Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 100 (2015) 187 – 195

Procedia Engineering

www.elsevier.com/locate/procedia

25th DAAAM International Symposium on Intelligent Manufacturing and Automation, DAAAM 2014

Energy Saving Techniques and Strategies for Illumination in Industry

Ruzena Kralikova[a]*, *Miriam Andrejiova*[a], *Emil Wessely*[b]

[a]*Technical University of Kosice, Letna 9, 040 01 Kosice, Slovakia*
[b]*Pod Kastielom 11, 040 21 Kosice, Slovakia*

Abstract

Lighting conditions in industrial operations are currently at a level, which in many cases does not satisfy the requirements set out by legislation and standards. Slovakia has highly energy-intensive industrial structure, where dominates the engineering industry. The proportion of electricity attributable to lighting is significant and not negligible. Installation and operation of energy efficient lighting systems is in most cases not yet considered a major priority, because the available funds are primarily used for the operation, modernization of production process, and other related activities, that are directly related to the production, and the existence of industrial enterprises and institutions. This paper presents new trends and progressive strategies to reduce energy consumption of lighting systems. In new installations energy efficient lighting costs are little more to provide than the older less efficient kind, but consumption of energy are lower, economical and environmental friendly.

Peer-review under responsibility of DAAAM International Vienna

Keywords: Energy saving; lighting; illumination; electricity

1. Introduction

The characteristics of industry are large and high spaces, fixed working positions, long work periods, adverse conditions, various levels of illuminance, high bay lighting, central lighting control, restricted maintenance opportunities. The above characteristics are also clear significant energy consumption for lighting. Recent developments in lighting technology combined with planned lighting control strategies can result in very significant cost savings, typically in the range of a third to a half of the electricity traditionally used for lighting.

* Corresponding author. Tel.: +421-55-602-28-25.
E-mail address: ruzena.kralikova@tuke.sk.

Peer-review under responsibility of DAAAM International Vienna
doi:10.1016/j.proeng.2015.01.357

The lighting technology is so one of the significant consumers of electricity. It takes more than 15 percent of overall electricity consumption, while at peak periods; it even takes approximately a fourth part. It is obvious at energy audits that exactly the electricity savings in the lighting are usually most evident and most easily feasible. A lighting technology is not only one of considerably developing industries of economy, but also one of the most progressive developing branches of the science and technology. New materials and technology, a penetration of thin layers, microelectronics and computer technology into the lighting technology enormously promote its development. The trends of development in the lighting technology influence the principal problems of a contemporary world and it is possible to generally summarize them as follows:

- Electricity saving in all spheres of the illuminating devices application.
- Lighting parameters quality improvement.
- Material savings.
- Living environment protection. [9]

2. Energy saving techniques and strategies

The base energy saving techniques and strategies are:

- Utilise the most energy efficient lamp/luminaire combinations.
- Maximise the use of dayligh
- Make lighting control as local as possible
- Use light coloured walls and ceilings
- Get staff involved in energy saving planning

These strategies, which the saving measures should be based on, are shown on Figure 1. [10]

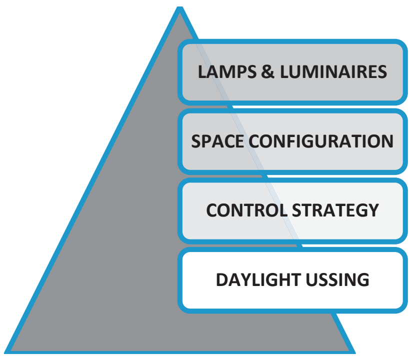

Fig. 1. Energy saving strategies.

2.1. Lamps and luminaires

The efforts to reduce energy consumption are most frequently concentrating on a use of more efficient or more effective lighting systems that would meet required lighting technical parameters. It is generally accepted that more effective transfer of electricity into a visible light requires more expensive lamps and related additional investment costs (ballasts, regulation devices, etc.). As a result, the relation between an acquisition price and a performance is the main obstacle in the effort to convince a user of the installation of energetically more efficient lighting systems. Energy efficient of lamps and luminaires[12]:

- 26 mm diameter fluorescent tubes with high frequency control gear are 25% more energy efficient than the older 38 mm diameter fluorescent tubes with electromagnetic control gear.
- High pressure discharge lamps are up to 35% more energy efficient than the 38mm diameter fluorescent tubes.
- Fluorescent lamp luminaires with open reflectors can be used up to 7m heights effectively. At greater heights use High Pressure Discharge Lamps.
- Modern luminaire and reflector designs have increased the efficient distribution of light by up to 30% over older models.
- By using a combination of general area lighting together with locally switched task lighting, energy savings of up to 20% are possible when compared with a regular array of luminaires providing the full illuminance.
- Modern lamp/luminaire technology, in addition to being more energy efficient, also delivers longer lamp life (up to 50%) with resulting lower maintenance costs.
- Luminaires which utilise energy efficient lamps and control gear also produce less heat. This means that less mechanical cooling is required to maintain working conditions.
- The future of energy-efficient lighting, many experts will tell you, is the solid-state LED (light-emitting diode).

3. Rationalization measures

Within the rationalization measures for the field of lighting technology, certified persons may can use the catalogue of rationalization measures, which is based on the methodology enshrined in standard EN 15193 (Energy performance of buildings - Energy requirements for lighting). It means that, in addition to well-known options of energy savings in the area of lighting, the catalogue also contains the specifics of the methodology of lighting energy consumption calculation. The catalogue need contains the terms of application of particular measures and quantifies the energy savings depending on a specific situation. The rationalization measures are coded according to this system, what makes entering into text documents or into calculation programs easier. The following rationalization measures are identified in a two-level classification of categorie and type (see Table 1) [12].

Table 1. Rationalization measures.

A	**Replacement of Lamps**		
A1	Incandescent Light Bulb	→	Compact Fluorescent Lamp
A2	Incandescent Light Bulb	→	Halogen Incandescent Light Bulb
A3	Halogen Incandescent Light Bulb	→	IRC Halogen Incandescent Light Bulb
A4	Replacement of Linear Fluorescent Lamp	→	Linear Fluorescent Lamp
A5	Linear Fluorescent Lamp T5 HO	→	HE
A6	Mercury Vapor Lamps	→	Sodium Discharge Lamp with Penning Mixture
A7	Sodium Discharge Lamp	→	SUPER
A8	Sodium Discharge Lamp	→	4 Y
A9	Quartz Metal Halide Lamp	→	Ceramic Metal Halide Lamp
A10	Application Of LED Lamps		Application Of LED Lamps
B	**Replacement of Luminaires**		
B1	With Incandescent Light Bulbs	→	With Fluorescent Lamps
B2	With Mercury	→	With Sodium
B3	With Mercury	→	With Metal Halide
B4	With Fluorescent Lamp T12/8	→	With Fluorescent Lamp T5
B5	Classical Ballast	→	Electronic Ballast
C	**Reconstruction of a Lighting System**		
C1	Replacement Of Fluorescent Luminaires T12/8	→	T5 with a change in the luminaire geometry number
C2	Installation of more effective luminaires		

C3	Change in the lighting system geometry in relation to the layout of workplaces		
C4	Zone lighting creation along with workplace layout change in relation to daylight		
D	**Lighting Control**		
D1	Classical ballast	→	Electronic ballast dimmable
D2	Application of R2 control	→	Auto OFF
D3	Application of R3 control	→	motion sensor: Auto ON + dimming
D4	Application of R4 control	→	motion sensor: Auto ON + Auto OFF
D5	Application of R5 control	→	motion sensor: manual ON + dimming
D6	Application of R6 control	→	motion sensor: manual ON + Auto OFF
D7	Application of R7 control	→	photocell: manual ON + dimming to constant illumination
D8	Application of R8 control	→	photocell: switching or dimming depending on daylight
D9	Application of R8 control	→	central control of lighting
D10	Application of R8 control	→	individual dimming
E	**Change in Maintenance System**		
E1	Change in maintenance interval		
E2	Implementation of regular maintenance system		
E3	Implementation of surface cleaning system within maintenance		
F	**Increase in Daylight Use**		
F1	Replacement of windows glazing		
F2	Replacement of windows without a change in window opening geometry		
F3	Replacement of windows with a change in window opening geometry		
F4	Installation of windows with thinner frames		
F5	Installation of skylights into floor structure		
F6	Installation of light guides		
F7	Implementation of regular cleaning of windows		
F8	Painting of walls		
F9	Change in a room geometry		
F10	Change in a room utilization purpose		

3.1. Replacement of lamps

A lamp is a primary component of a lighting system. The luminous and other parameters of the lighting system determine the whole lighting system from lighting and technique point of view, the operational and economic aspects, as well as from the operational maintenance side. The application of lamps depends on their utility properties. The electric lamps are of the greatest importance among artificial light sources. However, it is needed to take into account the fact that many utility properties depend on a luminaire used including a consideration whether it is equipped or not by ballast. The rate of efficiency of a lighting system depends on the right choice of a lamp. [9] [10] Basic parameters that describe the properties of lamps include: Luminous flux (Φ), Specific power (P), Color temperature, Color rendering index (CRI), Rated lifetime. The replacement of lamps is a measure with a considerable potential of savings. At the replacement of lamps, a difference arises in an installed input provided that a luminous flux is equivalent. Therefore, the affected parameter is directly installed input of a lighting system. However, this measure requires to meet certain conditions in order to ensure optical, electrical, technical and operational characteristics of the lamps – therefore, in some cases, a direct replacement of the lamps is possible and in other cases, an indirect replacement is needed, i.e. a simultaneous replacement of a luminaire is required. In addition to the luminous flux, it is necessary to take other photometric properties of the emitted light into account, such as a spectrum and so on, that are the subject matter of the given subchapter. A potential of elementary savings in the catalogue of rationalization measures is laid down based on a detailed calculation of the efficacies and calculations of luminous flux equivalencies for various types of lamps, inputs and manufacturers.

3.2. Renewal of lighting system

Renewal of lighting system presents a larger intervention and requires also a change in an electro-installation. Higher efficacy of lamps and luminaires may be reflected in a change in the number of luminaires (indirect replacement of luminaires) and, in the upshot, in a reduction of the installed load. If it is the case, there are no restrictions and completely new lighting system can be designed with an optimized selection of lamps, luminaires and their layout in a space. Energy saving potential is higher than in the case of a replacement of lamps and luminaires. Within this category of the rationalization measures, also the lighting efficacy is dealt with, in relation to a layout of workplaces, including a zone lighting with daylight utilization. The lighting system should be designed in such a way so that it could be possible to utilize a luminous flux as best as possible. The light should be directed only to the surfaces, where we can utilize it optimally. [5]

4. Space configuration

Space configuration can maximise the use of daylight to reduce the need for electric lighting. Roof lights are particularly efficient as they disperse light evenly over the whole floor area. Paint surfaces (including the ceiling) with matt colours of high reflectance to maximise the effectiveness of the light output. Light/bright colours can reflect up to 80% of incident light; dark/deep colours can reflect less than 10% of incident light.

4.1. Change in Installed Height of Luminaires

A potential of savings by an efficient utilization of the lighting systems can also be reached by appropriately designed installed height of luminaires. The factory buildings, in most cases, are at least 10 m in height, what results in a need to install the luminaires with high luminous flux, or numerous luminaires with lower specific flux as it was proved in the previous subchapter. In most cases, the installed height of a luminaire, 10, 12, 14 m, has its substantiation. The dimensions of the factory buildings are designed for handling the excessive heavy burdens, usually by industrial cranes. The crane rails are mounted as fixed ones in the heights that are necessary for a burden handling, in most cases, in a maximum possible building height. If it is the case, the height of a luminaire lighting point is above the crane rails level and in such a case it is not possible to change the installed height of the luminaire. However, there are rare situations, where a factory building was dimensioned for a crane, but currently it is utilized for different production processes and there is no need to use a crane. In such cases, it is possible to search for an energy saving potential in lighting by a lowering of the installed height of the luminaires to a maximum possible level not obstructing a continuous production process.

4.2. Lighting Zoning

Creation of zone lighting is carried out by a change in a layout of workplaces in relation to daylight by the reason of a creation of more appropriate working conditions. It is possible to create a lighting zone by suitable layout of the luminaires considering the workplaces.

Most of factory buildings is spatially divided into zones, according to the type of performed activities (a basic assembly, a machine operation, handling zones, warehouse premises within a shop, etc.). In such cases, if a reorganization of workplaces within the production process is not expected, it is possible to design the lighting system in such a way that particular zones can be illuminated at the requested level of illuminance by the performed activity type. In most cases, the requested values of the illuminance at the place of visual tasks are provided by a local lighting so as to ensure the specified values of the illuminance when they are higher than the value of illuminance supplied by the general lighting. However, there are cases, when the illuminance requirements for a certain activity in a plant are considerably higher than in other building sections, but the local lighting can not be installed by the reason of handling heavy burdens, or by other technical reasons. In such cases, it is needed to design the general lighting in such a way so as to provide the visual conditions for all working activities. The lighting system designed in this way does not meet a condition of a uniform layout of the luminaires any longer. The luminaires are installed in the space in such a manner so as to ensure the required values of the illuminance for particular zones [2].

5. Lighting control

Lighting control is one of the most progressive spheres in the area of lighting technology, the primary aim of which is to increase a comfort, lighting quality and last, but not least, electricity savings. Within this category of the rationalization measures, the lighting intensity is also dealt with in relation to a layout of workplaces, including a lighting zone with daylight utilization. Increasing number of operators interest in the lighting control in factory buildings by the reason of energy savings. There are especially manufacturing premises, storage premises and related administrative buildings. In these premises, it is needed to ensure a regulationl to a constant lighting intensity, also considering daylight, e.g. skylights in shops or windows in administrative sections of an installation. This system of lighting control is based on:

- Dimming control depending on daylighting intensity
- Monitoring of human presence
- Time scheduling
- Control of constant lighting level and other things. [11]

5.1. Application of electronic ballasts

The discharge lamps that include also fluorescent lamps need for their operation a ballast and a starter. The function of a classic ballast usually holds a ballast choke. The application of classic ballasts is forbidden in the structure of new luminaires, nevertheless, they occur in already installed luminaires, what provides a space for energy savings. [12] Most of luminaires of lighting systems in factory buildings are equipped by high-pressure sodium lamps that need and use the conventional ballast devices for their function of a light production. The conventional ballast device contains an electronic starter, a ballast choke and a compensating condenser. At present, electronic ballasts are increasingly employed. The electronic ballast works with higher frequencies (25 – 70 kHz), while a discharge starting and its stabilization takes also place by an electronic way. The following Figure 2 shows the comparisons of the change in input power, the change in current and the change in luminous flux of a high-pressure sodium discharge lamp depending on a supply voltage using the conventional and electronic ballasts.

The electronic ballasts are able to automatically disconnect burn-out fluorescent lamps. It brings considerable energy savings. The fluorescent lamps with classical ballasts permanently try to start and thus consume quite a lot of current. In addition, such a phenomenon has very adverse effect on a light comfort, tires eyes and produces a nerve tension.

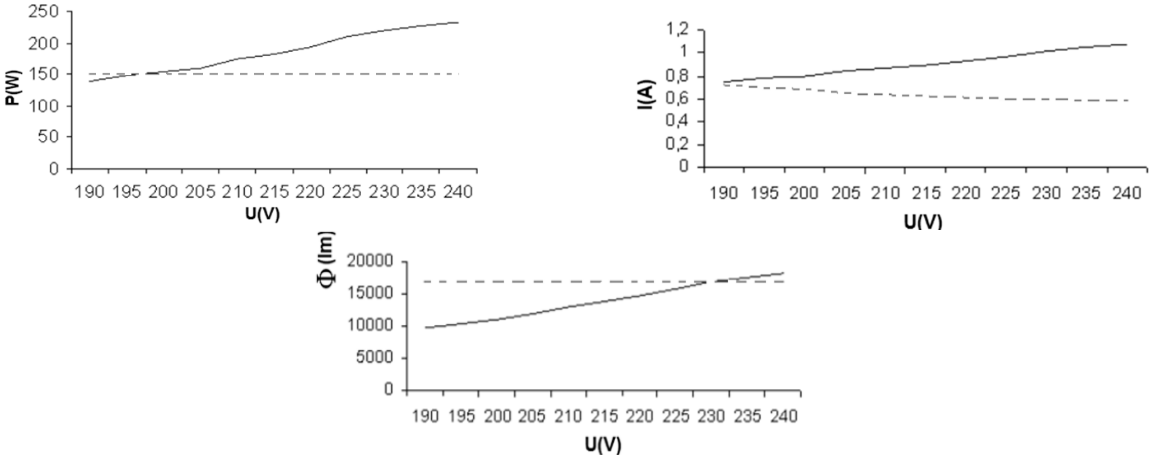

Fig. 2. Dependence of a changes consumption to the supply Voltage ussing : a) P- Input power b) I-Current c) Φ- Luminous flux
Legend: ——— conventional ballast - - - - - electronic ballast.

5.2. Digital addressable lighting interface

The digital ballast has a digital interface at the input, e.g. of DALI type. Lighting dimming saves electricity. The simplest way is the control of lighting by switches. However, this solution does not provide any options of a comfort improvement nor energy savings. Better and still relatively undemanding way is dimming of lighting by electronic dimmers. There are dimmers with a potentiometer, touch sensor or infrared remote control. More sophisticated control systems with a complete lighting system include a standard of the European directive EIB, LON standard and the systems based on this standard, Nikobus system, etc.

DALI (Digital Addressable Lighting Interface) that can be easily integrated within a complex central system of building control is an example of a simple and maximally automated lighting control. In connection with a visualization software (Fig. 3), the whole system can be monitored, set and controlled through a central unit by e.g. a touch panel or PC. Furthermore, the visualization software enables to monitor operational hours of individual luminaires and to display their lifetimes, what contributes to better and more efficient maintenance planning of the whole lighting system. [10]

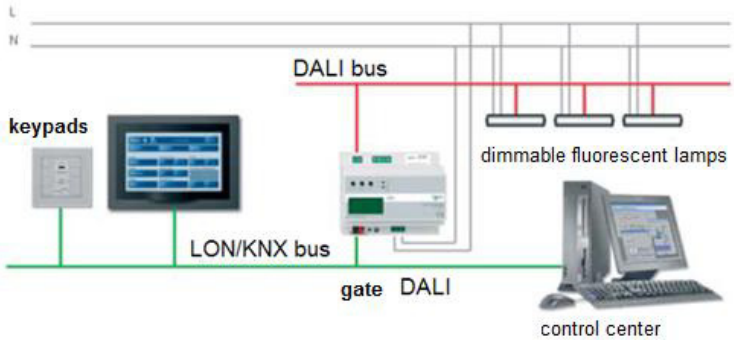

Fig. 3. Principle diagram of control system DALI (Digital Addressable Lighting Interface).

The introduction of time and/or daylight controlled switching can achieve 20-40% savings, with a pay-back period of 2-3 years. The provision of task lighting combined with local switching can achieve up to 20% savings, with a 3 year pay-back. The use of bi-level switching (reduced & normal illumination output) of discharge lamps in unoccupied areas (e.g. warehouses, stock rooms, loading bays) by presence detectors can achieve up to a 15% saving in energy. Where there are large spaces with the necessity to have a large number of lamps (either fluorescent or discharge type) switched on for extended periods, energy limiting devices can be very effective. These devices consist of auto-transformers which, once the lamps have been switched on and are stable, automatically reduce the voltage/current to the lighting circuits by 10-20%. The consequent reduction in light output is only 5-10%.

6. Daylight utilization

Daylight is of extraordinary impact on energy savings. The measures made in this respect especially include investment costs and almost no future costs, compared with other measures (daylight is for free). Daylight can be controlled by use of venetian blinds, roller blinds, marquises, redirecting, and special glazing and so on, in existing buildings. The options how to increase daylight utilization are also installation of skylights into a ceiling structure, installation of light guides, regular window cleaning, painting the walls, change in a space geometry and a space utilization purpose. [9]

7. Lighting system maintenance

The regular maintenance is very important for the efficiency of the lighting system. Therefore, the maintenance must be carried out in regular intervals. A correctly scheduled maintenance plan helps to maintain the illumination, reduce investment and operational costs and operate the system safely. The plan of maintenance is to include [9]:

- Interval of maintenance execution,
- Description of activities performed within the framework of a regular maintenance,
- description of activities performed within the framework of extraordinary maintenance (service action),
- Way of luminaires and surfaces cleaning.

Conclusion and discussion

Globally about 75% of all power plant generated electricity is used just to operate buildings. By adopting and enforcing intelligent and energy saving strategies we can assure the energy efficiency of buildings. Staff should be actively involved in energy saving also. Without their co-operation most control strategies will not be successful, because energy savings are not being made at the expense of their lighting conditions. Properly designed and implemented energy efficient lighting schemes will not degrade the working environment. Progressive and an achievable targets for lighting systems in industry is 1-3W / m^2 / 100 lx. Saving energy is good business for everyone. In this contribution we have shown how, at a national or a corporate level, energy efficient lighting can be an important part in industrial and business sustainability strategy.

Acknowledgements

This work was supported grant project APVV 0432/12.

References

[1]Matijević, M., Mrvac, N., Milković, M., Pavlović, I., Mikota, M. (2009). Evaluation of the perception of stimulus contrast in light tones of additive synthesis. In Annals of DAAAM for 2009 & Proceedings of the 20th International DAAAM Symposium (Vol. 20, No. 1)

[2]Trandabat, A. F.; Pislaru M. (2010).Distributed measurements system for active energy saving.(Report)." Annals of DAAAM & Proceedings. DAAAM International Vienna. 2010 (Vol. 21, No. 1).

[3]Gastermann, B.C.; Stopper, M. & Katalinic, B. (2012). Adapting CONWIP Characteristics for Conventional Production Planning, Chapter 46, In: DAAAM International Scientific Book 2012, pp. 553-564, ISBN 978-3-901509-86-5, ISSN 1726-9687, B. Katalinic (Ed.), Published by DAAAM International, Vienna, Austria.
[4]Wessely, E; Kralikova, R; Krupa, M; Beneova, A (2009)Using of computer intelligence for design of lightning systems in industry plants, In Annals of DAAAM for 2009 & Proceedings of the 20th International DAAAM Symposium (Vol. 20, No. 1)
[5]Civic, A., & Vucijak, B. (2014). Multi-criteria Optimization of Insulation Options for Warmth of Buildings to Increase Energy Efficiency. Annals of DAAAM & Proceedings. Procedia Engineering, 69, 911-920.
[6] Nedelcu, A. V., Duguleana, M., Sandu, F. (2014). Evaluating the Energy Overhead Generated by Interferences within the 2.4 GHz Band for a Hybrid RFID Network. Procedia Engineering, 69, 210-215
[7] Badida, M; Kralikova, R; Lumnitzer, E.(2011)Modeling and the Use of Simulation Methods for the Design of Lighting Systems .In. ACTA POLYTECHNICA HUNGARICA, (Vol. 8, No. 2) 91-102
[8] EN 12 464-1: Light and Lighting standard.
[9]Habel, J., Tak, P. (2010) The Energy Performance Lighting Systems. In.: Light, FCC Public s. r. o., Prague. (Vol.11, No.4.)
[10]Tak, P.(2009) Lighting Design and Energy Savings. In: Light. FCC Public s. r. o., Prague, (Vol. 10, No.2).
[11]Dlugopolsky, J.(2010) Eefficient lighting control in intelligent buildings,. Technologies for buildings. In: AT&P Journal, , HMH, s.r.o, Bratislava. (Vol.15, No. 3)
[12]Kralikova,R., Badida,M., Kevicka, M. (2013) Radiosity Methods in the Lighting Research. In: Annals of Faculty Engineering Hunedoara. (Vol. 11, no. 4) 33-38.
[13]Kralikova, R., Badida, M.,Sobotova, L., Dobrovic, J. (2014) Approach to Design of Energy Saving Illumination in Industry Plants.. In: SGEM 2014. 14th international multidiscilinary scientific geoconference. STEF92 Technology Ltd., Sofia. (Vol.14, No.1). 37-43.