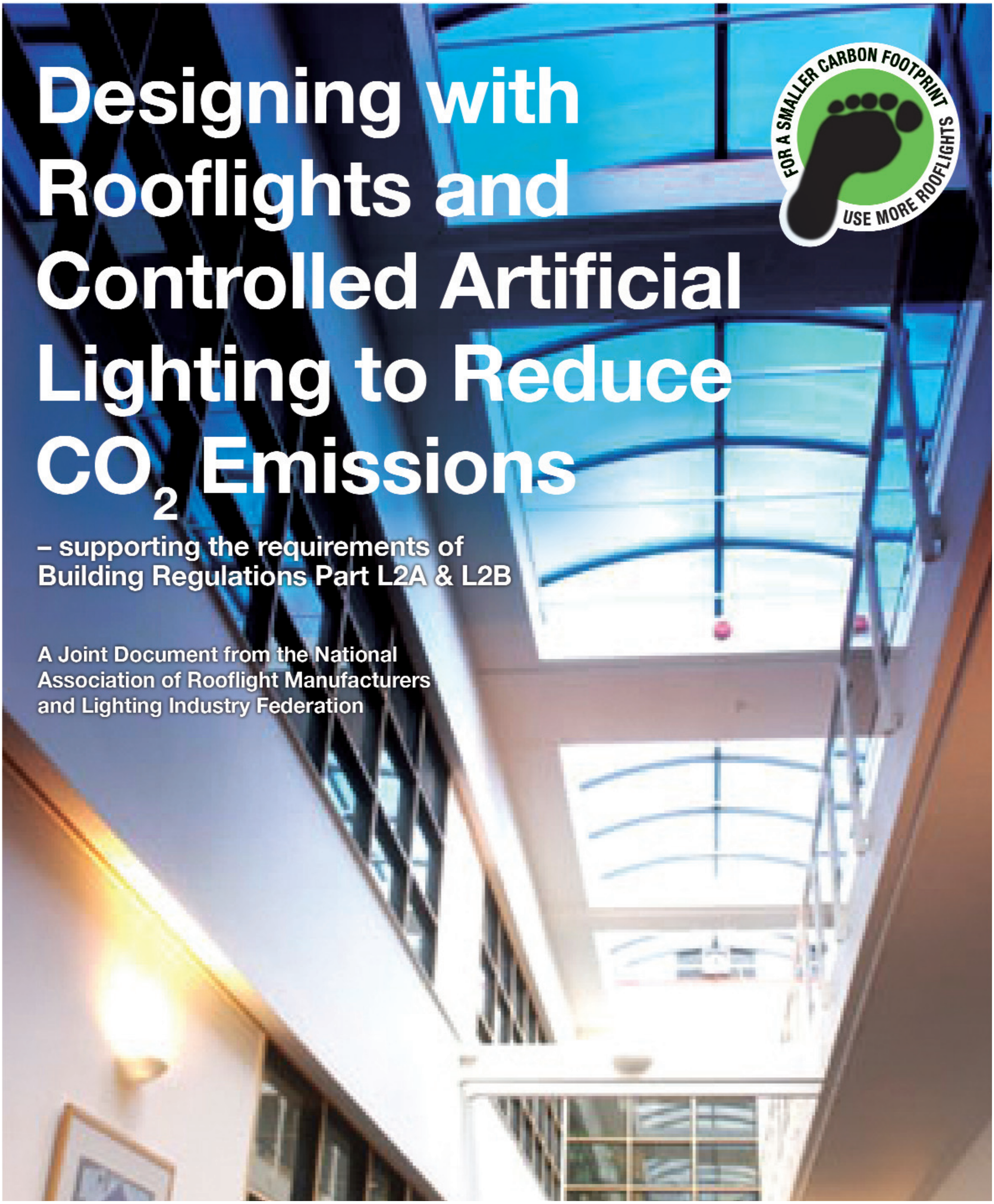
Designing with Rooflights and Controlled Artificial Lighting to Reduce CO_2 Emissions

– supporting the requirements of Building Regulations Part L2A & L2B

A Joint Document from the National Association of Rooflight Manufacturers and Lighting Industry Federation

FOR A SMALLER CARBON FOOTPRINT
USE MORE ROOFLIGHTS



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Introduction

This document has been prepared jointly by the National Association of Rooflight Manufacturers (NARM) and the Lighting Industry Federation (LIF). It is intended for designers in the roofing and lighting industry. It gives guidance on using rooflights and vertical glazing in buildings to significantly reduce the overall energy used in the building. This can lead to a marked reduction in associated greenhouse gas emissions. Compliance with Part L2A and 2B is made easier using suitable glazing and lighting controls.

Considerable savings in energy usage can be achieved by bringing daylight into a building through rooflights and windows and coupling this natural light with automatic controls that dim, or switch off, the lights during the day.

Artificial lighting is essential during parts of the working day, particularly in winter, but at other times may not be needed at all. In order to minimise the use of electricity, and maximise the benefits of daylight, artificial lighting should be effectively managed by automatic controls.

Designers should consider these key points:-

- The power for electric light is generally supplied from the National Grid, largely generated from fossil fuels, which is one of the least carbon efficient fuel sources.
- Without automatic controls, the lights in the work place are often turned on whenever natural daylight levels are low (e.g. in the morning) but are then left on all day, regardless of the need for them.

Natural illumination through rooflights is completely free and provides some useful solar gain along with a quality of light that makes the work place a pleasant environment, with beneficial effects for people inside the building.

Part L2 2006 and beyond

The Building Regulations Part L 2006, designed to save energy and power consumption in buildings, is part of an on going legislative programme by the Government. Further updates are planned over the next 10 years to create a long term building stock that will reduce the release of carbon dioxide (CO_2) into the atmosphere.

The 2006 Regulations consider the insulation values of the fabric of the buildings and construction details (e.g. thermal bridges and air leakage) which impact on the energy use of the heating and cooling systems. In addition the Regulations consider the type and efficiency of the various building services and control systems to establish the total energy needed to operate the building. This is considered in terms of CO_2 emitted to atmosphere whilst generating this energy, which has become known as the buildings 'carbon footprint'.

The interaction of building fabric and building services requires a fundamental re-think to the design parameters of buildings. A good example of this is the use of rooflights. A rooflight must allow daylight to be transmitted through the material, affecting the insulation values which can be achieved. If the fabric were to be considered in isolation, then minimising the area of rooflights would seem logical, as by its very design a rooflight will never have the same insulation values as the rest of the opaque insulated roof. However, if the interaction of fabric and services is considered, then it is clear that the area of rooflights should be maximised in conjunction with the use of automatic lighting control systems. This will reduce the total energy requirements by avoiding the need for electric lighting throughout the working day. The small effect of the rooflight on the overall insulation value will be more than compensated for by the reduced use of electric lighting.

In order for the designer to show compliance to Part L2A for new buildings other than dwellings, all the energy data is gathered and processed through approved software, such as the Simplified Building Energy Model (SBEM), that can be obtained online from the Department of Communities and Local Government (CLG) (www.ncm.bre.co.uk). Every aspect of fabric and building services and their effect on each other is considered when calculating the overall energy consumption and equivalent CO_2 emissions of the building.

The software calculates the CO_2 emissions for the actual building, the Building Emission Rate (BER). In order to comply this must be at least as low as the Target Emission Rate (TER), which is calculated as a given reduction in CO_2 emissions from the Notional Building (as defined in Part L 2002 Regulations). In the 2006 Regulations the improvements required from the Notional Building were 23.5% for naturally ventilated buildings or 28% for mechanically ventilated / air conditioned buildings – giving a TER of 76.5% or 72% respectively.

Future of Part L Regulations 2010, 2013, 2016 and 2019

The government still have to define the requirements for 2010 and beyond. It is likely that the TER will be reduced to 0% by 2016 leading to carbon neutral (including ‘plug loads’ i.e. the power used by typical equipment such as photocopiers and PCs, but not process plant) by 2019. There will be a reduction in the TER of at least 25% in 2010 with a possible interim step in 2013. What is for certain is that the Targets will be extremely demanding: in order to achieve them, both the fabric of the building and the efficiency of the services for heat, light and power, and the interaction between them, will all need to dramatically improve, giving the best possible performance, with use of renewable energy to provide the remaining energy demand.

Designing with rooflights to save energy

Research proves conclusively that rooflights can save energy in many applications. A well designed, properly oriented building, with a good spread of natural light, will benefit from passive solar gain and a reduced requirement for artificial light. The combination of these factors means that including rooflights can offer a dramatic reduction in a building’s total energy consumption and the associated emissions of CO_2. A naturally lit interior will save money, provide a more pleasant environment that people want to spend time in, and contribute to the government’s target to reduce emissions of CO_2. Daylight has many advantages over artificial light – not least the fact that it is a completely free, unlimited natural resource.

It is important to note that whereas natural daylight provides the best environment for people to work in, artificial lighting will always be necessary for those dull days and night time working. The major concern with saving energy is not that the artificial lights get switched on; it is that they do not get switched off when they are not needed. For energy saving to be achieved, artificial lighting must be used with automatic control systems.

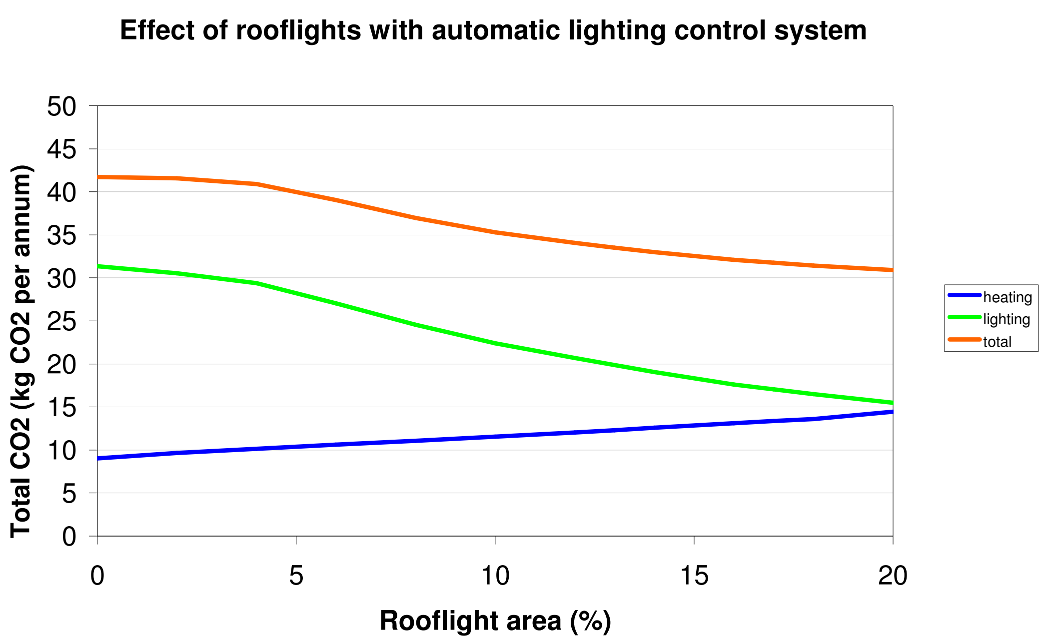
Many factors affect the contribution which rooflights can make, hence the optimum area of rooflights will vary from building to building. However, in general, the SBEM software shows that :-

- Rooflights always make a positive contribution. Omission of rooflights gives a very significant increase in CO_2 emissions.
- In most buildings, savings continue to be achieved as rooflight area is increased up to 20% of the floor area.
- In buildings used primarily during daylight hours:
    - the savings are significant as rooflight area increases up to 15% in all cases.
    - where illumination levels are relatively low, the further savings as rooflight area is increased above 15% are relatively minor
    - there are significant further savings as rooflight area increases up to 20% at higher illumination levels.

- In buildings used 24 hours a day :
    - there are savings as rooflight area increases up to 15% in all cases
    - where illumination levels are relatively low, the savings as rooflight area increases from 10% to 15% are relatively minor, with very slight increases in CO_2 emissions as area increases further, to 20%
    - at higher illumination levels, there are savings as rooflight area is increased up to 20%, but further savings as rooflight area is increased above 15% are relatively minor.

In most buildings the optimum will be around 20% of floor area. In many cases, a reduced area of 15%, whilst less than optimum, will give most of the available savings in overall energy use and CO_2 emissions.

These facts can best be demonstrated by the following graph. This shows results directly from SBEM for a typical large span single storey building and demonstrates how the total CO_2 emissions in $kgCO_2/m^2$ per annum, varies with rooflight area, up to 20% of the floor area when used in conjunction with an effective automatic lighting control system.



Key points to note :

- As the rooflight area is increased from nil to 15% rooflights, there is a dramatic reduction in CO_2 emissions
- The energy saving is generally optimum at around 20% rooflights
- The CO_2 emissions due to the lighting system are significantly higher (3 times) than the CO_2 emissions due to the heating system, when no rooflights are in place. One of the prime factors for this is that the energy for lighting is electricity from the National Grid, which is less carbon efficient at a CO_2 emission factor of 0.591kgCO_2/kWh compared with the energy for the heating system, which is typically Natural Gas at 0.206kgCO_2/kWh.
- The heat energy increases marginally as the rooflight area increases due to the additional heat loss through the rooflight compared to the opaque insulated roof panels when the building is operating at night time.
  NB. For daytime operations only, the heat loss through rooflights is compensated by solar gain and the effect is CO_2 neutral.

Automatic Lighting Controls

Lighting controls have been specified and used in a wide range of buildings over the last 30 years and are recognised as a widely accepted technology. The objective of any lighting control system is to ensure that no light is ON when it is not needed, whilst giving users an easily understood access to the lighting at all times. As highlighted in the table shown under the heading of **Lighting Equipment**, effectiveness of a lighting control system can be improved by the selection of the most compatible lighting equipment. Various aspects of lighting control systems and applications are highlighted below.

Basic functions

A control system can turn lights ON or OFF and, in most cases today, provide a dimming capability. These functions can be invoked in response to available daylight, occupancy sensing or according to the time of day. The best applied systems will also provide the user with a ready means to request such functions. The dimming and occupancy functions are those that are most affected by the choice of lighting equipment.

Dimming

Dimming is easily the most effective way of managing artificial light in response to the availability of daylight. As soon as there is a daylight contribution the electricity use can be reduced as the artificial lighting smoothly dims. Dimming, when done effectively, is barely noticed by the occupants and it always ensures that the minimum required lighting level is achieved. In contrast, if the lighting equipment is not compatible with dimming, then daylight linked switching can be used but the switch OFF can only occur when the daylight contribution exceeds the required lighting level by a factor of three (or more). Great care also needs to be taken when setting the switch ON and OFF levels to ensure the lighting does not ‘hunt’. Dimming is also a valuable function when combined with occupancy and manual controls.

Daylight sensors

In most applications the daylight sensors are either pointed North to take the sample of the current daylight level or internally mounted to sample the integrated light level (i.e. the combination of artificial and natural light). Any such sensors need to be dedicated to this task and be designed to match, as closely as possible, the eye’s sensitivity to the light spectrum. Daylight sensors should not be placed behind (for example) the lens of a passive infra red occupancy detector.

Occupancy sensors (or movement detectors)

Lights are not usually needed if there is no-one present. Effective movement detectors have been available for many years and there are now three technologies used.

- Passive infra red (PIR): This method uses an infra red sensor to 'see' the controlled area and keep lighting ON when there is a moving infra red signature present – i.e. there is someone there.
- Microwave: This method is used in larger rooms and detects movement using the Doppler shift phenomenon to confirm that something is moving within the observed space,
- Ultrasonic: This method also relies on the Doppler effect but has a smaller range than the microwave units.

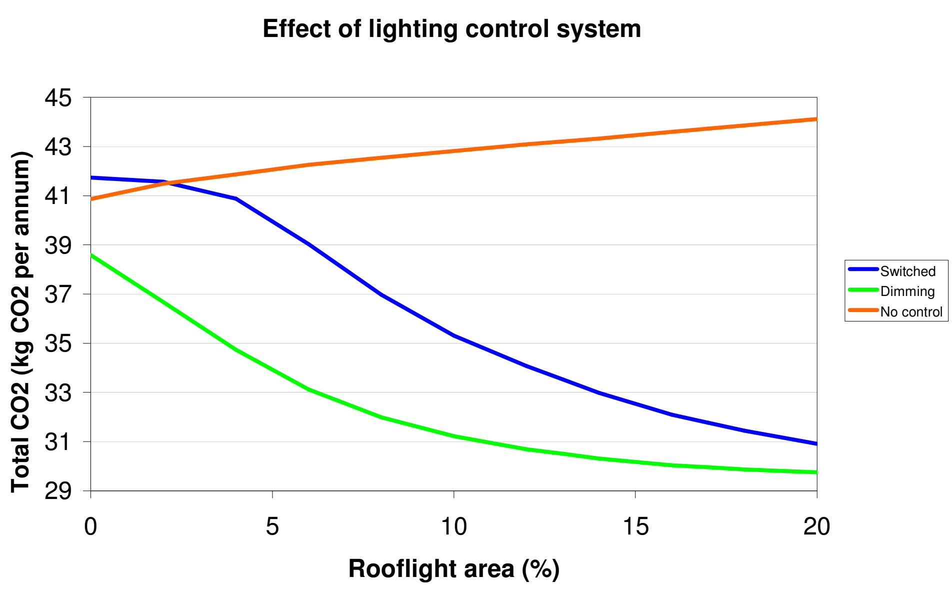
The key to successful occupancy control lies in the application of the sensors to correctly observe the space involved. Virtually all reported 'failings' of such devices have been traced to poor location choices.

Time control
Managing lighting according to the time of day can be most effective in reducing electricity consumption in those buildings that have a clearly defined operating schedule. Shops, retail sheds and malls are obvious applications where timed operation is beneficial. Time control can also be used to determine the overall mode of operation in a control system; for example a schedule can be used to determine when the daylight sensors or movement detectors are operational.

Manual control:
A vital element of any automatic lighting control system is the provision of convenient manual controls to be used by the occupants. This gives the occupants some choice regarding the amount of electric light in use, which usually results in a work place that is perceived to be more comfortable and one that, surprisingly, uses less energy.

Lighting Control Summary

The effect of lighting control is best demonstrated by the following graph using the building data entered into SBEM. It is based on the same typical industrial building as the previous section showing CO_2 emissions against rooflight area but with 3 different light control systems. The data has been highly simplified but the results are typical of the different systems shown.



Key points to note :

- The red graph is with no automatic control. The reality is that the lights get switched on in the morning when it is still dark or dull and then stay on all day. Thus, despite the use of 20% rooflights, there is no energy saving. The poorer insulation of the rooflights means there is a slight increase in heating load, and hence an increase in total energy use as rooflight area increases
- The blue graph is for lighting that automatically switches on and off by sensors.
- The green graph is for lighting where the automatic control is linked to dimmers that provide the lux levels needed.
- The graphs quite clearly demonstrate that if energy is to be saved by the use of rooflighting, control of the use of the artificial lighting is essential and the more responsive it is, the greater the energy savings will be and the lower the BER.

Lighting equipment

Typical lighting equipment that may be used in a building with rooflights and vertical glazing is outlined here. Commercial and industrial buildings, schools and hospitals are prime examples of the application areas envisaged.

Lamp & control gear combinations	**Luminaire Type**	**Lamp & Luminaire Efficacy (lumens/watt)**	**Colour Rendition**	**Instant Light**	**Lighting Controls** dimming, daylight, occupancy, time
T5 or T8 fluorescent lamps with high frequency control gear*	Batten with reflector *Type A*	Very Good	Very Good	Very Good 1-2secs typical	Well Established
	Batten with rack reflector *Type B*	Very Good	Very Good	Very Good 1-2secs typical	Well Established
	Luminaire with louvre or prismatic controller *Type C*	Good	Very Good	Very Good 1-2secs typical	Well Established
Compact fluorescent lamps with high frequency control gear**	Batten with open reflector *Type A*	Very Good	Very Good	Very Good 1-2secs typical	Well Established
Metal Halide lamps***	Low Bay *Type D*	Very Good	Good	5+ mins for full output****	Developing technology*****
	High Bay *Type E*	Very Good	Good	5+ mins for full output****	Developing technology*****
High Pressure Sodium Lamps ***	Low Bay *Type D*	Very Good	Moderate	5+ mins for full output****	Developing technology*****
	High Bay *Type E*	Very Good	Moderate	5+ mins for full output****	Developing technology*****
Tungsten halogen lamps	Emergency Lighting	Moderate	Excellent	Instantaneous	Not Appropriate

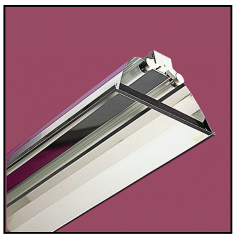
* Only tri-phosphor lamps should now be used (not the poorer halophosphate lamps)
** Only higher powered versions of these lamps should be used (see manufacturers data). All these lamps are tri-phosphor and therefore have very good colour rendition properties
*** Most of these lamps operate on conventional wire wound control gear, however some operate on electronic control gear and will subsequently be more efficient
**** Often used with auxiliary lamp to provide illuminance during the warm-up period
***** Most effective when specialist advice sought: see LIF website for suppliers and advice

Summary

This shows that modern lamps (such as T5 fluorescents fitted with high frequency ballast) have both high efficacy and are suitable for use with sophisticated control systems, offering dimming and presence control in conjunction with a range of sensors. Such lamps and control systems can offer the optimum solution for the majority of applications, including commercial, industrial and warehousing applications but professional advice should be taken from lighting suppliers and designers for each application to ensure lamps and controls are compatible and appropriate.

Luminaires

Type A   Reflector Batten
1200mm, 1500mm or 1800mm long
Used in industrial areas, storage, retail sheds



Type B   Rack Reflector
1500mm or 1800mm long
Used in warehouse gangways

Type C   Surface Luminaire
With prismatic controller (shown here) or louvres
Used in healthcare, hospitals, schools, colleges

Type D   Low Bay
Lamps typically 250W or 400W and used at mounting height 5 m to 8 m
Used in industrial areas, retail sheds

Type E   High Bay
With spun metal reflector (shown here) or with a prismatic reflector/refractor
Lamps typically 250W or 400W and used at mounting heights typically 6m to 10m
Used in industrial areas, retail sheds

Energy Saving from Automatic Lighting Controls – Case Study

Automatically controlling the lighting, particularly by switching and dimming when there is sufficient daylight for the activity in the building, can result in significant energy savings.

An example is given of a typical industrial building, with rooflights. Internal reflectances were assumed to be floor 20%, wall 50%, ceiling 70%. Maintenance factor was assumed to be 0.7.

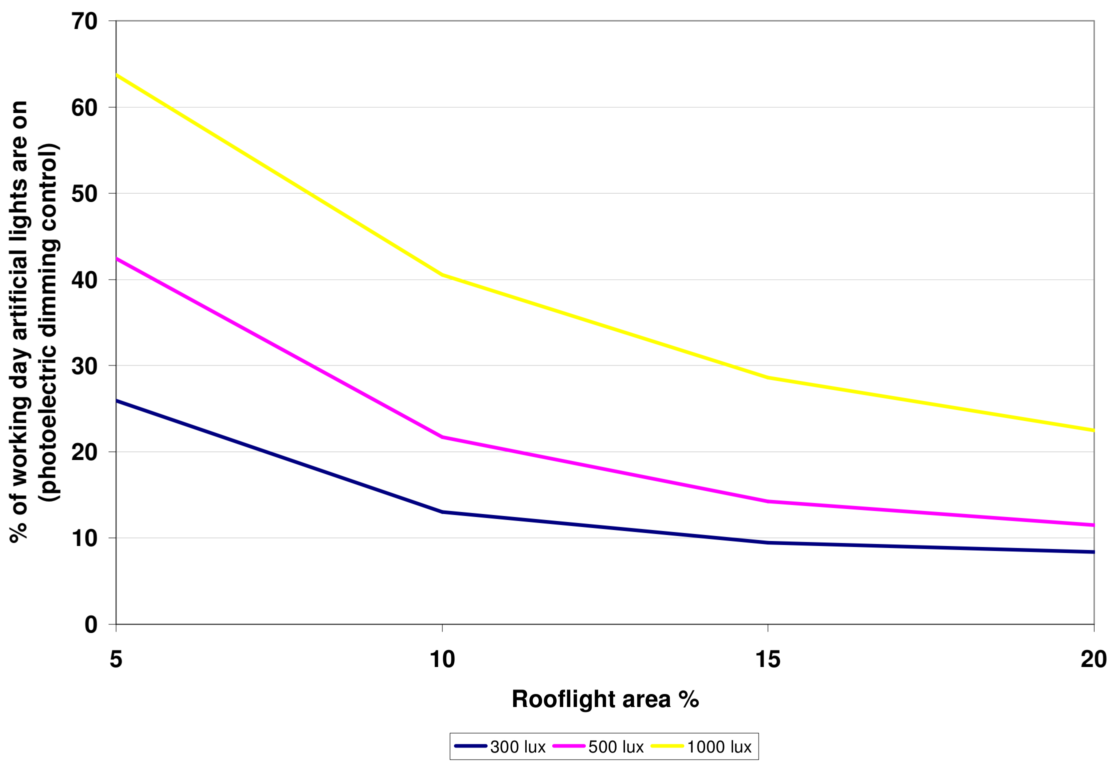
This building was analysed with 3 levels of illuminance, 300, 500 and 1000lux, and with varying rooflight area; it was assumed the building operated 2500 hours per annum.

The artificial lighting system comprised battens and economy luminaires, each with 2 x 58W T8 835 lamps giving 5200 lumens per lamp. These were installed as follows:

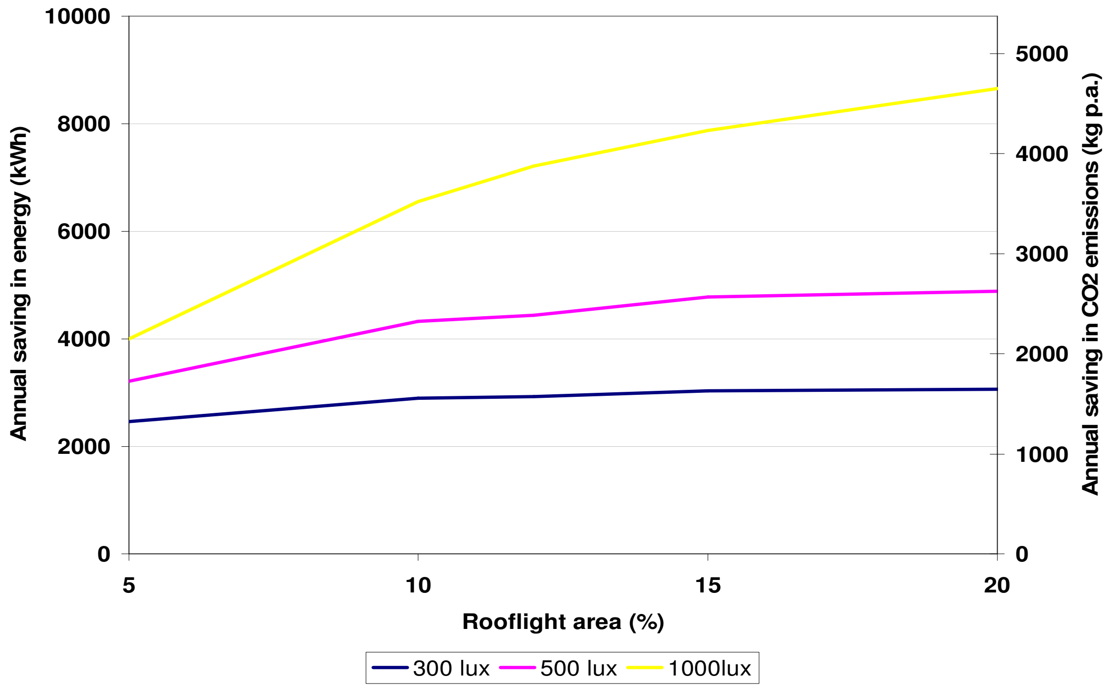
Average illuminance (lux)	300	500	1000
No. of luminaires/100 sq.m.	6	10	20
Total power (W) /100sq.m.	750	1250	2500

These were controlled with a dimming top up control system.

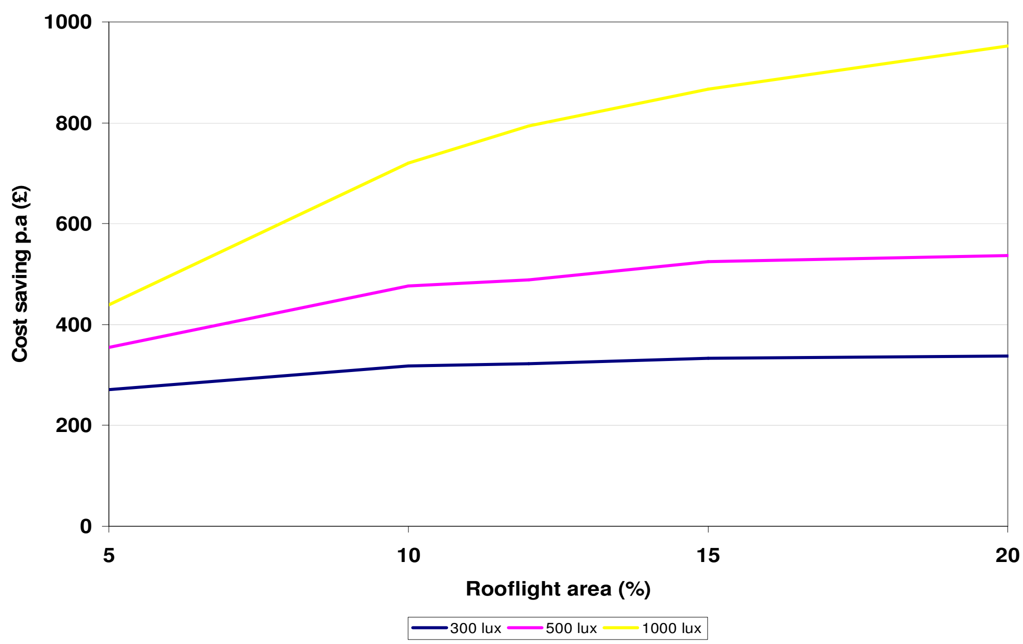
The graph below shows the effect of rooflights in conjunction with automatic control of the artificial lighting system, showing the reduction in use of the lighting system (expressed as percentage of working hours) that can be achieved by use of an automatic lighting control system.



The next graph shows the increased saving in energy used by the lighting system (expressed both as kWh per annum, and as the corresponding reduction in CO_2 emissions, assuming a conversion factor of 0.591kgCO_2/kWh) which is achieved by use of rooflights in conjunction with automatic control of the artificial lighting system.



The final graph shows how this saving can be converted into financial saving per annum (assuming electricity is 11p/kWh)



Internal Gains due to Electric Lighting

Internal gains due to lighting can be significant (for example, up to 15-20 W/m^2 in retail outlets), and could potentially present problems if artificial lighting was used in conjunction with rooflight areas over 10-12% at times of maximum solar gain.

However, the period of highest solar gain is simultaneous with the highest daylight illuminance; provided rooflight area is sufficient, the internal gains due to artificial lighting can be greatly reduced or eliminated by switching off the lights. Where this is done automatically (e.g. by photoelectric controls) the internal gain from artificial lighting would only be present when there is little daylight illuminance and hence little solar gain, so that it would seem reasonable to disregard the internal gains from artificial lighting when considering rooflight area coupled with automatic controls.

This is clearly recognised by Building Regulations. Approved Document L2A para 63 states:

"specifying efficient lighting with effective controls will reduce internal gains that will also help to reduce internal temperature rise in summer when daylight availability is at a maximum"

Emergency Lighting

This document does not consider Emergency Lighting Systems. Such systems are essential in most buildings, regardless of whether or not there are rooflights or vertical glazing to provide natural daylight within the building, and all installations should consider the emergency lighting requirements. Details on Emergency Lighting Systems can be obtained from the Lighting Industry Federation/ICEL website www.icel.co.uk

Conclusions

- Part L 2006 accounts for artificial lighting and heating
- The energy cost of artificial lighting is very significant
- Automatic control of lighting systems via sensors is essential to reduce energy and contributes to improved quality of light.
- 20% rooflight area is the optimum area to save energy and provide a pleasant place to work, where people feel better and work more efficiently
- Rooflights and automatic control of lighting systems can together make a significant contribution to reduce the carbon footprint.

References

Building Regulations Part L2A and L2B available online www.planningportal.gov.uk

NARM DCLG Approved 2nd Tier Document "Designing with Rooflights: Supporting the Guidance in ADL2A and L2B (2006)" available online www.narm.org.uk

BRE Digest 498 (2006) "Selecting Lighting Controls" available online www.brebookshop.com

Society of Light and Lighting, Code for Lighting (2006) available online www.cibse.org

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Note: it is expected that there will be on going updates to AD L2A & 2B over the next 2 years. As this happens, this NARM Guidance Document will be amended as necessary with a new issue number and date. The latest version will always be available to download from the NARM website www.narm.org.uk This issue relates to the Approved Documents issued by ODPM/DCLG in April 2006 and the SBEM results shown are from v1.2.a

Whilst the information in this publication is correct at the time of going to press, the National Association of Rooflight Manufacturers, the Lighting Industry Federation and their member companies cannot be held responsible for any errors or inaccuracies and, in particular, the specification for any application must be checked with the individual manufacturer concerned for a given installation.

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