer's model allows for more detailed information to be input on particular maintenance activities and the times taken whereas the Study model aggregates these. The calculations behind the manufacturer's model are not explicit, but its presentation of results is easily understandable. The manufacturer's model does not take into account the time cost of money, does not allow for inflation in staff and energy costs, and assumes that all of the potential savings in staff costs are realised. The Study model allows these parameters to be varied.

5.4.4. The above notwithstanding, common data was entered where possible, and then input parameters varied in the Study Model until its results for "break-even" on undiscounted cash flow broadly agreed with the "return on investment performance" output by the manufacturer's model.

5.4.5. Table 5.1 reviews the time taken to achieve positive cash flow and positive NPV in relation to the failure rate of the LED lights. Table 5.2 fixes the failure rate of the LED lights at 2% and reviews the effect on cash flow and NPV in relation to the proportion of staff cost savings actually achieved by adopting LEDs. The results are shown in the two tables below.

Table 5.1: Baseline calculation using study model to establish how assumed failure rate of LED units affects time to reach break even point (ie cash flow on original investment becomes positive) and NPV

Study model input parameters:

- 100% staff cost saving achieved; staff costs at rate indicated by PASE
- Credit of £1000 to allow for reduced transformer sizes in the LED installation
- 0% annual inflation in energy costs, 3% annual inflation in staff costs, 8% cost of capital
- Lights on for 5 hours per day

	Manufacturer's model used by GAE		Study model	
Assumed failure rate for LED AGL units	Time to break even	NPV over 10 year investment period	Time to break even	NPV over 10 year investment period
10%	10 yrs 7mths	Not calculated	>10 years	<0
5%	6 yrs 3mths	Not calculated	Year 8	<0
2%	5rs 0 mths	Not calculated	Year 6	>0 in year 8
0.5%	4 yrs 7mths	Not calculated	Year 6	>0 in year 7

Table 5.2: Using study model with variable staff cost saving to identify positive cash flow and NPV

Study model input parameters:

- The failure rate of LED AGL units is assumed to be 2%
- Credit of £1000 to allow for reduced transformer sizes in the LED installation
- 0% annual inflation in energy costs, 3% annual inflation in staff costs, 8% cost of capital
- Staff cost saving is varied between 100% (ie. all potential cost savings realised) and 50% saving; staff costs at rate indicated by PASE
- Lights on for 5 hours per day

Calculation model used	Staff cost saving achieved by fitting LEDs	Time to reach break even point	NPV over 10 year investment period
Manufacturer's model	100%	4 years 7 months	Not calculated
Study model	100%	Year 6	>0 year 8
Study model	80%	Year 7	> 0 in year 10
Study model	70%	Year 7	<0

5.4.6. Table 5.1 shows that, at the cost of overhaul used by Imtech, the Study model indicates that the failure rate for LEDs can not exceed 5% for NPV to remain positive over a 10 year period. Table 5.2 shows that at the staff costs used by PASE and a 2% failure rate for LED lights, at least a 80% of the theoretical savings in TH maintenance costs would have to made for NPV to be positive over 10 years.

5.4.7. Further runs of varying input data were undertaken using the Study model to establish how sensitive the NPV calculation was to changes in the input parameters. Table 5.3 below shows one such sensitivity, where the effect on NPV of varying the time the lights were on is examined.

Table 5.3: Sensitivity regarding the hours the lights are on each day; 50% achievement of potential staff cost savings

Study model input parameters:

- The failure rate of LED AGL units is assumed to be 2%
- Credit of £1000 to allow for reduced transformer sizes in the LED installation
- 0% annual inflation in energy costs, 3% annual inflation in staff costs, 8% cost of capital
- Staff cost saving is set at 50% of potential achievable; staff costs at rate indicated by PASE
- "Time lights on each day"(ie duration) varied from 5hrs in one hour increments to 10 hours

Calculation model used	Time lights on each day	Time to reach break even point	NPV over 10 year investment period
Study model	5hrs	Year 9	<0
Study model	6hrs	Year 7	>0 in year 10
Study model	7hrs	Year 6	>0 in year 8
Study model	8hrs	Year 6	>0 in year 7
Study model	9hrs	Year 5	>0 in year 6
Study model	10hrs	Year 4	>0 in year 5

5.4.8. Sensitivity runs confirmed that the results are very sensitive to the time the lights were on, staff labour rates, and costs of spares, and relatively unsensitive to changes in energy costs.

5.5. Billund Airport case study: decision whether to replace TH taxiway AGL with LEDs

Figure 5.3: View of Billund Airport showing passenger terminal and north apron in foreground (photo courtesy Billund Airport)**.**

5.5.1. An Aerodrome Chart for Billund Airport (Denmark), and information regarding the AGL used on its runway and taxiways is provided at Appendix 3. In 2011, Billund undertook a major project to rehabilitate taxiway Alpha at the airport. The taxiway provides a direct link from the south apron (adjacent the business aviation terminal) to runway 09 at the airport.

5.5.2. The taxiway was equipped with centreline lighting and 24 lights with power rating 100W would be replaced. The airport estimated that the lights were used no more than 5 hours per day. The choice faced was whether to replace the lights with new 48W TH units, or 18W LED units. Each LED unit cost €133 more than the standard TH unit. The airport calculated that at the prevailing energy cost of €0.2/kWhr, it would take some 20 years for the reduced energy costs of the LED lights to recoup the additional capital outlay.

5.5.3. Billund have estimated that the runway and taxiway lighting are responsible for around 3 to 4% of the total energy consumed at the airport; by far the greatest energy use is by the main passenger terminal building.

5.5.4. Billund also made the following commentary regarding maintenance and winter weather performance of LED AGL:

Maintenance of LED is minimal, close to nothing apart from the cleansing of lenses. However, we have discovered that winter control can be very hard on lenses and cause damage to them. Here LED is weak, as just a tiny bit of moisture ruins print in the lamp, especially with the approved thaw agents of today which break down surface tension in water, attack zinc and are electrically conductive.

5.5.5. Billund concluded that it was “not cost effective to use LEDs taxiways where the traffic load is minor” And that the current capital cost of the LED units was “much too high”.

5.6. Billund case study - discussion

5.6.1. Billund acknowledge that the maintenance expectation on LED lights is very low, but they have also factored in that the taxiway is not particularly heavily used. They concluded that, on cost of energy grounds alone, the costs of equipping with LEDs on this taxiway at this time did not make financial sense.

5.6.2. Billund’s response in the AGL questionnaire (Appendix 3) estimates that they de-ice around 75 days per year (ie nearly 20% of the time) and clear snow on around 35 days per year. Billund cite experience that winter cleaning operations could damage lenses and if the LED unit was damaged so that water entered it, then the lamp would be ruined.

5.6.3. The above has echoes of the concerns expressed by PASE at GAE, that if the LED units do suffer water penetration (in this case from winter deicing/snow clearing), then this in effect is likely to give rise to a “major overhaul” and hence could be very expensive. More information is required on this from airports as the technology becomes increasingly common.

5.6.4. If in future all-LED installations are used at airports, the relative small energy saving from the each individual airport budget may more be significant when considered in aggregate at the “macro” level.

5.7. London Southend Airport case studies – maintenance of TH runway AGL

Figure 5.4 London Southend Airport with new passenger terminal, station and control tower in foreground. Runway extension to top left of picture.

5.7.1. An Aerodrome Chart and information regarding the AGL used on LSA's runway and taxiways is provided at Appendix 3. At LSA, the maintenance team completed the first re-lamping exercise for the new runway AGL in October 2012, some six months after the newly extended runway re-opened in April 2012. Two members of staff undertook block replacement of runway centreline lights over 4 night shifts and a further two night shifts were required to change the runway edge lamps.

5.7.2. The runway centreline fittings were replaced in blocks of around 30 units. Each TH unit was removed and replaced with a pre-prepared fitting, and then returned to the workshop for re-lamping. Runway edge lamps were changed and cleaned in-situ.

5.7.3. Prior to the bulk replacement an increased rate of outright failure of centreline fittings was observed. When the lights were replaced, the new lamps were noticeably brighter than the surrounding lamps (ie those dating from the runway opening). The maintenance team at the airport had expected to have to do two bulk changes per annum, and the increased rate of outright failures validated this.

5.7.4. The staff involved in the re-lamping exercise above re-arranged shift patterns to do the work – ie the additional cost to the airport is largely the cost of the lamp spares and not additional staff cost.

5.7.5. The airport intends to undertake 4 photometric tests per annum of its runway AGL. The annual costs to hire the photometric testing rig exceed the annual re-lamping costs.

5.8. LSA taxiway AGL

5.8.1. LED AGL has performed very well. Failure modes so far observed on taxiway AGL were caused by incorrect installation leading to water ingress to two lights and physical damage causing the failure of a third light.

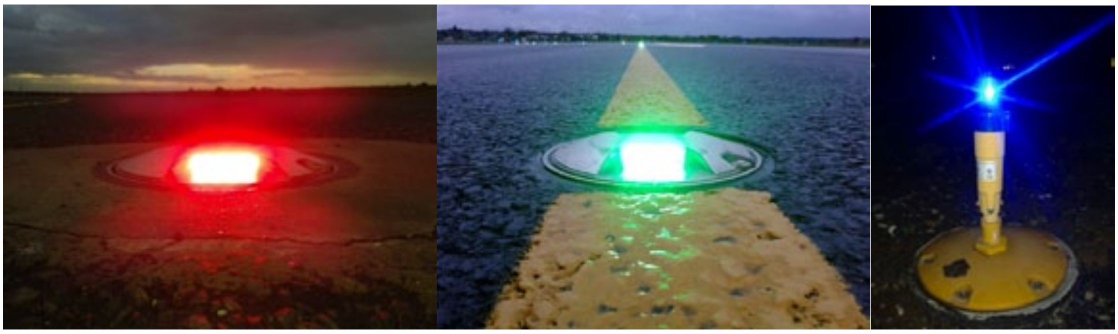


Figure 5.5 LED taxiway fittings at London Southend Airport – note "saturated" quality to the red, green and blue light.

5.8.2. Photometric testing of taxiway AGL is not undertaken. The contractor performing the photometric testing on the LSA runway evidently expressed an informal opinion to the effect that the output of LED taxiway AGL was likely to be so uniform that it could be tested once every four to five years.

5.8.3. The pictures below (Figs. 5.6a – c) are from the Technician's report to the manufacturer (ADB) for one of the lights above and show the diagnostic process undertaken to understand how it failed. This concluded that an incorrectly installed cable allowed water to penetrate into the LED light fitting and damage the electronic circuitry within.

EXTERIOR INVESTIGATION	
pinched, worn, folded, split cables?	YES
deformed, broken, bad connected connectors?	NO
missing, worn, damaged labyrinth gaskets?	NO
moistened, damaged prisms?	NO
marks, damaged surfaces, cracks or foreign objects on cover and inner pan?	NO
NOTES	

The cables seem to have some pinching damage.

6. Other developing uses for LED technology at Airports

6.1. LED in surface strip lighting

Figure 6.1 Trial encapsulated LED strip installation at JFK Airport New York circa 1997 ("yellow holding position line at a taxiway run-up position")
(Reproduced from report FAA/AR-05/2)

6.1.1. It is not known whether there are any in-pavement LED strip installations in service at European Airports at present.

6.1.2. Airport environments are extremely challenging, and features which are trafficked regularly have to be capable of withstanding high loading, jet blast, and dislodging forces (as generated from aircraft braking or snow clearing). Dislodgement of an LED strip installation would certainly affect its visual performance and could lead to it becoming a foreign object hazard to aircraft.

6.1.3. As a further general point, any LED strip installation which involves saw cutting into a concrete surface will entail the risk of water penetration into the channel. Subsequent freeze-thaw action may give rise to maintenance issues in the longer term.

WATERTIGHTNESS TEST	
waterproof test (0,7 bar): test passed?	NO
LEAK LOCATION & NOTES	

Putting the fitting in the water pressure test we see air escaping from the damaged cable. There is likely to be water damage inside.

INTERIOR INVESTIGATION	
Presence of moisture, water, traces of water intrusion?	YES
Damage to anti-rotation pin and mating surfaces?	NO
Oxidation?	YES
Damage to O-Ring?	NO
NOTES	

The PCB has been damaged by the water ingress and has caused the failure of the inset light.

Figures 5.6a – c: Diagnostic process undertaken following failure of an LED taxiway fitting. The power cables had been pinched between the casing and the seal, water ingress then damaged the circuit board and caused failure of the light. <u>This same failure mode also occurs on TH AGL, and hence TH lights are more at risk of suffering from it because they are dismantled and reassembled more frequently.</u>

6.1.4. Trials were undertaken of in-surface LED strip lighting in the mid-late 1990s at John F. Kennedy Airport and at Vancouver Airport. From around 1999 to 2004 the FAA funded a research programme to undertake a comprehensive evaluation over five years at its William J Hughes Technical Centre and at other airport locations[xxv]. The results of the trials are contained in report DOT/FAA/AR-05 published January 2005 (from hereon "report AR-05"). The abstract to the report is as follows:

With rapid advances in the light emitting diode (LED) design and production arena realized in the latter half of the 1990s, increases in intensity and reduction in cost made the use of LED source devices practical for airport use. In particular, airport engineers and designers realized that the LED, when configured in a linear array, might well serve to enhance and embolden the conventional paint markings on the airport movement area. This report describes the evaluation that was conducted to determine the effectiveness and applicability of the LED configured in a linear array to enhance paint markings on the airport surface, and to develop specifications and certification procedures for these sources. The evaluation was conducted over a 5-year period at the Federal Aviation Administration William J. Hughes Technical Center, and elsewhere [JFK, Vancouver, Eppley Omaha] *by subjective visual inspections and pilot opinion of various configurations, sizes, and colors. During this time, two different products were evaluated—a flexible strip of encapsulated LEDs and a rigid strip of encapsulated LEDs. The results of the investigation showed that both the flexible and rigid linear LED strips enhanced the visibility of the paint markings as indicated by the increased acquisition distances. However, the installation and robustness of these sources needs more attention from the vendors to enable the use of this product on airports. The specifications and certification criteria for LED linear strips were developed and are included in appendix A.*

6.1.5. The report states in its Executive Summary:

Virtually all the difficulties encountered during testing and evaluation of the LED-line devices resulted from installation problems.

6.1.6. Two types of encapsuated LED strip installations were reviewed by report AR-05: - rigid and flexible. Particular issues were encountered were as follows:

- the numerous electrical joints were required between lengths of encapsulated flexible LED strips constituted a failure path and resulted in a "broken" appearance of line markings which should ideally appear continuous
- inconsistent or mis-alignment of the encapsulated LEDs (manufacturing issue),
- for flexible LED strip, a requirement to provide a "U" shaped channel of constant and correct depth in the pavement to correctly support the LEDs and hold them at the correct viewing angle. Even with this, the flexibility of the strip tested made it extremely difficult to provide an installation flush with the surface along its length
- failures of individual LED lamps within the flexible strips making the pattern discontinuous
- damage occurred to the rigid installation during snow clearing activity
- issues with the visibility of the strip installations from certain viewing angles and heights
- issues with the brightness of the LEDs in daylight.
- cost of the LED apparatus and its installation

6.1.7. The photograph below from report shows a trial installation of flexible LED strip at a holding point at Eppley Field Airport (Omaha) at dusk. The LED strip had not been installed in a correctly shaped channel at uniform depth and the lines appear discontinous to the eye. In some installations part of the lights were visible some way off, but the totality of the feature was not visible until some way closer. The report sets out that this kind of performance characteristic could actually cause unnecessary distraction.

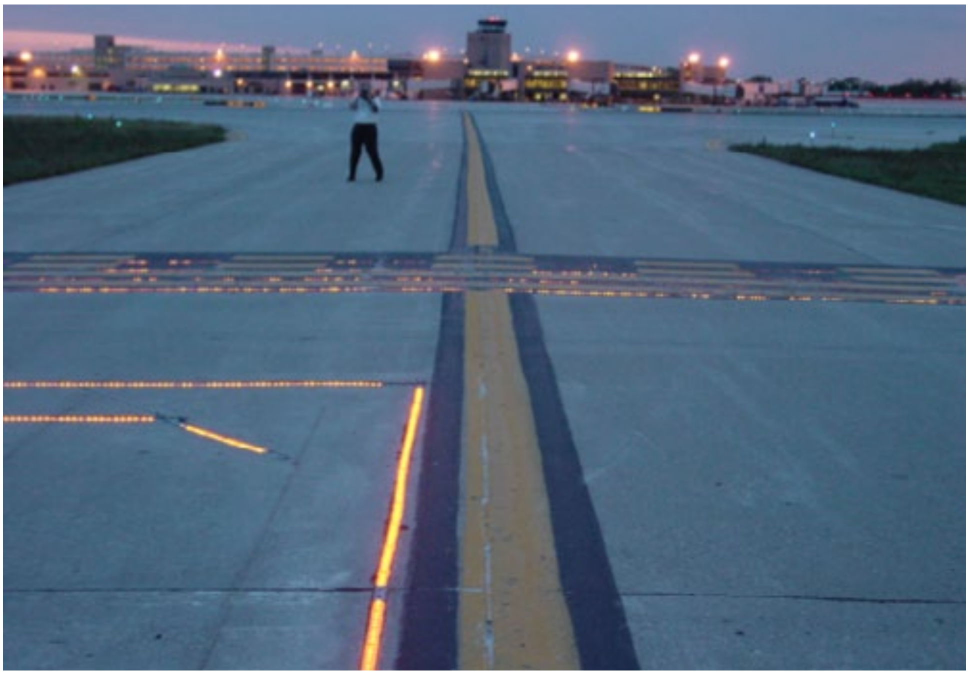


Figure 6.2 Visual effect of variations in channel depth, Note also jointing of LED strip in foreground
(Reproduced from report FAA/AR-05/2)

6.1.8. The report notes that LED strips were best suited to linear features for situations when these were viewed along the line of the installation (e.g. as a taxiway centreline or a runway designator) rather than across it (e.g. as a holding point bar).

Figure 6.3 LED runway designator to illuminate active runway
(Reproduced from report FAA/AR-05/2)

6.1.9. Report AR-05 concluded that LED strip installations have potential uses for airports, and that some of the issues observed could be overcome by improved manufacturing quality and installation techniques. The technology would have to be specifically developed for airports, however, to perform correctly and safely, and to withstand the demands of the airfield environment.

6.1.10. Since the time Report AR-05 was published (January 2005) there have been advances in LED technology and manufacture which might overcome some of the issues above – certainly with respect to brightness. Other, more "mechanical" issues may however, be inherently more difficult to resolve.

6.2. LED Apron floodlighting

6.2.1. Southampton Airport in the UK has recently replaced standard sodium vapour (SON) floodlights with LED floodlights to provide lighting for 14 stands on its main apron. The lighting contractor was required by the airport to provide a lighting design compliant with the standards of CAP168. The angle and number of the lights is critical in ensuring the correct coverage. Each main lighting tower has a different number of LED lamps depending on its location and the stand areas it is required to illuminate.

Figure 6.4 LED floodlighting illuminating stand areas at Southampton Airport (Photo courtesy Southampton Airport).

6.2.2. The results are excellent, with much improved brightness and colour rendering on the ramp. Shadow areas are, however, deeper and more sharply defined by LED lit areas than by the previous floodlighting. Engineers doing checks around the aircraft have been reported as using head-torches in some shadow areas because of this.

6.2.3. The CAP168 standards are designed for use with SON lighting. It is understood that the contractor had some difficulty with meeting the CAP168 standard for vertical luminance in the lighting design, and questioned the relevance of these.

6.2.4. There have also been some initial lamp failures (clearly unexpected given the claimed life for LED units). The reasons for these are being investigated with the contractor. The airport is discussing the overall performance of the lights with the CAA.

Figure 6.5 Further detail of LED floodlights (photo courtesy Southampton Airport).

6.3. LED PAPI units

6.3.1. The manufacturer ADB has showcased PAPI[xxvi] units at the October 2013 Inter-Airport Europe Exhibition in Munich. ADB indicate that their design substantially reduces the warm up time to service for the PAPI and that it meets ICAO and FAA standards.

6.4. Solar powered LED lights

6.4.1. The low power requirement and relatively high light output of LEDs allow them to be powered from batteries recharged from solar panels. This may provide a low cost solution for installation in remoter airfield areas where safety lighting is desirable, but provision of a fixed power supply to achieve it could be prohibitively expensive. Solar powered LED runway guard lights ("wig-wags") are now in use at many airports (see figure 6.6 below). Solar powered taxiway edge lights and obstruction lights are also in use.

Figure 6.6 Solar powered LED runway guard lights at London City Airport
(Photo Airports International.com)

6.5. Other uses for LEDs

6.5.1. There are now very few practical applications where LED lights could not replace other forms of lights, although the capital cost of the equipment continues to be higher. LED technology is ideally suited for applications where lights

- have to be on for extended periods,
- require to come on and off quickly or flash,
- are situated in areas where maintenance or access to them may be difficult,
- are in areas where light pollution (spill) is an issue
- are in locations where relatively low power/voltage sources (e.g. batteries) are all that's available.

6.5.2. Applications for LEDs which are known to be in use at Airports and in wider industry include:

- Airport car park lighting
- Lighting on Stand Number Indicator Boards
- Lighting in Terminals and Office buildings.
- IR Security lighting (LED illumination to floodlight areas to be monitored by infra-red sensitive cameras).

7. Conclusions

7.1. General performance of LED vs TH AGL

7.1.1. There is a sufficient body of independent evidence to support the conclusion that LED lights offer superior operational performance to tungsten halogen lights.

7.1.2. More data is required (from the UK at least) to validate manufacturers' claims regarding the long term performance of LEDs for runway AGL in high intensity/heavy aircraft runway operations. This data will, however, only be a matter of time in arriving owing to the decisions of major UK Airports (e.g. Heathrow, Gatwick, Manchester, Birmingham) to use LED AGL on their runways.

7.1.3. More information is also needed on the long term performance of LEDs at airports which need to clear snow or de-ice around lights over extended periods.

7.1.4. LED AGL is at present significantly more expensive than TH AGL. Manufacturers have claimed that this additional expense is rapidly recouped by savings from maintenance and energy costs. For larger airports, this Study has found that a small real saving in maintenance costs will make LED lights more cost effective than TH lights in real terms using NPV/IRR measures.

7.1.5. For smaller airports the financial case is not conclusively proven and will depend very much on the actual maintenance practices employed and whether any system optimisation has taken place. The wider benefits of LEDs, however, may be considered in some cases to outweigh the extra cost over comparable TH lights.

7.1.6. The greatest variable affecting light output at busy aerodromes appears to be the cleanliness of the lights whether the AGL is TH or LED.

7.1.7. LED AGL installations will not remove the need for all of the cleaning and inspection activity which currently takes place – e.g. to check torque settings on the fittings' seating ring nuts, and to inspect for general wear and tear.

7.2. Future development and Regulation of LED AGL

7.2.1. Future airfield lighting circuit design will be increasingly optimised for LED AGL to reduce power consumption and improve reliability. It is possible that the future airfield lighting circuit may not be based around use of high power, constant current circuits. This will, however, require approval from the national aviation Regulators.

7.2.2. The Annex 14 and UK CAP168 requirements were established when there was no practical alternative to TH AGL and reflect the inherent performance characteristics and limitations of TH lights. LED AGL installations have the potential to meet the ICAO Annex 14 standards to a much greater degree than comparable TH installations. If the standards had been drafted for LED lights, it seems likely that the benchmark performance levels would have been set higher. It also appears inevitable that at some point regulators will start to frame standards around the superior performance of LEDs.

7.3. Other developing uses of LED AGL

7.3.1. LED technology will increasingly become the “default” and is likely to replace other forms of lighting technology. Industry take-up is likely to accelerate as manufacturing costs decrease. Particular uses for airports general lighting in terminal buildings and offices, and in the floodlighting of aprons.

Acknowledgements

During the course of this study I met or spoke with several experts in the fields of variously, Aviation Regulation, the design & manufacture, and the maintenance and operation of Aeronautical Ground Lighting.

I would like to express particular thanks to the following for their time and patience during these conversations: Paul Fraser-Bennison of the UK CAA, Mike Curry of Manchester Airport, Regardt Willer of ADB, Tim Howell, Joe Eastwood and Sam Petrie of London Southend Airport, and Paul Cobby (of large experience with AGL at several London Airports). Dan Townsend at Southampton Airport provided advice on the airport's experiences with LED apron floodlighting. I would also refer the reader to the excellent report prepared by J. D. Bullough for the US FAA (ref 9). This contains a comprehensive review of the experiences of over 20 US Airports with LED AGL.

Mention of the above does not imply their endorsement of the report or agreement with its conclusions. The views expressed within this work, and any errors, remain entirely those of the author.

Murray Taylor November 2013.

Glossary of abbreviations

Term	Description
AGL	Aeronautical Ground Lighting (AGL) provides flight crew with location, orientation and alignment information in adverse visibility conditions and at night.
CAA	UK Civil Aviation Authority; the UK's national aviation regulator.
CAP168	CAA Civil Aviation Publication 168 "Licensing of Aerodromes". This is the principle licensing document for airports in the UK. It is based on ICAO Annex 14 SARPS.
CCR	Constant Current Regulator; device used in a series airfield lighting circuit to maintain a constant current within the circuit (and hence maintain constant brightness of the AGL).
EASA	European Aviation Safety Agency - the European Aviation Regulator. It will become increasingly precedent over national aviation regulators in the next six years.
FAA	United States Federal Aviation Agency; national aviation regulator for the US.
GSA	Green Sustainable Airports. These are the airports participating in the Sustainable Airport Solutions project which is being part funded by the Interreg IVB North Sea Region programme of the EU.
ICAO	International Civil Aviation Organisation. ICAO standards and recommended practices (SARPS) are adopted by the aviation regulators of ICAO member states.
IRR	Internal Rate of Return - the discount interest rate which if used in the NPV calculations to achieve NPV = 0. Can be compared against the cost of money or effective rate of return available elsewhere.
LED	Light Emitting Diode light.
LSA	London Southend Airport Ltd.,
NPV	Net Present Value - a financial measure determining whether a project adds to the wealth of an investor when the time value of money is taken into account.
PAPI	Precision Approach Path Indicator – provides glideslope information to pilots landing at an airport.
TH	Tungsten Halogen light.

Notes and references within text

[i] The extended runway at London Southend Airport opened in March 2012. Approval for LED AGL usage on runways was eventually given by the UK CAA on 17 August 2012 in IN-2012/126.

[ii] ADB are expected to bring in-surface high intensity approach fittings to the market within the next 12 months.

[iii] Civil Aviation Authority INFORMATION NOTICE Number: IN–2012/126 LIGHT EMITTING DIODES (LEDs) USED IN MARKINGS, AERONAUTICAL GROUND AND OBSTACLE LIGHTING SYSTEMS.

[iv] MOR - Mandatory Occurrence Reporting Scheme – CAP382 *"The objective of the MOR Scheme is to contribute to the improvement of flight safety by ensuring that relevant information on safety is reported, collected, stored, protected and disseminated. The sole objective of occurrence reporting is the prevention of accidents and incidents and not to attribute blame or liability."*

[v]This description of TH and LED AGL directly from the manufacturer Safegate; http://www.safegate.com/home/safegate-solutions/faq

[vi]This description of TH and LED AGL directly from the manufacturer Safegate; http://www.safegate.com/home/safegate-solutions/faq

[vii] D Rainey and S Ford, "Power Distribution for the All-Led circuit – Airport Magazine April/May 2007

[viii] CAP168 Licensing of Aerodromes

[ix] Issues with Use of LED Light Fixtures, J. D. Bullough, FAA Transportation Research Board (ACRP Synthesis 35), p14

[x] FAA AC 150/5340-30, Design and Installation Details for Airport Visual Aids.

[xi] The UK CAA are understood to be considering whether this level of specificity of circuit currents and circuit design is necessary. This level of detail could be removed in future editions of CAP168. If this occurred, it is potentially significant, as circuits could be designed differently from the outset to accommodate LEDs.

[xii] "FAA Engineering Brief 67D "Light sources other than Incandescent or Xenon for Airport and Obstruction Lighting Fixtures" of March 2012. Also provides helpful information regarding the required performance of LED lights from the FAA's perspective.

[xiii] "Power distribution for the All-LED circuit" (D Rainey and S Ford, Airport Magazine April/May 2007

[xiv] Very largely dependent on the extent to which the infrastructure is optimised. Actual power consumption will depend on the transformer sizes, CCR sizes, number of lights and the length of the circuits.

[xv] "Power distribution for the All-LED circuit" (D Rainey and S Ford, Airport Magazine April/May 2007

[xvi] Issues with Use of LED Light Fixtures, J. D. Bullough, FAA Transportation Research Board (ACRP Synthesis 35) pgs5 and 16; see also Transforming Airfield Lighting: The research into LED technology, J Taylor International Airport Review, Issue 5, 2010

[xvii] The GSA Airports are all located in countries which are ICAO member states. It is beyond the scope of this study to review differences which may exist between the GSA airports own Civil Aviation Authorities' interpretation of ICAO Annex 14 as incorporated into their own national legislature. In any case EASA will start to bring a harmonization of these rules from 2014. CAP168 is the UK's implementation of ICAO Annex 14 and for practical reasons this document references both it and ICAO documents as appropriate.

[xviii] ICAO Annex 14 Vol 1, Section 10.4 "Visual Aids" §10.4.1

[xix] ICAO Annex 14, Vol 1 §10.4.7 states:
The system of preventive maintenance employed for a precision approach runway category II or III shall have as its objective that, during any period of category II or III operations, all approach and runway lights are serviceable and that, in any event, at least:

a) 95 per cent of the lights are serviceable in each of the following particular significant elements:
(1) precision approach category II and III lighting system, the inner 450 m;
(2) runway centre line lights;
(3) runway threshold lights; and
(4) runway edge lights;

b) 90 per cent of the lights are serviceable in the touchdown zone lights;

c) 85 per cent of the lights are serviceable in the approach lighting system beyond 450 m; and

d) 75 per cent of the lights are serviceable in the runway end lights.

[xx] CAP168 Chapter 6 §9.3.1.(a) indicates that TH runway threshold and stop end lights may have to be run at 1 to 2 steps higher current setting to achieve equivalent brightness as the runway edge lights.

[xxi] ICAO Annex 14 — Aerodromes; Volume I §10.4.6

[xxii] Most of the failures occurred soon after the initial installation, thereafter there have been very few failures in centreline AGL.

[xxiii] ICAO Aerodrome Design Manual Part 4, Visual Aids, Chapter 16.

[xxiv] Source Stobart Developments January 2012; costs will vary depending on the commercial deal struck between supplier and Airport, and bulk discounts are possible when larger orders are placed. Unit costs are expected to reduce in the longer term as the technology matures and competitive pressure as new suppliers enter the market.

[xxv] Evaluation of Light Emitting Diode Linear Source Devices, Donald W. Gallagher, DOT/FAA/AR-05/2, January 2005

[xxvi] Precision Approach Path Indicators – the lights providing glideslope information to arriving aircraft.

Appendix 1: Details of manufacturers supplying LED AGL in Europe

The three major manufacturers supplying LED AGL in Europe at present are

ADB Airport Solutions
Regardt Willer
Regional Manager
(+44 (0) 1628 785339
* regardt.willer@adb-air.com
www.adb-airfieldsolutions.com
Registered office: Leuvensesteenweg 585 – B-1930 Zaventem, Belgium
Branch office: ADB BVBA, Suite 4, 110 High Street, Maidenhead, Berkshire, SL6 1PT

Safegate
Jim Jackson
Business Development Manager
Member of the Safegate Group
Thorn Airfield Lighting UK Ltd
22 Eldred Road
Childwall, Liverpool, L16 8PB
Direct: +44 (0)844 800 9232
Mobile: +44 (0)7814 029 008
E-mail: jim.jackson@safegate.com

Hella
Sonja Strand
Head of Airport Lighting
Rixbecker Straße 75 59552
Lippstadt / Germany Tel.: +49 2941 38-1114 Fax: +49 2941 38-47-1114 e-mail:
airportlighting@hella.com
Internet: www.hella.com/airportlighting

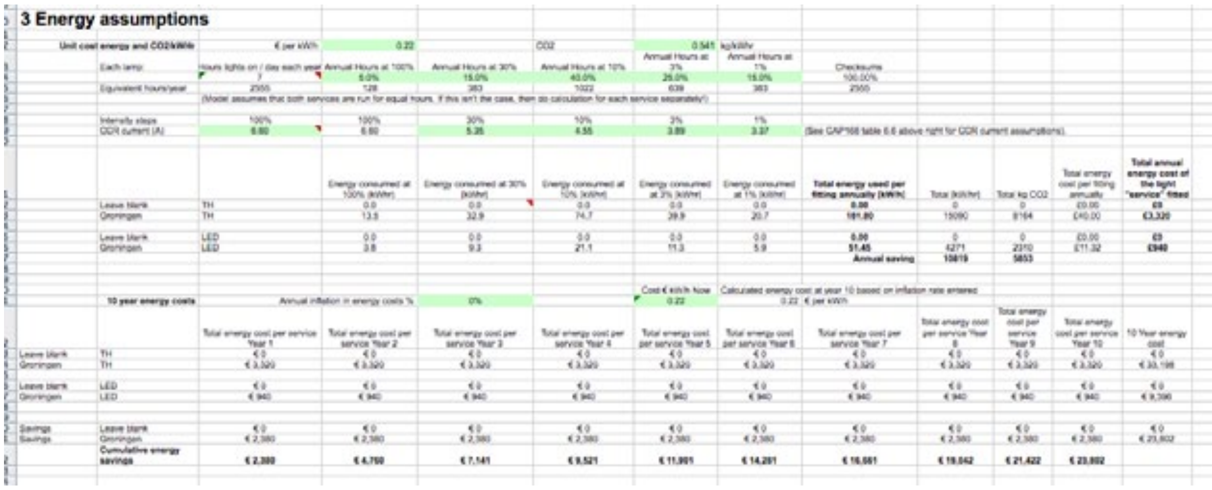
For LED Apron Floodlighting, and other industrial applications for LEDs
Vision Accendo Limited
Vision House Unit
6 Woodside Road
Eastleigh, Hampshire SO50 4ET; telephone +44 (0) 845 519 0203
http://www.visionaccendo.com/

This report
This report was prepared for London Southend Airport by Murray Taylor of Nicol Taylor Consulting Ltd.,
murray-taylor@live.co.uk; +44(0) 7802 4555 68

Appendix 2: Sample outputs from spreadsheet financial model

Output is cash flow, NPV and IRR

Inputs are as follows (cells with red triangles have information to explain assumptions)



4 Maintenance and cleaning labour assumptions

		Re-lamping on airfield			Cleaning lights on airfield			Relamping in workshop		
Staff resource used for AGL maintenance (tools, equipment transport to perform these tasks not included)		People on airfield	2	man	People on airfield	0	man	People in workshop	1	man
		Rate	€ 60	/hr	Rate	€ 60	/hr	Rate	€ 60	€/hr
		Total resource employed	€ 120	man/hr	Total resource employed	€ 0	man/hr	Total resource employed	€ 60	man/hr
		Each lamp takes								
		30	mins	0.5	hr	to remove and replace in the field				
		30	mins	0.5	hr	in the workshop				
		15	mins	0.25	hr	each light cleaned every	2	weeks		
						cleaning occurs over	50	weeks of the year		
			hrs/year spent cleaning each light	**6.25**	**hr**					

Spares costs

	Number of fittings	TH relamping	TH outright fail	LED overhaul/outright fail
Leave blank	0	€ 0		€ 550
Groningen	83	€ 25	€ 107	€ 550

Calculation of costs per fitting to change lamps and clean lights

Fitting	Assumed usual lamp Life hours/per annum (not at 100% - see note)	Annual lamp changes/fitting	Annual man hours lamp change cost per fitting	Annual Clean Cost per fitting		Annual total maintenance and cleaning hours cost per fitting		Annual spares cost	
TH lamp average life	2925	0.87	€ 79	0	assume identical to LED	€ 79		£1,810	relamping
LED average life	>50,000hrs	(see outright fail below)							
		Outright fail/per annum							
TH outright fail		1%	€ 1					£89	spares required for outright fail
LED outright fail		2.0%	€ 2	0	assume identical to TH	€ 2		£913	spares required for outright fail
Annual inflation (labour and spares costs)		3%							

5 Savings calculations based on input data - undisounted cash flow

		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	10 Year Maintenance hours Cost
Leave blank	TH man hours cost	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0
Groningen	TH man hours cost	€ 6,525	€ 6,721	€ 6,922	€ 7,130	€ 7,344	€ 7,564	€ 7,791	€ 8,025	€ 8,266	€ 8,514	€ 74,803
	TH spares (total)	€ 1,901	€ 1,958	€ 2,017	€ 2,078	€ 2,140	€ 2,204	€ 2,270	€ 2,338	€ 2,409	€ 2,481	€ 21,797
Leave blank	LED man hours cost	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0
Groningen	LED man hours cost	€ 149	€ 154	€ 158	€ 163	€ 168	€ 173	€ 178	€ 184	€ 189	€ 195	€ 1,713
	LED spares (total)	€ 913	€ 940	€ 969	€ 998	€ 1,028	€ 1,058	€ 1,090	€ 1,123	€ 1,157	€ 1,191	€ 10,467
	Savings											
	Leave blank	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0
	Groningen	€ 6,376	€ 6,567	€ 6,764	€ 6,967	€ 7,176	€ 7,391	€ 7,613	€ 7,841	€ 8,077	€ 8,319	€ 73,090
	Spares	€ 988	€ 1,018	€ 1,049	€ 1,080	€ 1,112	€ 1,146	€ 1,180	€ 1,216	€ 1,252	€ 1,290	€ 11,330
	Cumulative potential maintenance saving	€ 7,364	€ 14,949	€ 22,761	€ 30,808	€ 39,097	€ 47,633	€ 56,426	€ 65,483	€ 74,812	€ 84,420	
	Cumulative energy savings	€ 2,380	€ 4,760	€ 7,141	€ 9,521	€ 11,901	€ 14,281	€ 16,661	€ 19,042	€ 21,422	€ 23,802	
	Total possible cumlative savings	**€ 9,744**	**€ 19,709**	**€ 29,902**	**€ 40,329**	**€ 50,998**	**€ 61,913**	**€ 73,088**	**€ 84,523**	**€ 96,234**	**€ 108,222**	

Recoup of extra over for LEDs achieved in year where cumulative saving above exceeds extra over cost for LED of € 40,500 is indicated by green cells. (only if assuming zero cost of capita and 100%of savings are credited).

6 Splitting out direct savings and potential savings - undiscounted cash flow

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Cumulative real direct savings in energy and spares										
Energy	€ 2,380	€ 4,760	€ 7,141	€ 9,521	€ 11,901	€ 14,281	€ 16,661	€ 19,042	€ 21,422	€ 23,802
Spares	€ 988	€ 1,018	€ 1,049	€ 1,080	€ 1,112	€ 1,146	€ 1,180	€ 1,216	€ 1,252	€ 1,290
Potential savings in staff costs	€ 6,376	€ 13,931	€ 21,713	€ 29,728	€ 37,984	€ 46,488	€ 55,246	€ 64,268	€ 73,560	€ 83,131
	106	**man hours per year at**	**€ 60**	**/hr or approx**	**3**	**man weeks**				
Checksum total possible cumulative saving	**€ 9,744**	**€ 19,709**	**€ 29,902**	**€ 40,329**	**€ 50,998**	**€ 61,913**	**€ 73,088**	**€ 84,523**	**€ 96,234**	**€ 108,222**

(Assuming all potential savings are credited. See "Cost of Capital" spreadsheet regarding this)

Appendix 3: Summary of information returned in questionnaire from GAE, Billund and LSA Airports

Groningen Airport Eelde

Groningen Airport Eelde is a civilian airport near Eelde, in the northeastern Netherlands. It is 4.8 NM south of the city of Groningen. Its main runway is 2500m long, CAT1 ILS equipped for runway heading 23, non precision approach for runway 05.

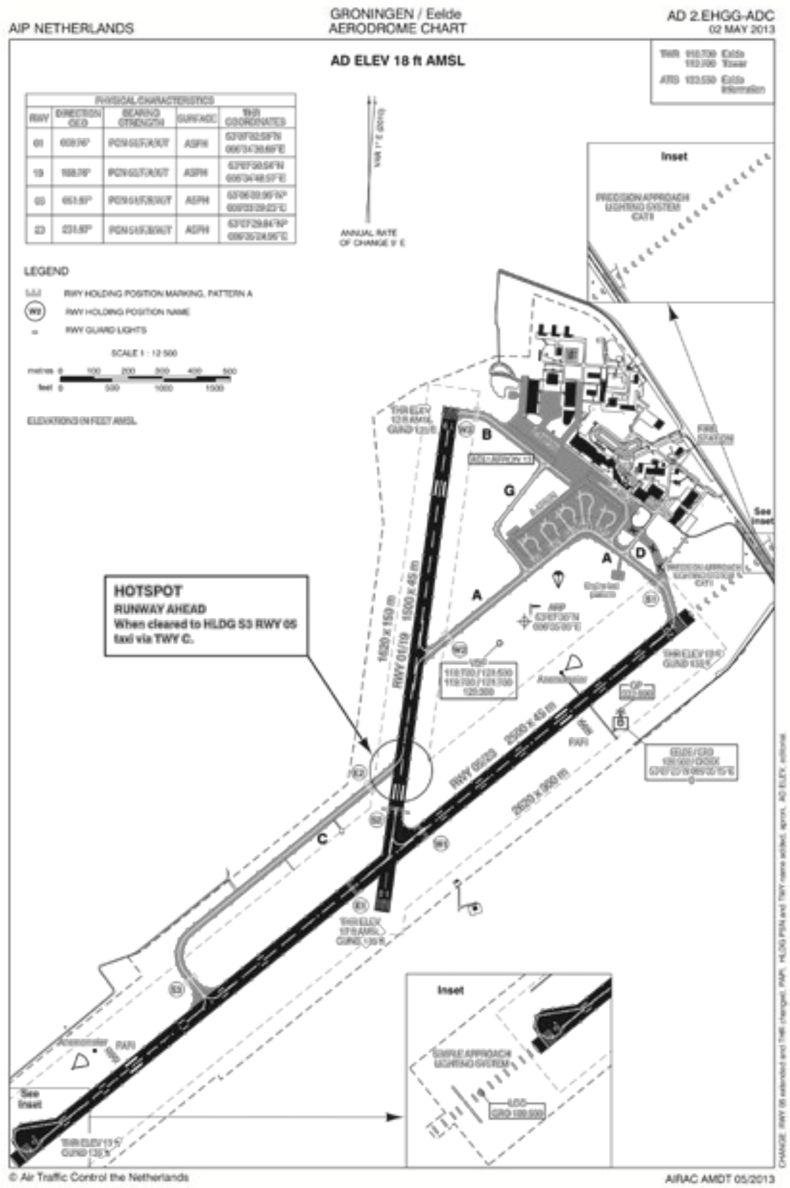


Table A3-1 Aircraft type and proportion of movements at Groningen

Aircraft types	ATMs (estimated)	%
Code A	35,000	77.7%
Code B	5000	11.1%
Code C	5000	11.1%
Code D	circa 10 p.a.	-
Code E	circa 30 p.a.	-
Total	45,000	

Table A3-2 Runway and taxiway AGL available at Groningen

Type/location of AGL	Tungsten Halogen	LED
Runway & taxiway		
Runway approach	242	
Runway edge	79	
Runway centreline	82	
Threshold and runway end	59	
Touchdown zone lighting	0	
PAPIS	8	
Taxiway edge	40	40
Taxiway centreline		14
Taxiway stop-bar		
Turnpad		16
Totals	**510**	**70**
Approx split TH/LED	88%	12%

Operational

Energy cost	€0.22/kWhr (source PASE)
Lights estimated on at	6hrs per day estimated
Deicing on	10 days per year
Snow clearing	10 days per year

Maintenance

Carried out by contractor, PASE.

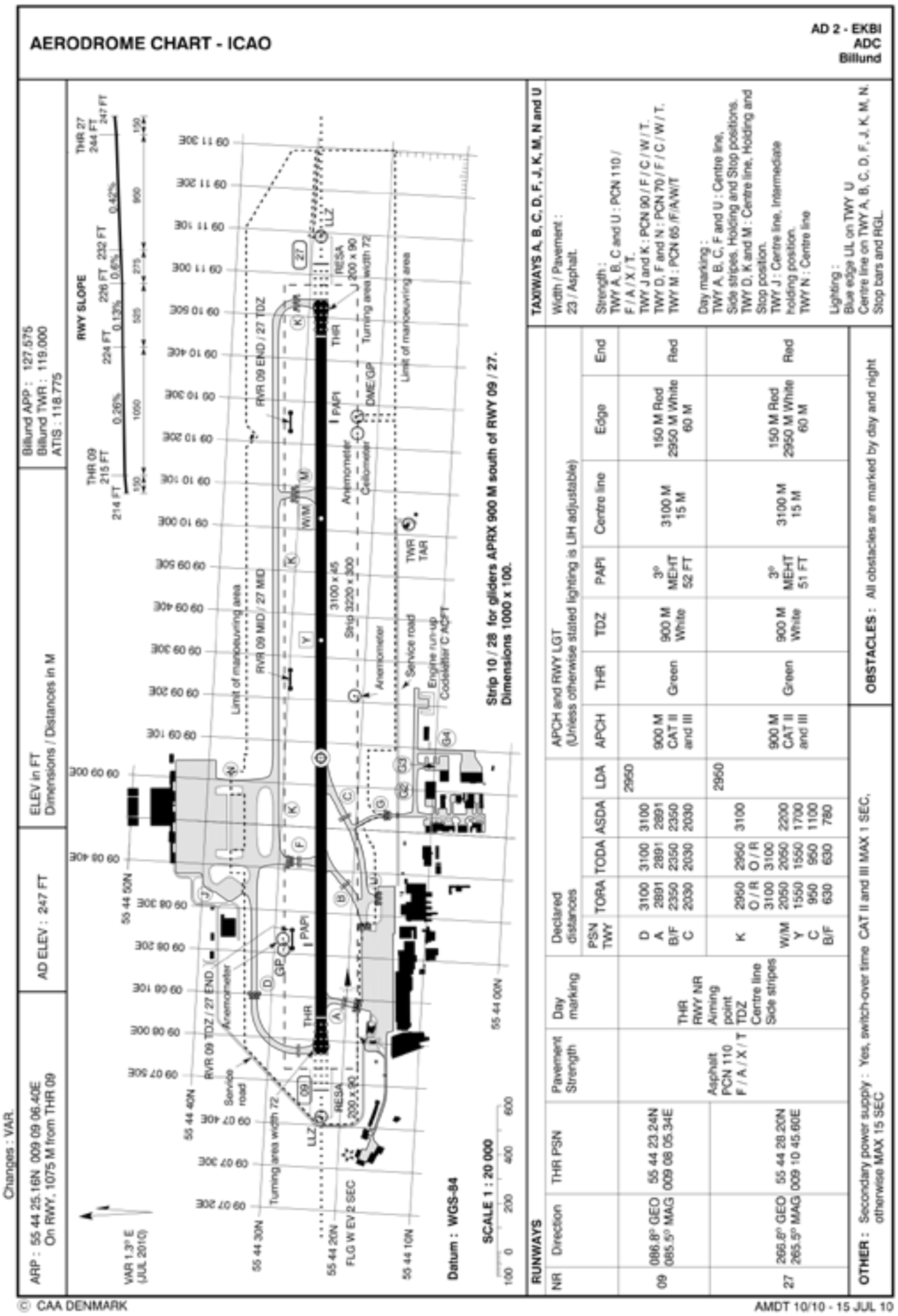
Future plans

GAE have no further plans within the next 5 years to increase the use of LED AGL

Data provided by O. De Jong, Airport Manager 2 November 2013.

Billund Airport Denmark

Billund Airport is located 1 nautical mile (1.9 km; 1.2 mi) northeast of Billund, Denmark. Its runway is 3,100m long and is equipped with CATIII ILS to both runway 09 and 27 headings.



Aircraft type and proportion of movements at Billund
54,600 movements annually (breakdown not provided)

Table A3-3 Runway and taxiway AGL available at Billund

Type/location of AGL	Tungsten Halogen	LED
Runway & taxiway		
Runway approach	400	
Runway edge	104	
Runway centreline	206	
Threshold and runway end	82	
Touchdown zone lighting	360	
PAPIS	24	
Taxiway edge	30	
Taxiway centreline	1027	35
Taxiway stop-bar	66	8
Totals	**2299**	**43**
Approx split TH/LED	98.2%	1.8%

Operational

Energy cost	€0.11/kWhr
Lights estimated on at	Estimate not provided
Deicing on	72 days per year
Snow clearing	35 days per year

Maintenance
Block changes of lights twice a year with two staff on the runway. About 20% of runway centreline lights estimated to fail before scheduled maintenance intervention. Photometric testing is carried out.

Future plans
Billund have indicated they are considering replacing TH taxiway AGL with LED AGL in 2017

Data provided by Karsten Hallesen, Work & Environment Manager

London Southend Airport

LSA is located 1.5 miles north of the Southend-on-Sea conurbation. It is some 40 miles east of London. Its main runway is 1799m long and is equipped with CAT1 ILS to both runway 24 and 06 headings.

Aircraft type and proportion of movements at LSA

Circa 30,000 movements (further breakdown not provided)

Table A3-4 Runway and taxiway AGL available at LSA

Type/location of AGL	Tungsten Halogen	LED
Runway & taxiway		
Runway approach	131	
Runway edge	60	
Runway centreline	122	
Threshold and runway end	50	
Touchdown zone lighting	0	
PAPIS	24	
Taxiway edge		97
Taxiway centreline		163
Taxiway stop-bar		68
Turnpad		31
Totals	**387**	**359**
Approx split TH/LED	52%	48%

Operational

Energy cost	€0.067/kWhr
Lights estimated on at	12hrs per day estimated
Deicing on	66 days in winter 2012/2013
Snow clearing	6 days per year

Maintenance

Block changes of lights twice a year with two staff on the runway.
About 6% of runway centreline lights estimated to require intervention before scheduled maintenance lamp change.
2 people on the runway changing lights, done as block change twice a year.
Photometric testing is carried out.

Future plans

LSA have no further plans within the next 5 years to increase the use of LED AGL owing to the recent major infrastructure upgrades to the airfield.

Data provided by Sam Petrie, Airport Development Coordinator


SafeLED

Contact

Provincie Drenthe: Project Management
Mr. Ben van Os, b.os@drenthe.nl
Ms. Deirdre Buist, d.buist@drenthe.nl
Website: www.greenairports.eu

Graphic design
Docucentrum, provincie Drenthe

ROM&N13101801

October 2013