Original Article

Energy-efficient lighting design: A case study in an exclusive spa project

Received (in revised form): 18th December 2008

Rusdy Hartungi
is a prominent expert in sustainable engineering technology. Before his appointment at The University of Central Lancashire, he was working for many years in Consulting Engineer in the United Kingdom and abroad including Switzerland, Austria and the Netherlands. Dr Hartungi is an active member of Chartered Institution of Building Services Engineers (CIBSE) and Institution of Electrical Engineer (IEE/IET). He is one of very few UK chartered engineers who has gained international recognition as a member of the International Professional Engineers (IntPE UK) as well as European Engineer (Eur Ing).

Correspondence: Rusdy Hartungi, School of Built and Natural Environment, Kirkham Building, University of Central Lancashire, Preston, Lancashire PR1 2HE, UK

ABSTRACT This research investigates and analyses the use of energy-efficient lighting design in an exclusive spa project in the southwest of England. The originality of this work is the area of investigation, which is in an exclusive spa. Before this study, hardly any investigation has been done in this kind of building, as many previous studies focused on energy-efficient lighting in office buildings. The main area of this investigation includes the study and analysis of the good practice of energy-efficient lighting. The method used in this case study is to some extent similar to ethnographic research because the researcher was heavily involved in the energy-efficiency lighting design as a lead building services design engineer from stage B to stage K of the Royal Institute of British Architects (RIBA) plan of work. The major findings in this case study are that the energy-efficient lighting design could still be achieved without sacrificing the visual comfort and aesthetic requirement of the building, which are a critical feature of an exclusive spa. Energy-efficient lighting could be implemented if it is considered right from the early design stage.
Journal of Building Appraisal (2009) **4,** 287–299. doi:10.1057/jba.2009.1

Keywords: energy-efficient lighting; spa; daylighting; energy; sustainability

INTRODUCTION

The use of energy in buildings has increased in recent years because of the growing demand in energy used for heating, ventilating and air conditioning (HVAC) and lighting in buildings. Owing to the consistently growing demand, much effort has now been put towards reducing the demand for energy through energy efficiency in design. Energy efficiency is energy intensity, which, in simple terms, refers to the use of less energy to provide the same level of energy service or to do more work with the same unit of energy (EIA;[1] IEA;[2] Fickett *et al*, 1990). This objective can be achieved primarily by using a more efficient technology or process rather than by changes in individual behaviour (Diesendorf, 2007).

For many years it has been suggested that the widespread adoption of energy-efficient technologies, especially within commercial sectors, is a cost effective way of reducing the demand for energy in buildings (Fickett *et al*, 1990; Lovins, 1990). Other studies indicate that improvements in energy efficiency in buildings will reduce energy-related environmental problems (Star, 1993; Levine *et al*, 1995; Hollander and Schneider, 1996; Kamal, 1997; Reddy and Parikh, 1997).

The amount of energy consumed in a building might vary depending on the building envelopes and the building fabric (Piette *et al*, 1995; Kamal, 1997). But, most importantly, it depends on how the HVAC equipment and lighting systems are operated and controlled (Levine *et al*, 1995). Reduction in the amount of energy consumption might be achieved, if it is considered early in the design stage. Apparently, the HVAC systems consume the most energy in a building. However, in commercial buildings, such as in a spa project, lighting consumes a significant percentage of building energy use and accounts for 30–40 per cent of the total building energy use (Swisher *et al*, 1994; Yarnell, 1995; Li and Lam, 2003). Therefore, if reducing the demand for energy use in building is to be achieved, energy-efficient lighting design has to be considered seriously.

Lighting systems and energy efficiency

It has been reported that around 30–40 per cent of the total building electricity energy used in many commercial buildings is consumed by the lighting systems (Swisher *et al*, 1994; Yarnell, 1995; Li *et al*, 2002). Research shows that a fair number of newly built buildings are still not designed in the way that the energy is used efficiently (Littlefair, 1996; Li and Lam, 2001). There are several instances in which lighting energy in the building has not been used efficiently. This could be because daylight is not efficiently integrated with the artificial lighting system, or in cases where integration does exist, energy savings using energy-efficient lighting technology have not been fully explored.

Many studies have revealed that proper use of sustainable technology in lighting, such as the use of daylighting controls and low energy lighting, has a strong potential for reducing the demand for energy in commercial and industrial buildings (Busch *et al*, 1993; Nilsson and Aronsson, 1993; Min *et al*, 1997; Knight, 1999; Kim and Mistrick, 2001) and there is potential for improving the energy efficiency of lighting systems throughout the world (Mills and Piette, 1993). A recent survey of several companies has found that 23 per cent of all energy-saving opportunities could be achieved by improving the energy efficiency of lighting systems (BIE, 1996).

The present study and its originality

Although there have been several studies investigating energy efficiency in lighting design in buildings, many of these studies are focusing on office buildings or commercial buildings other than spa buildings (see, for instance, Santamouris *et al*, 1994; Fu Min *et al*, 1997; Kim and Mistrick, 2001; Li and Lam, 2001; Atif and Galasiu, 2003). There is hardly any study that investigates energy-efficient lighting in an exclusive spa project. The distinctive feature of lighting design in an exclusive spa is the use of a lot of feature and spot lighting as premier customers expect that the spaces are attractively lit. An attractive lighting system will help to maintain the aesthetic features, warm welcoming atmosphere while highlighting the exclusive features of the building, The distinctive features of an efficient lighting design in an exclusive spa project, which differentiate them from office lighting, make the lighting design in the exclusive spa worthy of investigation.

METHODOLOGY

This is a real case study of an exclusive spa project in the southwest of England in which energy-efficient lighting has been used. The main reason for the selection and investigation of this case is that there are many good practices of energy-efficient lighting that can be identified and analysed. The method used in this case study is, to some extent, similar to ethnographic research as the researcher was directly involved in the energy-efficient lighting design as a lead building services design engineer from stage B (strategic brief) to stage K (construction to practical completion) of the RIBA plan of work. RIBA plan of work is an internationally recognised process of managing and designing building projects and administering building contracts into a number of key work stages (RIBA[3]; Churcher, 2006).

AIMS AND OBJECTIVES

The main objective of this study is to demonstrate that energy-efficient lighting design is not only applicable to typical office buildings but is achievable in luxurious spa buildings as well. In addition, to obtain a clear understanding of how energy-efficient lighting can be achieved, the most feasible and sustainable technique needs to be identified.

To achieve the above objectives, this study investigates and analyses the use of sustainable energy in lighting, which includes:

– Daylight harvesting technology and making the most of daylight, such as heliostat light catcher and light tube.
– The use of high efficacy lamps with energy-efficient control gear.
– Using the cutting edge technology of Solid-State Lighting, such as light-emitting diode (LED) lighting.
– Reducing the energy demand for lighting, controlling the use of lighting such as by using daylight-linked control, occupancy-linked control and localised switching.

A BRIEF DESCRIPTION OF THE PROJECT IN CASE STUDY

Project X is a new luxurious spa project in the southwest of England. This project is part of the extension of the existing five star hotel that was completed a few years ago. As shown in Figure 1, project X mainly comprises an outdoor and indoor swimming pool, treatment rooms, steam rooms, saunas, spa, health club, beauty centre, restaurant and bar, gym, changing and shower rooms.

In general, the design of project X is based on the aspiration for high-quality architectural design, visual transparency from inside to outside and with high emphasis on sustainability.

Low-profile construction is required in keeping with the original walled courtyard and surrounding landscape. For this reason, a basement area has been formed for plant, distribution of services and storage in order to keep the height of the building to a minimum and avoid taking up ground floor area.

The sustainability concept of the design for this project includes the following main features:

– Pool area – high-performance roof glazing with external moveable shading spanning steel rafters.
– Planted trees to provide shading in summer and allowing the sun at a low angle to penetrate below the canopy.
– High level of glazing for daylight and views of the outside.
– Use of low-energy lighting to be enhanced with good lighting control.
– Use of daylight harvesting technology.

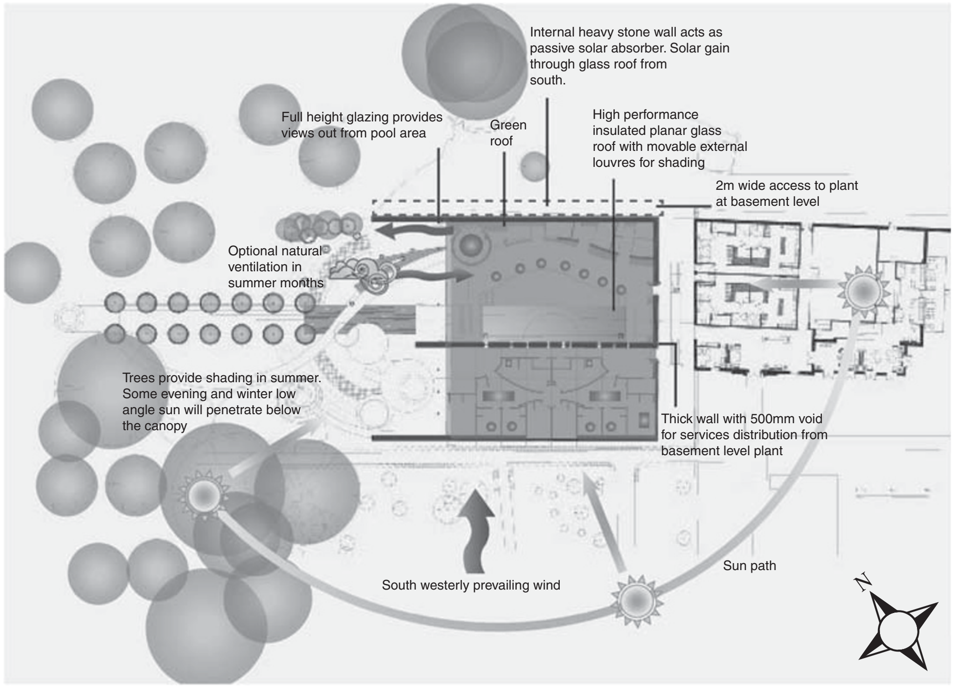

Figure 1: Project X with sustainability features.

– Use of low-energy M & E equipments.
– Preliminary ideas for alternative energy sources and renewable energy.

In terms of an energy-efficient lighting design in this project, it is important to recognise that this objective is only met if the energy-efficient feature is achieved without sacrificing the visual comfort and aesthetic value of this luxurious spa project.

In this paper only the features that directly relate to energy-efficient lighting design will be explored and analysed.

HARVESTING DAYLIGHTING

Daylight makes an important contribution to the lighting of an interior and may provide supplementary illumination for substantial periods in some buildings. The major factors affecting the daylighting entering the building depend on the depth of the room, the size and location of windows and rooflights, the glazing system and any other external obstructions (CIE, 1994; Bell and Burt, 1995; Littlefair, 1996).

Appropriate planning at the design stage might produce a lighting system that will be more energy efficient and will have a pleasing internal and visual appearance. The design engineer may be able to have a greater influence at the design stage in improving daylight intensity in the building. Research in the United Kingdom has shown that significant improvements in building energy efficiency are possible through the use of daylight as a passive solar design option (Knight, 1999).

The main feature of daylight harvesting in this spa project is the use of heliostats as a daylight catcher (Figure 2). It is further enhanced through the use of light tubes and automatic louvres (Figure 3). What makes project X efficient in lighting design is the provision of these alternatives early in the design stage.

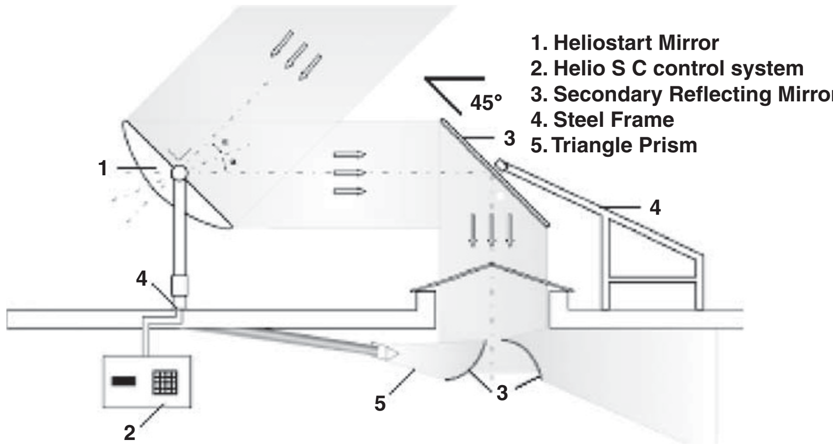

Figure 2: The heliostat principles.

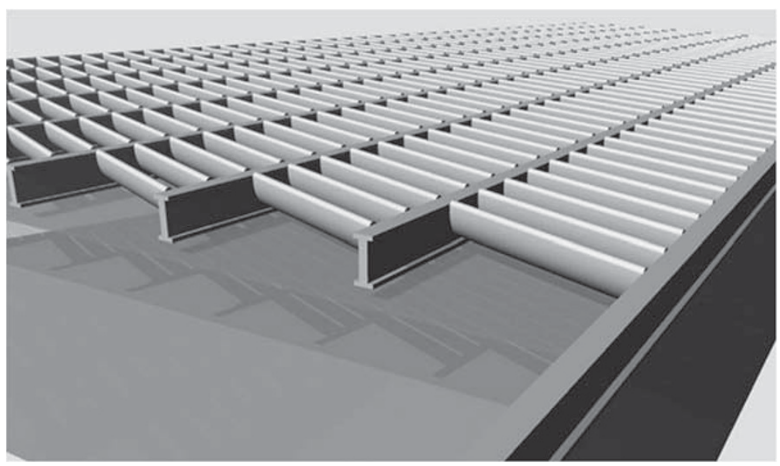

Figure 3: Computer visualisation of automatic shading louvres.

Daylight harvesting using heliostats and an automatic shading system in project X

In the project brief, the requirement of low-profile construction in order to keep the original walled courtyard and surrounding landscape in place has been highlighted. This is certainly a major challenge if the daylight factor is to be maximised in the building as height if the glazing is limited. The way to overcome this is to maximise daylight harvesting from the rooftop.

In this project, a heliostat daylight catcher is installed on the rooftop to track the movement of the sun by sensing its position throughout the day. The sensing equipment of the heliostat is used to orient a projection mirror that is part of the heliostat and throughout the day it is used to project sunlight along a fixed axis towards a stationary target in the pool and restaurant areas.

The harvesting of the daylight through the rooftop also affects the thermal performance of the building as the glazed roof also admits solar gain. In summer time when a lot of solar radiation enters the building, there might be an overheating problem. Therefore, it is important to find a solution to avoid overheating in summer. In this project, this is achieved by the use of an automatic shading system, which is an automatic louvre mounted on the rooftop.

Energy-efficient lighting system in an exclusive spa without seeing it in the context of the total design could lead to lit environments that are perhaps inappropriate, uncomfortable or unpleasant, for the spa customers and staff, all of which might lead the spa investors run out of business. So, in an energy-efficient lighting design a holistic approach that considers customers' needs, cost implication should be fully considered. The decision to install the automatic shading system (louvre) and heliostat was fully coordinated with the architects, the structural engineer, project management and the quantity surveyor (QS) team. The architect has to consider the aesthetic feature; the structural engineer is more concerned with the load on the rooftop, while the QS team is concerned with assessing the cost implication.

Daylight using a light tube

The treatment rooms of these spa projects are on the other side of building, opposite the pool and restaurant areas. Owing to the construction load issue as well as the cost implication, it is difficult to increase the size of the automatic shading system to cover these areas. The way to overcome this is to install a distributed daylight technique using light tubes (Figure 4). Therefore, daylight harvesting in these areas is basically achieved through the use of light tubes. Generally speaking, this light tube is a transparent round tube that is used to transport natural light. The light tube, which is lined with highly reflective material, leads the light rays through the rooms, starting from an entrance point located on its roof. The entrance point comprises a dome, which has the function of collecting and reflecting as much sunlight as possible into the tube. They have directional 'collectors', 'reflectors' that assist in collecting and directing light down the tube.

Light transmission efficiency in the light tube is greatest if the tube is short and straight (Jenkins and Muneer, 2003; Canziani *et al*, 2004; Zhang and Muneer, 2005). In longer, angled, or flexible tubes, part of the light intensity is lost. In project X, the tubes throughout the treatment rooms are made as short as possible. In addition, to minimise losses, high reflectivity of the tube lining is used. Light tubes used in the treatment rooms are then supplemented with decorative lighting, mainly from LED lighting, to enhance the aesthetics while maintaining the exclusivity of the luxurious spa project (Figure 5).

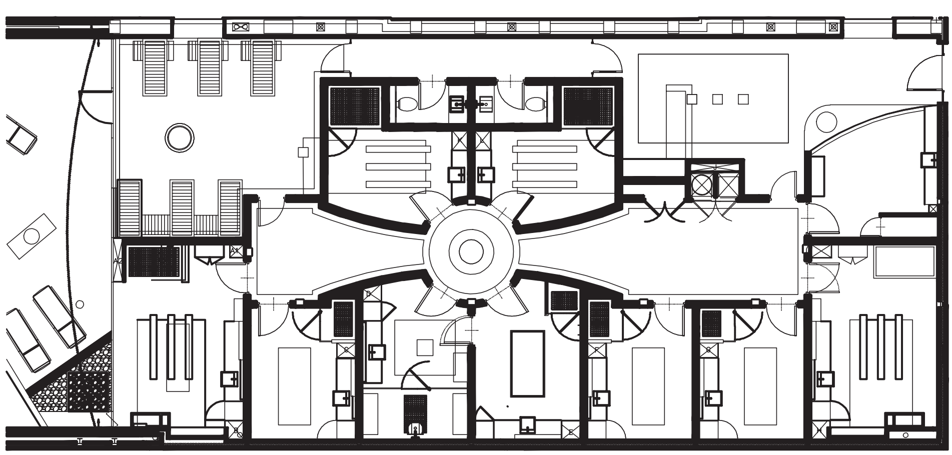

Figure 4: Example of the use of light tube in the treatment rooms.

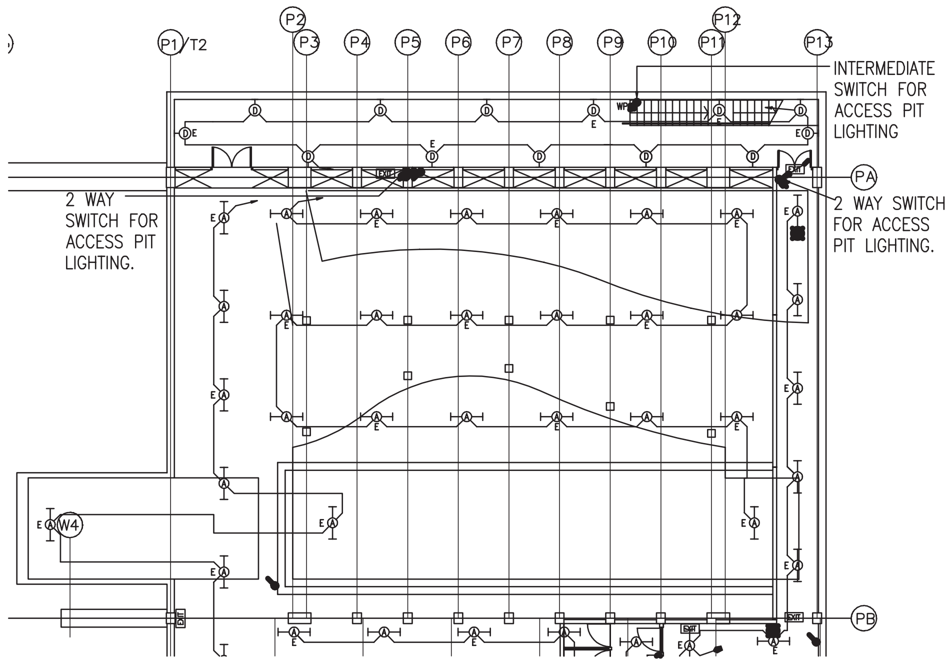

Figure 5: Example of the layout of high efficiency luminare in the basement plant room.

USE OF ENERGY-SAVING AND HIGH EFFICACY LUMINAIRES

One way to demonstrate energy efficiency in lighting design is to show compliance with approved document – Part L of the Building Regulations for England and Wales. The approved document requires a luminous efficacy greater than 40 lumens per circuit-watt. Circuit-watts means the power consumed in lighting circuits by lamps and their associated control gear and power factor correction equipment. The efficacy of luminaires could be achieved by careful selection of lamps, control gear and power factor correction equipment. Scientists in lighting agree that the most efficient luminaires are associated control gear and the lamps (Bevington and Rosenfeld, 1990; Mills and Piette, 1993; Yarnell, 1995).

In the general areas of the existing hotel, which was completed before project X, were constructed, the conventional T12, 38 mm diameter, fluorescent lamps are used. In the new spa project energy-efficient luminaires with T8 lamps with electronic control gear have been used in the back house areas, such as in the plant room, storage and switch room. T8 luminaires consume 25 per cent less energy in giving the same light output as the T12 lamps. T8 lamps use greater phosphor technology such that they can produce the required light output from a smaller surface area and smaller diameter. A smaller diameter lamp consumes lesser energy, which in turn enables more efficient production of light within the lamp.

Table 1 shows nominal input wattages and efficacy (lighting efficiency in lumens/watt) for T12 and T8 fixtures with comparable light output.[4]

In line with the visual comfort requirement defined by the standard (BS EN, 12464, 2002, Part 1; CIBSE Guide A, 2006), the task lighting for working areas in the kitchen, such as above bench and workbench, is to brighten the kitchen to the required illuminance level of at least 500 lux. This is, to some extent, to save energy as the other areas around the kitchen are provided with illuminance level of only about 300 lux.

Table 1: Nominal input wattages and efficacy (lighting efficiency in lumens/watt) for T12 and T8 fixtures with comparable light output

Number of lamps	*T12 with magnetic ballast*		*T8 with electronic ballast*	
	Input watts	*Efficacy (lumens/watt)*	*Input watts*	*Efficacy (lumens/watt)*
2	72	73	58	94
4	144	73	112	97

Source: Alliant Energy (see Note 4).

The use a high-efficacy luminaire in the general areas of this spa project and task lighting in certain areas enhances the energy performance of this building.

USE SOLID-STATE LIGHTING

Solid-state lighting used in this spa project refers to a type of lighting that utilises LED as sources of illumination rather than electrical filaments, plasma or gas. LED lighting has been widely recognised as one of the most efficient lamps (Foster, 2005). In this project, LED lighting is used primarily for underwater swimming pool lighting and the lighting around the bar and the restaurant counters. In term of energy efficiency, LED lighting consumes much less power than the traditional low-voltage underwater luminaires (Figure 6). Both the white and multi-colour LED lights are used in this project. The colour change multi-colour LED, which continuously changes the colour modes, enhances the aesthetic feature and preserves the exclusive features of this exclusive spa project. In the bar, restaurant counters area, LED down lighters are used in lieu of the conventional halogen. They are typically 2 watts, compared with the 35 watts of a halogen droplight, which are currently used in the existing hotel.

LIGHTING CONTROL STRATEGY FOR ENERGY-EFFICIENT LIGHTING

Appropriate lighting controls can result a substantial improvements in lighting energy efficiency (Calwell *et al*, 1999; Li and Lam, 2001). These improvements arise principally from the utilisation of available daylight to reduce electric lighting use and from switching off electric lighting when a space is unoccupied (Calwell *et al*, 1999; Li and Lam, 2001; Onaygil and Gutler, 2003).

In the project, various lighting control techniques have been used to improve energy efficiency in lighting. The four basic methods of lighting control: daylight-linked control, time-based control, occupancy-linked control and localised switching, can be achieved in a number of ways.

Daylight control

Lighting control integrated with daylighting is recognised as an important and useful strategy in energy-efficient building designs and operations (Slater *et al*, 1996). Treado and Kusuda (1980) argue that if daylight entering through window can be used appropriately, controlled and dimmed, very large energy saving can be expected. Furthermore, it has been reported that, in daylight corridors, photoelectric lighting controls can give excellent energy savings (Slater *et al*, 1996; Li and Lam, 2003). The energy-saving potential of dimming control of electric light with the integration of daylight control is significant and this mode of control is acceptable to the occupants (Slater *et al*, 1996).

Recognising energy efficiency through the provision of daylight control, daylight control techniques are used mainly in the swimming pool hall. This daylight control is

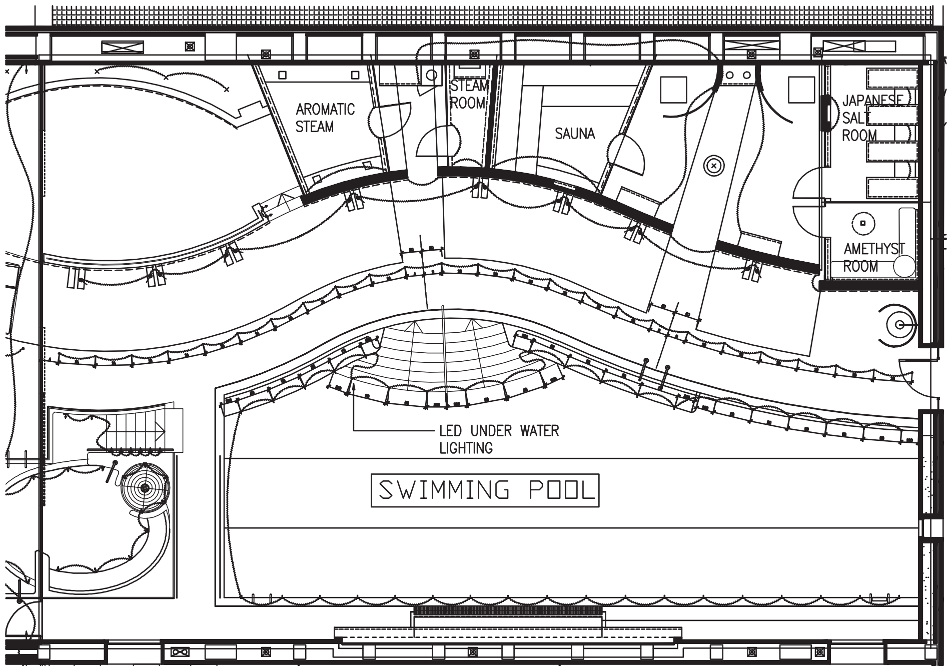

Figure 6: Example of the use of LED lighting for underwater lighting in the swimming pool.

integrated with the automatic louvre on the rooftop as well as the daylight sensor. The daylight control system in this project ensures that the sum of daylight and electric lighting always reaches the design level by sensing the total light in the swimming pool and adjusting the output of the electric lighting to top up the daylight. If daylight alone reaches the luminance level of 300 lux in the swimming pool hall, electric lighting is dimmed to extinction.

Time base control

Research has shown that the probability of switching off the lights in the general areas when they are not needed is very low (Slater *et al*, 1996). So one way to overcome this problem and save energy in lighting is by recognising this building occupant behaviour. The provision of time base control of lighting in particular areas of the building can overcome this problem. Time base control of the lighting system in this project is used along the corridors to ensure that the lighting is switched off when it is not needed. Time signals in this project are derived from multi-position solid-state switches. These signals are then transmitted to the luminaires through a communications channel. This is achieved through mains wiring themselves to receivers in each luminaire. The local override switch is provided for group control of lighting so that lighting can be restored from the central control system.

Occupancy-linked control

As argued by Slater *et al* (1996), the probability of switching off the lights in the general areas when is not needed, is very low. Moreover, it is sensible not to expect the visitors of an exclusive spa to switch off the lights when they are not needed. So one way to overcome the problem of switching off the lights in the areas such as in the toilets, particularly storages, is through the provision of occupancy-linked control.

In project X, occupancy-linked controls are used in the general areas such as the toilets, particularly storages. Occupancy linking is achieved by using a passive infra-red (PIR) detector, which detects the movement of the building's occupants. These PIR dectectors will switch the lighting on when occupancy is detected and off again once they have failed to detect occupancy for a set time. In this project a time delay built into the system is provided, in anticipating that the occupant may remain still or quiet for short periods while remaining in the space but would not wish the lighting to be extinguished before he has actually left.

Localised switching

Localised switching is important where only small part of a large space requires the electric lighting to be on, either because the other parts are unoccupied or because daylight there is adequate. Studies in open offices have shown wide variations in user preference for lighting with some occupants switching their lighting on under almost all conditions and others doing so only on rare occasions (Nilsson and Aronsson, 1993). This produces noticeable energy savings compared with the common situation where the lighting in the entire space is controlled with a single switch.

In project X, localised switches are provided in the large plant room in the basement areas.

The light switches are arranged according to a zoning system, allowing the connection of luminaires in groups and to be switched on/off in rows. This allows the people who enter the plant room to only switch the light in the space that needs to be lit.

DISCUSSION AND CONCLUSION

A holistic approach to lighting design to achieve energy efficiency in building, which considers all the requirements and constraints in spa buildings, is necessary. Energy efficiency in an exclusive spa, without seeing it in the context of the total design, could lead to lit environments that are perhaps inappropriate, uncomfortable or unpleasant, for the spa customers and staff, all of which could lead to an unsustainable solution in terms of the existence of the spa. In the spa project, it has been shown in this case that the holistic approach early in the design stage, which involves a multi-disciplinary design team of engineers, architects, project management and QS, will lead to innovative solutions in which energy efficiency can still be achieved. This is because in the early stage the major decisions, such as the lighting control strategy, how to harvest the daylight, as well as the use of highly efficacy luminaires, are made in coordination and consultation with other teams. It has been shown in this project that energy-efficient lighting can still be achieved without sacrificing the visual comfort and aesthetic value of a luxurious building.

Although the benefit of energy efficient lighting design is undoubtedly clear, there are still barriers in the implementation of energy efficient lighting. Various barriers have been identified in the previous researches such as: lack of information and confidence, the influence of particular industrial lobbying, and lack of legislation to encourage its use.

Lack of information and confidence

Architects, decision makers and the public tend to be ignorant of the possible benefits of daylighting design and few studies of the economic aspects are available. (Hollander and Schneider, 1996; Fu Min *et al*, 1997). From the client's perspective, many clients are not aware of potential of the long-term energy saving that could be converted to a money-saving exercise. In China, for instance, there is a common perception that the energy-efficient lighting is something that '*saves energy but not money*' because of the high cost of investment. Moreover, when the cheaper poorer quality products of energy-efficient lighting technology are being installed, some consumers lose all confidence in the technology (Fu Min *et al*, 1997). This is all due to lack of information, which, in turn, creates lack of confidence. In fact, research shows the potential of long-term saving of the lighting system during the life cycle of the building.

The influence of particular industrial lobbying

There is a strong industrial lobby in favour of artificial lighting from electric utilities and international manufacturers, which has no pro-daylighting equivalent (Fu Min *et al*, 1997).

Lack of legislation to encourage its use

In the United Kingdom, energy efficiency in term of energy conservation is covered by the four Approved Documents (Parts L) of the Building Regulations (April 2006) for England and Wales. In terms of lighting design, 'The aim of the Regulations is to improve the overall energy efficiency of lighting installations without limiting the quality of lighting design.'

The lighting regulations for compliance with Part L are divided into the following four sections:

– L1A Conservation of fuel and power in new dwellings;
– L1B Conservation of fuel and power in existing dwellings;
– L2A Conservation of fuel and power in new buildings other than dwellings;
– L2B Conservation of fuel and power in existing buildings other than dwellings.

However despite all of these regulations, it is still insufficient to persuade people to use more energy efficient lighting design.

Nevertheless, in this project it has been demonstrated that that energy-efficient lighting can be achieved in the building which traditionally known as a high lighting energy consumption building.

NOTES

1 EIA, Energy Information Administration, the official energy statistics from the US government http://www.eia.doe.gov/.
2 IEA (The International Energy Agency), an intergovernmental organisation that acts as energy policy advisor to 28 member countries in their efforts to ensure reliable, affordable and clean energy for their citizens, http://www.iea.org/.
3 RIBA is the UK body for architecture and the architectural profession, http://www.architecture.com/TheRIBA/Home.aspx.
4 Alliant Energy, Alliant Energy Corporation is a regulated, investor-owned public utility holding company, http://www.alliantenergy.com/.

REFERENCES

Atif, M.R. and Galasiu, A.D. (2003) Energy performance of daylight-linked automatic lighting control systems in large atrium spaces: Report on two field-monitored case studies. *Energy and Buildings* 35(5): 435–531.

Bell, J. and Burt, W. (1995) Designing Buildings for Daylight. The Building Research Establishment (BRE- BR288).

Bevington, R. and Rosenfeld, A.H. (1990) Energy for buildings and homes. *Scientific American* 263(3): 39–45.

BS EN 12464. (2002) Light and Lighting – Lighting of Work Places Part 1: Indoor Work Places. British Standard Institution (BSI).

Bureau of Industry Economics (BIE). (1996) Energy Efficiency and Greenhouse Gas Abatement – The Role of Co-operative Agreements in Australia. Canberra: Australian Government Publishing Service. Report 96/5.

Busch, J.F., Du Pont, P. and Chirarattananon, S. (1993) Energy efficient lighting in Thai commercial buildings. *Energy – The International Journal* 18(2): 197–210.

Calwell, C., Granda, C., Gordon, L. and Ton, M. (1999) Lighting the Way to Energy Savings: How Can We Transform Residential Lighting Markets? Natural Resources Defence Council.

Canziani, R., Peron, F. and Rossi, G. (2004) Daylight and energy performances of a new type of light pipe. *Energy and Buildings* 36(11): 1163–1176.

Churcher, D. (2006) A Design Framework for Building Services. A BSRIA Guide BG 6/2006.

CIBSE Guide A. (2006) *Environmental Design*. The Chartered Institution of Building Services Engineers.

CIE Technical Report. (1994) Guide to Recommended Practice of Daylight Measurement. Commission Internationale De L'eclairage (CIE 108–1994).

Diesendorf, M. (2007) *Greenhouse Solutions with Sustainable Energy*. New South Wales, Sydney: UNSW Press.

Fickett, A.P., Gellings, C.W. and Lovins, A.B. (1990) Efficient use of electricity. *Scientific American* 263(3): 29–36.

Foster, R. (2005) Light-Emitting Diodes: A Guide to Technology and Its Application. Building Services Research and Information Association. BSRIA Guide BG3/2005.

Fu Min, G., Mills, E. and Zhang, Q. (1997) Energy efficient lighting in China: Problems and prospects. *Energy Policy* 25(1): 77–83.

Hollander, J.M. and Schneider, T.R. (1996) Energy efficiency: Issues for the decade. *Energy – The International Journal* 21(4): 273–287.

Jenkins, D. and Muneer, T. (2003) Modelling light-pipe performances – A natural daylighting solution. *Building and Environment* 38(7): 965–972.

Kamal, W.A. (1997) Improving energy efficiency – The cost-effective way to mitigate global warming. *Energy Conservation and Management* 38(1): 39–59.

Kim, S.Y. and Mistrick, R. (2001) Recommended daylight conditions for photo sensor system calibration in a small office. *Journal of the Illuminating Engineering Society* 30(2): 176–188.

Knight, I.P. (1999) Measured energy savings due to photocell control of individual luminaires. *Lighting Research and Technology* 31(1): 19–22.

Levine, M.D., Koomey, J., Price, L., Geller, H. and Nadel, S. (1995) Electricity end-use efficiency: Experience with technologies, markets, and policies throughout the world. *Energy – The International Journal* 20(1): 37–61.

Li, D.H.W. and Lam, J.C. (2001) Evaluation of lighting performance in office buildings with daylighting controls. *Energy and Buildings* 33(8): 793–803.

Li, D.H.W. and Lam, J.C. (2003) An investigation of daylighting performance and energy saving in a daylit corridor. *Energy and Buildings* 35(4): 365–373.

Li, D.H.W., Lam, J.C. and Wong, S.L. (2002) Daylighting and its implications to overall thermal transfer value (OTTV) determinations. *Energy – The International Journal* 27(11): 991–1008.

Littlefair, P.J. (1996) Designing with Innovative Daylighting. Building Research Establishment Report (BRE-BR 294).

Lovins, A.B. (1990) Four revolutions in electric efficiency. *Contemporary Policy Issues* 8(3): 122–141.

Mills, E. and Piette, M.A. (1993) Advanced energy-efficient lighting systems: Progress and potential. *Energy – The International Journal* 18(2): 75–97.

Min, G.F., Mills, E. and Zhang, Q.I. (1997) Energy efficient lighting in China. Problems and prospects. *Energy Policy* 25(1): 77–83.

Nilsson, P. and Aronsson, S. (1993) Energy-efficient lighting in existing non-residential buildings: A comparison of nine buildings in five countries. *Energy – the International Journal* 18(2): 115–122.

Onaygil, S. and Gutler, O. (2003) Determination of the energy saving by daylight responsive lighting control systems with an example from Istanbul. *Building and Environment* 38(7): 973–977.

Piette, M.A., Nordman, B., De Buen, O. and Diamond, R. (1995) Findings from a low-energy, new commercial-buildings research and demonstration project. *Energy – The International Journal* 20(6): 471–482.

Reddy, B.S. and Parikh, J.K. (1997) Economic and environmental impacts of demand side management programmes. *Energy Policy* 25(3): 349–356.

Santamouris, M., Argiriou, A., Dascalaki, E., Balaras, C. and Gaglia, A. (1994) Energy characteristics and savings potential in office buildings. *Solar Energy* 52(1): 59–66.

Slater, A.I., Bordass, W.T. and Heasman, T.A. (1996) People and Lighting Controls. BRE Information Paper IP 6/9.

Star, C. (1993) Global energy and electricity futures. *Energy-The International Journal* 18(3): 225–237.

Swisher, J., Christianson, L. and Hedenstrong, C. (1994) Dynamics of energy efficient lighting. *Energy Policy* 22(7): 581–594.

Treado, S. and Kusuda, T. (1980) Daylighting Window Management Systems and Lighting Control. National Bureau Standard, NBSIR, pp. 80–2147.

Yarnell, K. (1995) Lamp and ballast choice are key to energy savings. *Facilities Design and Management* 6: 37.

Zhang, X. and Muneer, T. (2005) A design guide for performance assessment of solar light pipes. *Lighting Research and Technology* 34(2): 149–169.