Energy management in Lighting Systems

Thomas BAENZIGER

SYNOPSIS

Lighting control and energy management, dimming of high intensity discharge (HID) and fluorescent lamps utilising standard ballast and ignitor/starters. This new technology can save between 30-40% of energy in most lighting installations.

ABSTRACT

In the past few years more and more attention has been focused on the application of lighting controls to provide an energy efficient lighting installation in indoor as well as in outdoor applications. From the simplest of systems which switch lights on and off at predetermined times to more sophisticated daylight and occupancy linked control systems. This paper shall discuss the technologies of stepless or dimming based systems. Three case studies are presented at the end.

Measures to improve energy efficiency must offer investors competitive returns on investment. Without a reasonable return energy management has no future. Although energy conservation can take many forms the efficient use of commercial, industrial and public lighting in particular will save the community many millions of dollars in electricity charges and reduced generating plant requirements, as well as many millions of tonnes of coal and CO_2 emission annually. And, all this is achievable without any requirement to work below current illuminance standards - ***simply to utilise available daylight, compensate for lamp lumen depreciation and due to that save on air-conditioning costs.*** The total savings of a stepless lighting control system range from 20% to 50%, typically 35%. Daylight is not absolutely necessary to achieve good savings. Important is that a lighting control system is not disturbing the occupants, meaning a successful system is completely transparent to the „user“. Systems can be installed in new installations as well as in retrofit situations. The proper design and the commissioning are important to achieve good savings. Lighting control systems can be linked to a building control system however the experience shows that the simpler a system the easier they are to operate and the more reliable they operate. ***„Everything has to be done as simple as possible but not simpler“*** (quote Albert Einstein).

1. INTRODUCTION

The current approach to energy conservation lies in the underlying requirement that any initiatives in respect be viewed in terms of 'reasonable return on investment'. That is the cost of saving $1000 per annum should not exceed a capital cost of $2000 - $4000 and ideally less than $3000 - a return on funds in less than three years, is in order. This however, represents only the quantifiable requirements, in addition solutions to energy conservation should blend in to improve the current work environment rather than impose restrictions or distractions on work practices. Apart from saving energy a successful Lighting Control System (LCS) must meet the following requirements:

a) **must not disturb occupants of a lit area**
b) **must be reliable**
c) **must conform to the lighting standards**
d) **must conform to the commercial RFI standards (CE)**
e) **must have a reasonable pay back period**

A LCS can be based on at least one or both of the following techniques:

A) **Stepless Lighting Controls**
B) **Switching Lighting Controls**

Both techniques play an important role and both techniques do not necessarily comply with the five requirements when installed in different applications.

2. LIGHTING MAINTENANCE

2.1. General: Our experience shows that many commercial and industrial installations do not have a proper maintenance scheme in place nor a person responsible and educated to perform this important task. Lamps are exchanged one by one or in small groups when they fail. The replacement lamps are bought in rather small quantities and the person in charge of buying the lamps has usually no knowledge of lighting and lamps. The cheapest lamps are bought. This is often done because people in charge think that this is cheapest solution! **This is by far the most expensive way to have a lighting installation which does not even fulfil the minimum recommendations and standards!**

2.2 Maintenance: Proper maintenance of a lighting installation is important. To exchange lamps when they fail is not good enough. The majority of older type lamps fail when their light output has depreciated by some 50% or more. That means the lighting level is not sufficient to perform the task comfortably and safely, but still, the power consumed by the lighting is at 100%. That means you pay for 100% and you get 50%! It is therefore essential and cheaper to bulk replace lamps when their economical life is finished. The economical life of a lamp differs from product to product. Ask your supplier. Good lamps would last some 12'000 hrs or more, this is about 3-4 years or more. Lamps failing before that are replaced when they fail. We recommend the installation of a meter, measuring the hours of operation of a representative circuit. To give you an idea of this information.

2.3 Choice of Replacement Lamps

The person in charge of buying lamps must have some knowledge about lighting. If this is not possible talk to a lighting engineer, ask him what the best lamps would be for your installation. Price is not everything! For example standard 36W lamps are available for less then $1.00, a similar product of good quality can cost you more then $2.00. You get what you pay for! The major differences between the poor and the good product are: Lamp life, light output, colour rendering (quality of colour spectrum) and colour temperature (i.e. warm white, neutral white, cool white). In order to ensure an even and good light the replacement lamps should be bought in big quantities. This gives the added advantage of a better price.

3. WHERE DOES A LCS DERIVE ITS SAVINGS?

3.1 Lumen Depreciation Compensation: Due to the fact that all discharge lamps including fluorescent lamps "age" or reduce their luminous flux during their life a maintenance factor of 0.6 to 0.8 is applied to the lighting design. This means that with a maintenance factor of i.e. 0.7 the illuminance level is 30% higher with new lamps then it should. Once the lamps have reached the end of their economical life, the illuminance level equals the target design, not taking into account any over design. With a closed loop, stepless system this ageing process can be compensated and the illuminance can be regulated and maintained on the target illuminance. With a suitable control system between 12% and 25% of energy can be saved. These savings are accurately predictable.

3.2 Over Design Compensation: At the time the design of the lighting is done, many parameters are unknown. Therefore assumptions have to be made. These assumptions are normally made on the conservative side. Building constraints, i.e. ceiling grids or design constraints such as the requirement of having a continuous band of luminaries do increase the illuminance level. Due to all these factors over design is a common feature. With a closed loop, stepless system in place the over design can be compensated. This leads to substantial energy savings between 0% and 50% (25% typically). Savings do depend much on the degree of over design and are accurately predictable as long as the exact lighting design parameters are known.

3.3 Daylight Savings: Savings due to daylight are far more difficult to predict. But as long as architectural details are known these savings can be predicted with a certain degree of accuracy because the daylight availability averaged over the year is very much predictable. In order to maximise these savings it is important to control luminaries with similar "daylight exposure" the same way, meaning the circuits should run parallel to the windows. With suitable circuiting and reasonable daylight penetration between 20% and 30% of the total lighting energy use can be saved in a typical office application. In factories with good sky lighting, up to 40% can be saved during daylight hours.

3.4 Reduction of Illuminance Levels at Certain Hours: During cleaning or non-occupancy hours the lighting can be reduced by dimming evenly to i.e. 50%. Control is achieved with timers or occupancy sensors. If time control is used the savings are accurately predictable. In case occupancy sensing is used the savings depend obviously on the occupancy pattern. These need to be analysed carefully in advance.

3.5 Air Conditioning Savings: In addition to the savings discussed above air conditioned applications will benefit from a lower A/C load. Depending on the A/C system and the location of the application the lighting savings can be multiplied by a factor of 1.1 to 1.8.

3.6 Total Savings with stepless system: The total savings of a stepless LCS range from 25% to 50%, typically 35%. Daylight is not absolutely necessary to achieve good savings.

3.7 Switching Type LCS: The switching pattern are normally occupancy, time or daylight based. Switching systems do achieve good savings but depending on the application they may interfere with the occupants. I recommend careful consideration in the choice of a switching systems. In many instances occupants were not satisfied or disturbed. Savings depend much on the occupancy and are therefore difficult to predict.

4. FINANCIAL RATIONALE

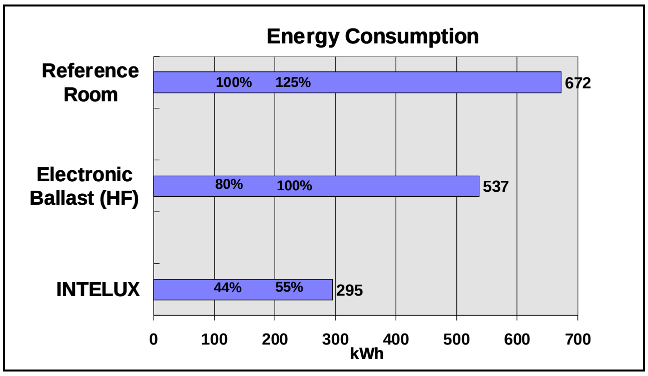
Provision for lighting can be divided in two different cost components, initial investment and operational cost. Unfortunately the initial investment influences to a high degree the operational cost which are by far more substantial over the life span of a lighting installation. The decision to choose adequate lighting is many times left to the builder, who has in most cases no incentive to look at the overall efficiency and quality of such an installation. It is many times only after the construction phase when operational cost become apparent and ways are thought to reduce them. The trend to design an construct facilities eliminates the expert advice specialised electrical engineers would be able to provide. It is therefore of great importance that building occupiers put great emphasise in the provision of energy efficient lighting and lighting controls in order to minimise energy consumption and operating cost. The benefit resulting out of a higher investment in the first place can be paid back in many cases within a commercially viable period of time. The resulting benefit is not only to the occupier in form of reduced operational cost for the entire life span of the lighting installation but represents as well a major contribution to our environment.

5. HARDWARE CONFIGURATION

Two basic systems are available. The centralised control system, where a whole circuit of luminaries is controlled by a Source Controller (power module) or a decentralised system, where the controller is part of the luminaries (Unit Source Controller as case of HID or HF ballast in case of fluorescent lighting). In order to conform with requirement "e" it is essential to keep the capital cost down. In many cases this leaves us with the first and far more economical option; the centralised system. Important here is that the system can handle standard control gear and even more important because of the number of luminaries controlled by one unit, the product must conform with the requirements "a" and "b". A basic LCS of the centralised approach can consist of two components only: The Source Controller, which is placed at the start of a circuit (normally the distribution board or the ceiling space) and a photoelectric cell, which is placed on the ceiling in the centre of that circuit. The PE cell is calibrated on site in order to maintain a constant illuminance level. It is transmitting its signal to the Source Controller which is now regulating the flow of power supplied to its circuit. All luminaires are equipped with standard iron core ballasts, standard starters and standard lamps. With this technology the lamps can be controlled in a range of about 100% to 50% of light, which equates 100% to about 42% of power in case of fluorescent lamps. In a bigger room, i.e. a factory with even sky lighting all the circuits can be controlled from the same PE cell. A Central Control Unit (CCU) is then placed between the PE cell and the Source Controllers, because as soon as the PE cell is not easily assessable (the height of a factory is usually >4m) it is not practical to have any adjustments on the PE cell. The CCU is installed in the distribution board where the settings (target illuminance) can be changed easily. **With this particular technology even high intensity discharge lamps (HID) can be controlled**. The control gear of the lamps must be standard reactor ignitor type and must not contain any power factor correction capacitors, as they will interfere with the Source Controller. Power factor correction is done centrally on the line side of the Source Controller. Depending on the type of lamp used a dimming range of 100% down to 20% can be achieved. It all sounds so easy! Yes it is easy! But to achieve this more then 10 years of extensive R&D and experience was necessary! Systems like this are installed in more then 20 countries in Europe, Asia, Africa and Australia. Systems like this are suitable for retrofit and new installations.

6. COMPARISON OF DIFFERENT DIMMING SYSTEMS

In 1992 KEMA Transport & Distributie started to test 4 different dimming systems. The four systems, two operating with electronic ballasts and two operating with magnetic low loss ballasts were installed in 4 identical offices. All systems were continuos dimming systems and calibrated to maintain an illuminance level (light level) of 500 Lux. One of the two systems operating on magnetic ballasts failed early in the test, the other three systems operated until the end of the test.



Graph 1 illustrates the test results of the three operating systems until 25. January 1994 (236 days). The reference room is equipped with magnetic low loss ballasts without any control (energy consumption 672 kWh). The result of the electronic ballasts is the average consumption of the two brands installed (energy consumption 537 kWh). The result of the dimmed system with magnetic ballasts is 295 kWh or 56% less than the reference office.

Graph 1: : Test results of all systems until 25 January 1994 (236 days)

7. CONCLUSION

Lighting Control for Energy Management has become an important issue. Regardless of the system or technology used in a Lighting Control System, the five requirements of a LCS for Energy Management must be checked thoroughly in advance. Virtually every type of lamp HID and fluorescent is dimmable utilising standard magnetic (reactor) control gear. No modifications are necessary on inductive luminaires. Finally a successful application has not only something to do with energy savings and short pay-back periods, but with happy customers. Service, credibility and reliability add to the five requirements as they do in most of the cases, where new technologies are implemented.

8. CASE STUDIES

8.1 Office Tower Melbourne Central

Summary: The stepless Lighting Control System was installed on more then 20 floors measuring about 1200 m^2 each. The cost of the LCS including installation was about (AUD) 14'000.00 (Australian Dollars, AUD 1.00 = approx. DM1.00) per floor. Each floor has about 33kW of fluorescent lighting. These are about 390 luminaires with two compact fluorescent lamps PLL 36W and low loss iron core ballasts and standard starters. The total annual savings per floor due to the LCS are AUD 4'700.00. A very favourable pay-back of 3 years is the result.

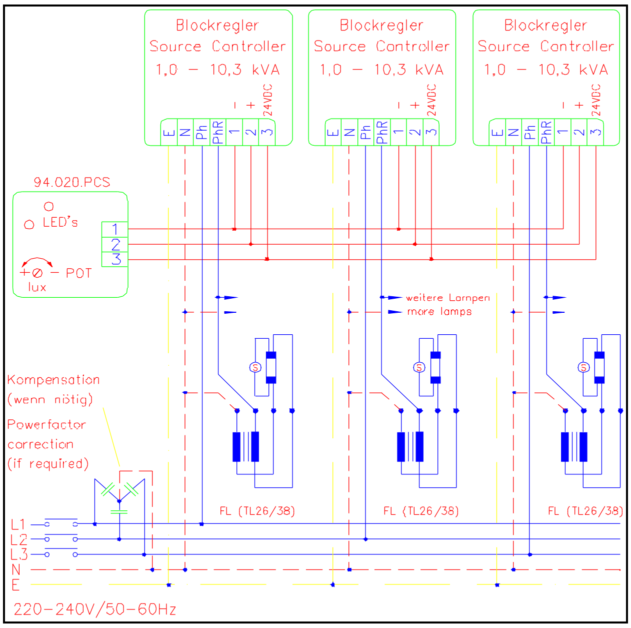


Figure 1 schematic diagram of the installation

Installation: A typical floor is equipped with 8 photo cells, 2 per face. One for the outer and one for the inner two rows of luminaires parallel to the windows. About 24 Source controllers are installed, one for each lighting circuit. The Source Controllers are housed in a small enclosure, placed at the start of each circuit in the ceiling space.

Energy Verification: In order to verify the performance of the lighting control system recorders have been installed on several floors. The cost savings on the 20 floors equipped are about DM 120'000.00. The total investment was about DM 360'000.00 part of which was paid by the local electricity supply company. The over all cost of the system installed per m^2 is about DM 15.00, or per W about DM 0.55. **Table 1 below** illustrates the individual parameters of the ROI (return of investment) calculation. Notable is the very low cost of energy of about DM 0.13 per kWh in this installation. Needless to mention that with energy costs of DM 0.26 per kWh the ROI would be some 18 months!

Hours of operation p.a.	A	3'250	h	
Cost of energy	B	AUD 0.11		
Lamp power	C	36	W	
Ballast loss	D	6	W	
No. of lamps	E		785	pcs
Usage without LCS	F	A x E x (C+D)	107'196	kWh
Usage with LCS	G	I x (1-F)	63'996	kWh
Energy savings p.a.	H	F-G 43'200	kWh	
Average energy savings I	measured	40.3%		
This equates to about	estimate	43	t CO_2	
Cost savings per year	K	H x B	AUD 4'752	
Total investment	L		AUD 14'256	
Return on Investment ROI	**I/K**	**3.06**	**years**	

Table 1: Return of Investment Calculation (ROI) per floor Melbourne Central

8.2 Retail Application

Introduction: Countless retail shops were supplied with a stepless lighting control system. Migros, Coop and CC-Prodega in Switzerland or the Praktiker Baumarkt in Germany as well as BATA stores in the Czech Republic are using INTELUX in some of their outlets. In any of these installations between 30% and 45% of energy could be saved.

Summary: Mid 1994 the CC-Prodega branch in Pratteln near Basel, Switzerland was completely refurbished. A total of 42kW of fluorescent lighting was installed to achieve a maintained illuminance of 500-600 Lux.

Installation: All luminaires contain standard iron core low loss ballasts and starters. INTELUX Source Controllers were installed in the central distribution board, a total of 8 photoelectric cells were placed over the wholesale market. The building was divided in three zones, the three Central Control Units were calibrated to maintain the required illuminance.

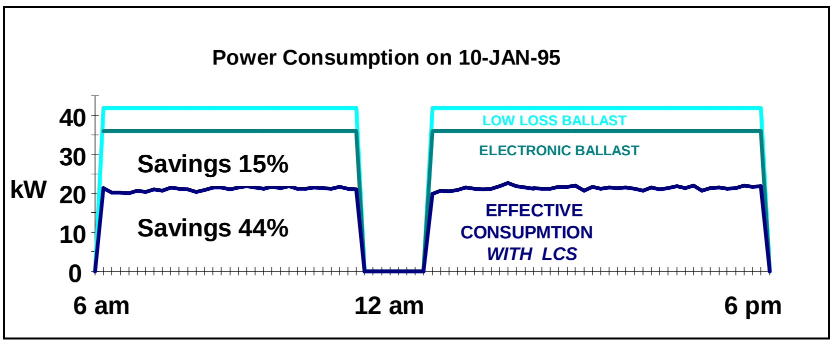
Energy Verification: After the commissioning of the lighting control system the energy consumption of the lighting was measured during a period of two weeks. The energy savings were found to be 44% compared to non controlled low loss ballasts and 36% compared to non-dimmable electronic ballasts.

ROI Analysis: This ROI compares the INETLUX system and low loss ballasts with non dimmable electronic ballasts.

Hours of operation p.a.:	3'120	h
Price of energy:	0.107	CHF (Swiss Francs)
Energy usage with elec. ballasts:	112'560	kWh/year
Energy usage with INTELUX:	72’488	kWh/year
Energy savings:	47'013	kWh/year
Cost savings:	**5'030.00**	**CHF**
Additional cost INTELUX*:	5'650.00	CHF
Return of Investment (ROI):	**1.1**	**years**

Table 2: Return of Investment Calculation CC-Prodega

Graph 3 shows the power consumption of different systems. In this installation 15% of energy could have been saved with non-dimmable electronic ballasts compared with low loss ballasts. This figure takes into account that the light output of a lamp operated with electronic ballast can be lower than when operated with a magnetic ballast. The savings of the lighting control system, which were verified are 44% compared with an installation using low loss ballasts with out a LCS



Graph 3: Power consumption of different systems calculated and measured.

8.3 Street Lighting, DYNO

Summary: In order to find the optimal lighting system for high traffic volume motorways the Dutch Directorate-General for Transport, Public Works and Water Management in Rotterdam instigated the DYNO project in 1995. The aim of the research project is to increase traffic safety and traffic capacity by way of dynamic lighting without wasting energy. So far high traffic volume motorways in the Netherlands were lit based on the roads peak traffic volume, using only one lighting level (normally 1 cd/m^2). Except during rush hours, the luminance is often excessive and could be reduced.

Test Section Motorway A12: In order to find out what luminance would produce the best results under certain conditions a 15 km test section on the A12 has been equipped with a dynamic lighting control system. The 3 lanes for each direction were lit with 400W high pressure sodium lamps, one lamp every 50m. In total about 600 lamps or 264 kW. About 100 Source Controllers (*NCWI-Dimmers, NCWI stands for non critical wave form intersection*) at 10 kVA each were installed in the distribution boards. They allow a continuous dimming of the high pressure sodium lamps from **100 to 10%** of luminous flux. They are controlled via a centrally located control system taking into account traffic density and weather conditions (rain, frost and fog). **Test Phases:** During all phases, in total three years, traffic parameter were measured by the TNO Human Factors Research Institute under contract with the Transport Research Centre. Phase one (1995/96) was without any lighting at all, phase two (1996/97) with a fixed luminance of 1 cd/m^2 and phase 3 (1997/98) with a dynamic luminance of 0.2 cd/m^2 to 2 cd/m^2. Driving behaviour was recorded during the three phases. For evaluation purpose inductive loop data, video-recordings, road user questionnaires and an accident analysis were done.

Some of the Results of the Project:

1. The Dutch authorities recommend now to install dynamic public lighting on all Dutch motorways with a luminance variation from 0.2 - 1.0 cd/m^2.
2. The luminance levels chosen in phase three were: 0.2 cd/m^2 for 67%, 1.0 cd/m^2 for 31% and 2.0 cd/m^2 for 2% of the time the lighting was switched on.
3. Lighting slightly increased the average traffic speed.
4. No indications for a reduction of traffic safety was found when lighting was installed.
5. No considerable difference was found between 1 cd/m^2 and 2 cd/m^2.
6. The driving behaviour during rain on a lit road was similar to the behaviour without rain and without lighting.
7. From interviews it was found that the concept of dynamic lighting is appealing to the road users.
8. In terms of traffic performance, the effects can be described as advantageous.
9. The installation of lighting improved the roadway capacity.
10. For now it was concluded that in favourable conditions (dry weather, low traffic volumes) the 0.2 cd/m^2 can be applied.
11. The 2 cd/m^2 level is likely not to be installed in future projects. In this case the energy savings resulting from the dimming are about 41% in comparison to a constant luminance of 1.0 cd/m^2.

9. REFERENCES

Individual Paper

- Mulder G.J.W. 1995 „Final Report on the Test of Lighting Control with Daylight Compensation“. Published by KEMA Transport & Distributie Arnhem, 29 March 1995.
- Folles, E. (1993). *A new generation of road lighting.* Proceedings of Right Light, 2nd European Conference on Energy-Efficient Lighting (26-29 September 1993), pp.329-341. Arnhem.
- Folles, E. (1998). *A new generation of road lighting.* Paper, Licht 98’ Bregenz

Internet

- **Richard van der Horst & Jeroen Hogema** (1995), TNO Human Factors Research Institute, www.minvenw.nl/rws/avv/dyno/“.

Author: Dipl. Ing. Thomas D. Baenziger, Managing Director INTELUX AG,
9422 Staad, Switzerland, Tel. +41 71 855 7676, Fax +41 71 855 7679
e-mail: sales@intelux.com, home page: www.intelux.com